the collaborative for high performance schools

Best Practices Manual

VOLUME II

DESIGN

2006 EDITION

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Disclaimer

Preface

This is a unique period in California history. The state, already educating one out of every eight students in America, has seen historical enrollment rates four times higher than national averages. Hundreds of schools a year are being built to house the influx of new students moving into the system. The California Department of Education predicts that there will be more than 900,000 students without a classroom through the year 2009[1]. At the same time, school facility infrastructure across the state is aging—the Department of Education predicts more than 1.2 million California students are in classrooms that are more than 25 years old, with almost 50,000 of the classrooms scheduled for modernization between now and 2009.

Real estate and energy prices also add to the challenges specifically facing California school districts. The Los Angeles Unified School District, among other agencies, have reported paying double and triple their estimates for land when projects were proposed years ago. And California schools are spending nearly $700 million per year on energy[2] in a time of rising concern over energy supplies and tight school budgets. These figures illustrate an enormous opportunity for our state's school districts to build the next generation of school facilities that improve the learning environment while saving energy, resources, and money.

The goal of this Best Practices Manual is to create a new generation of high performance school facilities in California. The focus is on public schools and levels K-12, although many of the design principles apply to private schools and higher education facilities as well. High performance schools are healthy, comfortable, energy efficient, resource efficient, water efficient, safe, secure, adaptable, and easy to operate and maintain. They help school districts achieve higher test scores, retain quality teachers and staff, reduce operating cost, increase average daily attendance (ADA), and reduce liability, while at the same time being friendly to the environment.

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1 California Department of Education, www.cde.ca.gov/ls/fa/sf/facts.asp

2 California Energy Commission

BEST PRACTICES MANUAL ORGANIZATION

This Best Practices Manual is split into six volumes:

- *Volume I: Planning*. This volume addresses the needs of school districts, including superintendents, parents, teachers, school board members, administrators, and those persons in the school district that are responsible for facilities. These may include the assistant superintendent for facilities (in large districts), buildings and grounds committees, energy managers, and new construction project managers. Volume I describes why high performance schools are important, what components are involved in their design, and how to navigate the design and construction process to ensure that they are built.
- *Volume II: Design Guidelines*. This volume contains design guidelines for high performance schools. These are tailored for California climates and are written for the architects and engineers who are responsible for designing schools as well as the project managers who work with the design teams. Organized by design disciplines, these guidelines address effective strategies to build schools that meet the CHPS high performance school criteria.
- *Volume III: Criteria*. These criteria are a flexible yardstick that precisely define a high performance school so that it may qualify for supplemental funding, priority processing, and perhaps bonus points in the state funding procedure. School districts can also include the criteria in their educational specifications to ensure that new facilities qualify as high performance.
- *Volume IV: Maintenance and Operations*. This volume discusses operations and maintenance for high performance schools. This volume provides information required to ensure that high performance school buildings continue to operate as their designers intended, providing optimal health, efficiency, and sustainability.
- *Volume V: Commissioning*. This volume provides important information on commissioning high performance schools—a critical step in ensuring that the technologies and high performance elements designed are actually built and tested to meet specifications.
- *Volume VI: Relocatable Classroom*. This volume packages all the high performance information in one place for school districts who are purchasing or leasing relocatable classrooms.

The Best Practices Manual is supported by the Collaborative for High Performance Schools' Web site (www.chps.net/), which contains research papers, support documents, databases, and other information that supports the manual.

COLLABORATIVE FOR HIGH PERFORMANCE SCHOOLS

The Collaborative for High Performance Schools (CHPS) began in November 1999, when the California Energy Commission called together Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison to discuss the best way to improve the performance of California's schools. Out of this partnership, CHPS grew to include a diverse range of government, utility, and non-profit organizations with a unifying goal to improve the quality of education for California's children. With the successful launch of the Best Practices Manuals in 2001, interest in high performance design grew, and CHPS expanded its focus beyond California, developing a national version of the manuals as well as other state-specific versions. In early 2002, CHPS incorporated as a non-profit organization, further solidifying its commitment to environmentally sound design that enhances the educational environment for all schoolchildren.

ACKNOWLEDGEMENTS

The 2006 update to the CHPS Best Practices Manual Volume II was funded by San Diego Gas and Electric, California Energy Commission, Pacific Gas and Electric Company, Southern California Edison, and the California Integrated Waste Management Board. CHPS gratefully acknowledges the financial assistance of these organizations.

A great number of people have contributed to the development of the 2006 Best Practices Manual, Design Volume. Charles Eley is the Executive Director of CHPS and served as the technical editor.

- Charles Eley coordinated the update of the general conditions, site planning and interior surfaces chapters with significant contributions from David Goldman, Sara Greenwood, and Dana Papke.
- Charles Eley updated the lighting and daylighting chapter with significant contributions from James Benya and Barbara Erwine.
- Erik Kolderup the updated of the HVAC chapter with help from Pete Jacobs, John Arent, Ray Dodd and Tony Pierce.
- Kyra Epstein lead the update of the Other Equipment and Systems chapter with assistance from Vern Smith and David Goldman.
- Kyra Epstein, Camren Cordell, Dale Nelson and Emily Anicich provided editing and report production services.

The 2006 edition build from previous editions and much of the material remains unchanged. The following persons made significant contributions to the first and second editions of the Design Volume: Jim Benya (Benya Lighting Design); Anthony Bernheim (SMWM), Barbara Erwine (Cascadia Conservation); Lisa Heschong (Heschong Mahone Group); Erik Kolderup, Joe Kastner, and Anamika Prasad, Kimberly Got, Arman Shehabi, and Randy Karels (Eley Associates); Hal Levin (Building Ecology Research Group); Kathleen O'Brien (O'Brien and Company); Kerry Parker (TMAD Engineers); Jane Simmons (O'Brien and Company); Kerry Parker (TMAD Engineers); and Adam Wheeler (Control Group).

The best practices manual benefited from the careful review of a number of persons and organizations. The following persons offered comments and constructive criticism on one or more of the best practice manual editions: Alice Sung (GreenBank); Andrew Gorton and Dennis Paoletti (Shen Milsom & Wilke / Paoletti); Anthony Bernheim (SMWM); Bill Jones and Bob Axelrad (United States EPA); Bill Orr, Dana Papke, Clark Williams and Kathy Frevert (California Integrated Waste Management Board); Brian Dougherty (Dougherty + Dougherty Architects) ; Craig Hoellwarth and Wael El-Sharif (Geothermal Heat Pump Consortium); Dennis Bottum (GreenWorks); Dennis Dunston (HMC Architects); Don Cunningham (Los Angeles Department of Water and Power); Duwayne Brooks, Tony Hesch, and Diane Waters (California Department of Education); Gary Flamm (California Energy Commission); Gary Mason (Wolfe Mason Associates); George Wiens (WLC Architects).; Grant Duhon (Pacific Gas & Electric); Greg Golick (Coalition for Adequate School Housing); Gregg Ander, Christine Magar, Tony Pierce, Manuel Alvarez, Jan Johnson and Lisa Stoddard (Southern California Edison); Jed Waldman and Toni Stein (California Department of Health Services); Jim Barnett and Jim Parks (Sacramento Municipal Utility District); John Guill (Quattrocchi / Kwok Architects); Julia Curtis (Natural Resources Defense Council); Karen Mandell and Richard Sheffield (Office for Public School Construction).; Kathleen McElroy (Xenergy); Lisa Fabula, Chuck Angyal, Chip Fox (San Diego Gas & Electric); Lynn N. Simon (Simon & Associates); Panama Bartholomy, Richard Conrad and Chip Smith (Division of the State Architect); Randall Higa (Southern California Gas Company) ; Ray Darby (The Energy Guy); Steve Newsom (LPA Incorporated); Tav Commins, Gary Flamm, Don Kazama, Claudia Orlando, Daryl Mills and Mike Sloss (California Energy Commission); Tom Phillips (California Air Resources Board); and Tor Allen (Rahus Institute)

Finally, the current and past CHPS Board of Directors deserves special acknowledgement for their continued guidance and support. Current chair Jackalyne Pfannenstiel (California Energy Commission) and past chairs Steve Castellanos (State Architect) and Robert Pernell (California Energy Commission) provided exceptional leadership and directions. Current board members include: Gregg Ander (Southern California Edison), Jessica Mack (Southern California Gas), Chip Fox (San Diego Gas & Electric), Jim Barnett (Sacramento Municipal Utility District), John Palmer (San Juan Unified School District), Brian Dougherty (Dougherty + Dougherty), Bill Orr (California Integrated Waste Management Board) and Oliver Kesting (Pacific Gas and Electric). The current Advisory Board includes: Kathleen Moore (California Department of Education) and Karen Mandell (Office of Public School Construction). Past board and advisory board members include Randall Higa (Southern California Gas), Chuck Angyal (San Diego Gas and Electric, Duwayne Brooks (California Department of Education), and Grant Duhon (Pacific Gas & Electric).

Introduction

The characteristics of a high performance school, outlined in Volume I, reflect a mix of environmental, economic, and social objectives. Because of this mix of characteristics, the design process needed to achieve high performance schools is fundamentally different from conventional practice. To be most effective, this process requires a significant commitment on the part of design professionals to:

- Meet energy and environmental performance criteria.
- Maintain a view of the building and site as a seamless whole within the context of its community.
- Work with the understanding that the building exists within the context of a natural ecosystem even when the setting is urban.
- Incorporate interdisciplinary collaboration throughout the design and construction process.
- Maximize student performance by keeping standards high for air quality and increasing the use of daylighting.
- Integrate all significant building design decisions and strategies—beginning no later than the programming phase.
- Optimize design choices through simulations, models, or other design tools.
- Employ life-cycle cost analysis in all decision making.
- Design all systems to be easy to maintain and operate.
- Commission all building equipment and systems to ensure continued optimum performance.
- Document high performance materials and techniques in the building so that maintenance and repairs can be made in accordance with the original design intent.
- Encourage sustainable construction, operations, and building maintenance.
- Provide clear guidance, documentation, and training for operation and maintenance staff.

The typical design process for schools begins with programming and selecting the architectural-engineering team. It then proceeds through schematic design, design development, contract documents, construction, commissioning, and occupancy. The sooner high performance goals are considered in the design process, the easier and less costly they are to incorporate. Many of the guidelines presented in this document must be considered early in the design process for them to be successful. Figure 1 below shows a timeline through the design process and indicates the types of measures and design strategies that can be considered along the way.

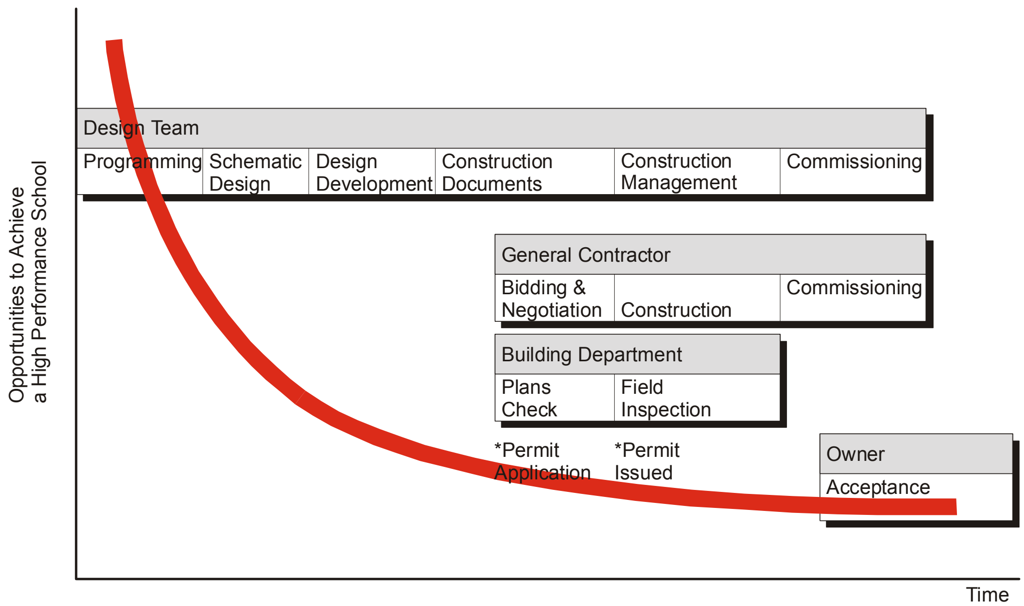


Figure 1 – Opportunities in the Design Process

As mentioned, Volume I outlines the characteristics of a high performance school. In Volume II, these characteristics are described in more detail in the discussion of Goals and Cross-Cutting Issues. For best results, these high performance goals should be reflected in all aspects of project documentation. High performance goals established during programming should be clearly stated in the educational specifications, in the request for proposals (RFP) to select the design team, in the instruction to bidders, and as part of the project summary. These goals are best expressed in terms of performance. The Collaborative for High Performance Schools (CHPS) Criteria in Volume III have these goals clearly formulated so that they can be appropriately referenced.

INTEGRATED DESIGN

Integrated design is the consideration and design of all building systems and components together. It brings together the various disciplines involved in designing a building and reviews their recommendations as a whole. It recognizes that each discipline's recommendations have an impact on other aspects of the building project. This approach allows designers to optimize both building performance and cost. Too often, heating, ventilation, and air conditioning (HVAC) systems are designed independently of lighting systems, for example, and lighting systems are designed without consideration of daylighting opportunities. The architect, mechanical engineer, electrical engineer, contractors, and other team members each have their scope of work and often pursue it without adequate communication and interaction with other team members. This can result in oversized systems or systems that are optimized for non-typical conditions.

Even a small degree of integration provides some benefits. It allows professionals working in various disciplines to take advantage of efficiencies that are not apparent when they are working in isolation. It can also point out areas where trade-offs can be implemented to enhance resource efficiency. Design integration is the best way to avoid redundancy or conflicts with aspects of the building project planned by others.

The earlier that integration is introduced in the design process, the greater the benefit. For a high performance school, project team collaboration and integration of design choices should begin no later than the programming phase. In addition, the project team is likely to be more broadly defined than in the past, and may include energy analysts, materials consultants, lighting designers, life-cycle cost consultants, and commissioning agents. Design activities may expand to include charrettes, modeling exercises, and simulations.

This manual provides details and implementation rules for individual design strategies. Though these individual strategies can improve a building's energy efficiency, only through whole-building analysis and integrated design can energy and cost concerns be balanced most effectively.

GOALS AND CROSS-CUTTING ISSUES

This manual is organized into eight technical chapters that correspond to the major disciplines in the building design process. The guidelines presented in each chapter are directed toward building schools that achieve the following goals, which are issues that cut across each of the major disciplines:

- Health and Indoor Air Quality (IAQ)
- Thermal Comfort
- Visual Comfort
- Acoustic Comfort
- Security and Safety
- Ecosystem Protection
- Energy Efficiency
- Water Efficiency
- Materials Efficiency
- Buildings as a Teaching Tool.

Table 1 below shows which of the goals (or cross-cutting issues) apply to each of the technical chapters. The rest of this section describes these relationships in more detail and provides checklists that summarize the key high performance design strategies for each discipline.

Table 1–Relationship between Goals and Technical Chapters

	Goals/Cross-Cutting Issues									
Technical Chapters	**Health and IAQ**	**Thermal Comfort**	**Visual Comfort**	**Acoustic Comfort**	**Security and Safety**	**Ecosystem Protection**	**Energy Efficiency**	**Water Efficiency**	**Materials Efficiency**	**Building as a Teaching Tool**
General Conditions	●				●	●	●	●	●	
Site Planning	●	●	●	●	●	●	●	●	●	●
Interior Surfaces & Furnishings	●			●		●	●		●	●
Electric Lighting and Controls		●	●				●			●
Daylighting and Fenestration		●	●		●		●		●	●
Building Enclosure		●		●			●		●	●
HVAC	●	●		●	●		●	●	●	●
Other Equipment and Systems							●	●	●	●

Health and IAQ

The quality of the air inside a school is critical to the health and performance of children, teachers, and staff. A high performance school should provide superior quality indoor air by eliminating and controlling the sources of contamination, providing adequate ventilation, preventing unwanted moisture accumulation, and implementing effective operation and maintenance procedures.

According to the U.S. Environmental Protection Agency (EPA), the concentration of pollutants inside a building may be two to five times higher than outside levels. Children are particularly vulnerable to such pollutants because their breathing and metabolic rates are high relative to their size. Maintaining a high level of IAQ is therefore critical for schools. Failure to do so may, according to the EPA, negatively impact student and teacher performance, increase the potential for long- and short-term health problems for students and staff, increase absenteeism, accelerate deterioration, reduce efficiency of the school's physical plant, create negative publicity, and create potential liability problems.

To eliminate or control contamination, select materials that are low emitters of substances such as volatile organic compounds (VOCs) or toxins. CHPS suggests using materials that meet the standards set out in the CHPS Materials Specifications Section 01350 and the subsequent Department of Health Services' (DHS) Standard Practice (www.chps.net has more information). Some of these building materials may be unfamiliar to custodial staff, so provide training to the staff, and select durable products and avoid products that unnecessarily complicate operation and maintenance. Any material can affect the acoustic and visual quality of a school; be sure to consider this when evaluating these materials. The following checklist summarizes strategies to improve a school's IAQ.

A Closer Look—Alder Creek Middle School, Truckee, CA

Alder Creek Middle School in Tahoe Truckee Unified School District opened in fall of 2004 and is the third CHPS demonstration school. The school exceeds Title 24 Energy requirements by 20%— quite an accomplishment considering that Truckee is located in one of the coldest climates in the nation.

In addition, Tahoe Truckee is one of the first schools designed with healthy building materials certified by standards set in the California Section 01350 specification.

The architects, Lionakis Beaumont Design Group, used low emitting and recycled content products whenever possible and cost effective. Working with manufacturers who sometimes agreed to modify their products so that the design would meet the CHPS standards, the architects and school district gained credit for using Section 01350 certification for paint, carpeting, plywood in cabinets, fiberglass insulation, ceiling tile, and linoleum.

The district also won a $250,000 grant from the California Energy Commission to help fund the high performance school design. Energy savings alone are estimated to yield at least $17,000 in savings annually.

Source: Tahoe Truckee Unified School District

Health and IAQ Checklist

Eliminate or control contamination at the source

- ✓ *Require a construction IAQ plan.*
- ✓ *Test the site for sources of contamination such as radon, hazardous waste, or fumes from nearby industrial or agricultural uses.*
- ✓ *Locate sources of exhaust fumes (e.g., from vehicles) away from air intake vents.*
- ✓ *Consider recessed grates, "walk off" mats and other techniques to reduce dirt entering the building.*

Avoid materials that contaminate indoor air

- ✓ *Use materials that pass the emissions limits in the CHPS Material Specifications Section 1350.*
- ✓ *Specify composite wood or agrifiber products containing no urea-formaldehyde resins.*

Provide adequate ventilation

- ✓ *Allow adequate time for installed materials and furnishings to "off-gas" before the school is occupied. Run the HVAC system continuously at the highest possible outdoor air supply setting for at least 72 hours after all materials and furnishings have been installed.*
- ✓ *Design the ventilation system to provide a minimum of 15 cfm/person of filtered outdoor air to all occupied spaces. Consider 20 cfm/person.*
- ✓ *Ensure that ventilation air is effectively delivered to and distributed through the rooms in a school.*
- ✓ *Provide local exhaust for restrooms, kitchens, labs, janitor's closets, copy rooms, and shop rooms.*

Prevent unwanted moisture accumulation

- ✓ *Design the ventilation system to maintain the indoor relative humidity between 30% and 50%.*
- ✓ *Design to minimize water vapor condensation, especially on walls, the underside of roof decks, around pipes or ducts.*
- ✓ *Design to keep precipitation out of the building, off the roof, and away from the walls.*

Operate and maintain the building effectively

- ✓ *Regularly inspect and maintain the ventilation system so that it continues to operate as designed.*
- ✓ *Install CO_2 sensors in large assembly areas for real-time monitoring of air quality.*
- ✓ *Minimize the use of toxic cleaning materials.*
- ✓ *Use the EPA's "Indoor Air Quality—Tools for Schools" to guide the operation and maintenance process.*
- ✓ *Use the EPA's "Mold Remediation in Schools and Commercial Buildings" to control moisture problems. Available at www.epa.gov/iaq/molds or (800) 438-4318.*

Thermal Comfort

Thermal comfort is an important variable in student and teacher performance. Hot, stuffy rooms—and cold, drafty ones—reduce attention spans and limit productivity. They also waste energy, adding unnecessary cost to a school's bottom line. Excessively high humidity levels can also contribute to mold and mildew. Thermal comfort is primarily a function of the temperature and relative humidity in a room, but air speed and the temperature of the surrounding surfaces also affect it. A high performance school should ensure that rooms and HVAC systems are designed to allow temperature and humidity levels to remain within the "comfort zone" at all points in an occupied space. Thermal comfort guidelines are provided in the technical chapter on HVAC.

Thermal comfort is strongly influenced by how a specific room is designed (for example, the amount of heat its walls and roof gain or lose, the amount of sunlight its windows let in, whether the windows can be opened) and by how effectively the HVAC system can meet the specific needs of that room. Balancing these two factors—room design and HVAC system design—is a back-and-forth process that continues throughout all the stages of developing a new facility. In a high performance school, the process ends with an optimal blend of both components: rooms configured for high student and teacher productivity served by an energy-efficient HVAC system designed, sized, and controlled to maintain thermal comfort under all conditions.

Thermal Comfort Checklist

Design in accordance with ASHRAE standards

- ✓ *Design systems to provide comfort in accord with American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55–2004, Thermal Environmental Conditions for Human Occupancy.*
- ✓ *When a design incorporates natural ventilation (e.g., operable windows to provide direct outdoor air during temperate weather), consider adjusting the requirements of ASHRAE Standard 55–2004 to account for the impact.*

Install controls and monitor system performance

- ✓ *Install controls in each classroom to give teachers direct control over thermal comfort. Evaluate the potential impact of such controls on the overall efficiency of the HVAC system.*
- ✓ *Consider providing a temperature and humidity monitoring system to ensure optimal thermal comfort performance.*
- ✓ *Consider including temperature and humidity monitoring as part of the building's overall energy management system.*

Analyze room and system layouts

- ✓ *Analyze room configurations and HVAC distribution layouts to ensure all parts of a room are receiving adequate ventilation.*
- ✓ *Analyze placement of windows and skylights and provide adequate, controllable shading to avoid "hot spots" caused by direct sunlight.*

Visual Comfort

Performing visual tasks is a central component of the learning process for both students and teachers. A high performance school should provide a rich visual environment—one that enhances, rather than hinders, learning and teaching—by carefully integrating natural and electric lighting strategies; by balancing the quantity and quality of light in each room; and by controlling or eliminating glare.

Students spend much of their day engaged in visual tasks—writing, reading printed material, reading from visual display terminals, or reading from blackboards, whiteboards, and overheads. They must constantly adjust their vision from a "heads-up" to "heads-down" position and back again. Inadequate lighting and/or glare can seriously affect a student's ability to learn. On the other hand, a comfortable, productive visual environment—one that takes into account more than simply the amount of light hitting the desktop—will enhance the learning experience for both students and teachers.

Visual comfort results from a well-designed, well-integrated combination of natural and artificial lighting systems. Any strategy for enhancing the visual environment will therefore strongly affect the size and configuration of both these systems (for example, number, type, and placement of windows; number, type, and placement of light fixtures; etc.). The final configurations will, in turn, affect a school's HVAC systems.

An optimized overall design will provide a high quality luminous environment and will use daylight effectively to reduce the need for artificial lighting. Less artificial lighting means lower electricity bills and less waste heat that, in turn, means less demand for cooling and lower HVAC operating expenses.

Visual Comfort Checklist

Integrate natural and artificial lighting strategies

- ✓ *Take the amount of daylight entering a room into account when designing and sizing the artificial lighting system for that room.*
- ✓ *Provide controls that turn off lights when sufficient daylight exists.*
- ✓ *Consider dimming controls that continuously adjust lighting levels to respond to daylight conditions.*

Balance the quantity and quality of light in each room

- ✓ *Avoid excessively high horizontal light levels.*
- ✓ *Use the newly revised 9th edition of the Illuminating Engineering Society of North America (IESNA)'s Lighting Handbook: Design and Application as a guide.*
- ✓ *Design for "uniformity with flexibility."*
- ✓ *Illuminate spaces as uniformly as possible, avoiding shadows or sharp distinctions between dark and light.*
- ✓ *Provide task or accent lighting to meet specific needs (e.g., display areas, whiteboards, team areas).*
- ✓ *Develop individual lighting strategies for individual rooms or room types (e.g., classrooms, hallways, cafeteria, library, etc.). Avoid "one size fits all" approaches.*

Control or eliminate glare

- ✓ *Consider how light sources in a room will affect work surfaces. Design to avoid direct glare (from sources in front or to the side of a work area); overhead glare (from sources above the work area); and reflected glare (from highly reflective surfaces, including glossy paper and computer terminals).*
- ✓ *Consider increasing the brightness of surrounding surfaces, decreasing the brightness of light sources, or both as control methods.*
- ✓ *Consider interior (shades, louvers, blinds) or exterior (overhangs, trees) strategies to filter daylight and control glare from sunlight.*

Acoustic Comfort

Parents, students, teachers, and administrators across the country are increasingly concerned that classroom acoustics are inadequate for proper learning. Noise from outside the school (from vehicles and airplanes, for example), hallways (foot traffic and conversation), other classrooms (amplified sound systems and inadequate sound transmission loss), mechanical equipment (compressors, boilers, and ventilation systems), and even noise from inside the classroom itself (reverberation) can hamper students' concentration.

Trying to hear in a poor acoustical environment is like trying to read in a room with poor lighting: stress increases, concentration decreases, and learning is impaired. This is especially true for younger students (the ability to sort meaningful sounds from noise is not fully developed until children reach their teens); those for whom English is a second language; and those with hearing impairments. Although little consideration has historically been given to acoustic design in classrooms—as opposed to lighting and ventilation—this situation is beginning to change. The information and tools needed to design classrooms for high acoustical performance now exist. They can be used to ensure that newly constructed classrooms provide acoustical environments that enhance the learning experience for students and teachers.

A Closer Look**—**Cesar Chavez Education Center, Oakland, CA

The Cesar Chavez Education Center opened in winter of 2004 housing two elementary schools both exceeding the CHPS certification level. The project, placed in an urban setting, presented many acoustical challenges for its designers. The building structures were positioned along the north side of the campus to minimize the sound from the BART trains, which are as close as 400 ft from the classrooms. Acoustic laminated glass was used on windows facing the train tracks with a larger air space than is typical. In addition, the designers used additional layers of gypsum board on the ceiling with acoustic tile as well as additional sound absorptive acoustic panels on the walls made of fiberglass with a cork face that can also double as tack surfaces.

Source: CASH Registrar Volume XXV, No.11

Acoustic Comfort Checklist

Ensure a superior acoustical environment

- ✓ *Reduce sound reverberation time inside the classroom.*
- ✓ *Limit transmission of noise from outside the classroom.*
- ✓ *Minimize background noise from the building's HVAC system.*

Security and Safety

Safety and security have become critical concerns for students, teachers, and parents across the country. A high performance school should create a safe and secure environment by design. Opportunities for natural surveillance should be optimized; a sense of territoriality should be reinforced; access should be controlled; and technology should be used to complement and enhance, rather than substitute for, a facility's security-focused design features.

Crime and vandalism—and the fear they foster—are problems facing school populations throughout the United States. While better buildings alone cannot solve these problems, they can be powerful factors in helping reduce crime and other antisocial behavior. Thoughtful design that builds on basic Crime Prevention through Environmental Design (CPTED) principles is the key.

Security-based design strategies will influence a school's basic layout and site plan. If properly integrated from the beginning of the development process, these influences will complement and enhance other high performance design strategies used in the facility. For example, daylit classrooms can "share" their natural light with adjacent corridors through windows or glass doors provided primarily for surveillance purposes. This "free" natural light can, in turn, be used to offset the need for electrical lighting in the corridors. Security technology strategies will not strongly impact other systems in the school, unless they are incorporated into a comprehensive automated control system for the whole facility.

Security and Safety Checklist

Increase opportunities for natural surveillance

- ✓ *Design landscaping to minimize places that are hidden from view. Ensure that key areas—parking, bicycle storage, drop-off points, play equipment, entries—are easily observable from inside the building.*
- ✓ *Design exterior lighting to facilitate nighttime surveillance.*
- ✓ *Consider providing views through glazed doors or windows from classrooms into circulation corridors.*
- ✓ *Design to minimize areas within the building that are hidden from view.*
- ✓ *Consider open stairwells.*

Reinforce a sense of territoriality

- ✓ *Foster a sense of “ownership" of the school for students and teachers by clearly defining borders—what is part of the school and what is not.*
- ✓ *Consider decorative fencing and special paving treatments to delineate the boundaries of the school grounds.*
- ✓ *Consider designing common areas, particularly corridors, so that they are less institutional and more “room-like."*

Design for easy maintenance

- ✓ *Consider graffiti-resistant materials and finishes.*

Control access to the building and grounds

- ✓ *Consider decorative fencing to control access to school grounds.*
- ✓ *Limit the number of entries to the building. Allow visual surveillance of all entries from inside the school.*
- ✓ *Provide capability to “lock-down" parts of the school when the facility is used for after-hours activities.*

Integrate security technology

- ✓ *Consider incorporating interior and exterior surveillance cameras.*
- ✓ *Ensure that all high-risk areas (office, cafeteria, shops, labs, etc.) are protected by high security locks.*
- ✓ *Consider metal detectors and other security technologies as appropriate.*
- ✓ *Motion sensors for lighting can also provide effective security control.*

Ecosystem Protection

A high performance school protects the natural ecosystem. As much as possible, the school incorporates products and techniques that do not introduce pollutants or degradation at the project site or at the site of extraction, harvest, or production. Give preference to materials that are locally extracted or harvested, and locally manufactured to eliminate potential air pollution due to petroleum-based transportation.

> ***A Closer Look—Sakai Intermediate School, Bainbridge Island, WA***
>
> *This new facility is an excellent example of a school project that went the extra mile to protect the natural environment. The building and sports field's footprint was reduced to increase a buffer zone far beyond what was required in order to protect an adjacent wetland and salmon stream. A culvert that blocked salmon passage was removed. A system separating groundwater from stormwater allowed the groundwater to recharge the natural wetland, and allowed designers to reduce the size of the stormwater retention pond.*
>
> *Students and other community members were involved in restoring the salmon stream and building an outdoor classroom platform, and they acted as tour guides for the open house explaining the special site protection features.*

Some of these building materials may be unfamiliar to custodial staff. Avoid products that unnecessarily complicate operation and maintenance procedures, and provide training to ensure proper upkeep and ensure full service life. When evaluating materials, be sure to consider their impact on the acoustic and visual quality of a school.

High performance school design is environmentally responsive to the site, incorporating natural conditions such as wind, solar energy, and moisture to enhance the building's performance. Natural features and areas of the site should be preserved; damaged areas should be restored. Take steps to eliminate stormwater runoff and erosion that can affect local waterways and adjacent ecosystems.

The use of these strategies can help teach students about the importance of protecting natural habitats and the impact of human activities on ecological systems.

Ecosystem Protection Checklist

Specify indigenous materials

- ✓ *Specify materials appropriately adapted for the building and site, such as native landscaping and locally extracted building materials.*

Specify wood products that are harvested responsibly

- ✓ *Set a goal of having 50% of the school's wood-based materials certified in accordance with the Forest Stewardship Guidelines for wood-based components.*

Avoid materials that harm the ecosystem

- ✓ *Eliminate materials that harm the natural ecosystem through toxic releases or by producing unsafe concentrations of substances.*
- ✓ *Eliminate the use of ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) as refrigerants in all HVAC systems.*
- ✓ *Give preference to locally manufactured materials and products to eliminate air pollution due to transportation.*
- ✓ *Eliminate products that pollute water, air, or other natural resources where they are extracted, manufactured, used, or disposed of.*
- ✓ *Evaluate the potential impact of specified site materials on natural ecosystems located on site or adjacent to the site.*

Preserve and restore natural features and areas on, and near, the site

- ✓ *During construction, develop and implement a construction operations plan to protect the site.*
- ✓ *Develop the site to prevent stormwater runoff and erosion.*
- ✓ *Restore damaged natural areas.*
- ✓ *Maintain connection to nearby natural ecosystems.*

Energy Efficiency

Energy-efficient schools cost less to operate, which means that more money can be used for books, computers, teacher salaries, and other items essential to the educational goals of schools. Energy-efficient schools also reduce emissions to the environment, since energy use is related to emissions of carbon dioxide (CO_2), sulfur oxides (SO_x), nitrous oxides (NO_x), and other pollutants. Smaller air conditioners also reduce the likelihood of ozone-depleting gases escaping to the atmosphere. All the chapters and guidelines in this manual relate to energy efficiency in some meaningful way. By following the guidelines in this manual, energy use can be reduced by up to 40% compared to conventional buildings that minimally comply with the California's Title 24 Energy Efficiency Standards for Residential and Nonresidential Buildings.

Guidelines explicitly related to energy efficiency are provided in five of the chapters: electric lighting, daylighting and fenestration, building enclosures, HVAC systems, and other equipment and systems. The key issues are summarized below.

A Closer Look—Georgina Blach Intermediate School, Los Altos, CA

This project, part modernization and part new construction, resulted in Georgina Blach becoming a CHPS demonstration school—a school building that demonstrates the feasibility of creating a CHPS high performance school and a school that is intended to serve as a example for other districts implementing the CHPS criteria. These, and other energy savings methods, have allowed the school to yield electricity savings of 38 percent beyond the minimum code requirements along with associated cost savings. Furthermore, a commissioning process was completed that will help ensure that these savings will continue into the future.

Source: Ken Rackow, Gelfan RNP

Electric Lighting

Electric lighting systems interact closely with a school's daylighting and HVAC systems. Daylighting strategies that are well integrated with lighting equipment and controls will reduce the demand for electric light. This decrease in demand, if it is met by a combination of high efficiency electric lighting equipment and controls, can substantially lower a school's electricity usage.

An added benefit: more efficient lighting produces less waste heat, reducing the need for cooling and further reducing operating costs. Cooling equipment can be downsized, resulting in first cost and operating cost savings to the school.

These savings are achievable now—in any school—using readily available equipment and controls.

Energy Efficiency Checklist for Electric Lighting

Design for high efficiency and visual comfort

- ✓ *Develop individual lighting designs for individual rooms or room types (classrooms, hallways, cafeteria, etc.). Avoid over lighting any space.*
- ✓ *Consider a mix of direct and indirect light sources for each design.*
- ✓ *Optimize each design so that overall lighting levels (W/ft^2) are as low as possible while still providing optimal task illumination.*
- ✓ *Analyze the impact of the lighting system on the HVAC system and resize the HVAC system as appropriate.*
- ✓ *Design systems to facilitate cleaning/lamp replacement.*

Specify high efficiency lamps and ballasts

- ✓ *Use "Super" T-8 fluorescent lamps with electronic ballasts for most general lighting applications (classrooms, offices, multipurpose rooms, cafeterias). Consider using T-5 lamps if justified by life-cycle cost.*
- ✓ *Consider dimmable ballasts, especially in daylit rooms.*

Optimize the number and type of luminaires

- ✓ *Use suspended indirect or direct/indirect luminaires in classrooms to provide soft uniform illumination.*
- ✓ *Consider using additional accent and directional task lighting for specific uses (such as display areas).*
- ✓ *Consider using a smaller number of higher efficiency luminaires to light specific spaces, resulting in fewer fixtures to purchase, install, maintain, and clean.*

Incorporate controls to ensure peak system performance

- ✓ *Use occupancy sensors with manual overrides to control lighting (on-off) in classrooms, offices, restrooms, and other intermittently occupied spaces. Consider scheduled dimming and/or time clocks in other rooms.*
- ✓ *Consider incorporating lighting controls into the facility's overall energy management system.*

Integrate electric lighting and daylighting strategies

- ✓ *Treat the electric lighting system as a supplement to natural light. Design for daylighting first and use the electric system to add light as needed during the day and provide sufficient illumination at night.*
- ✓ *Provide controls to dim or turn off lights at times when daylight is sufficient. Consider photoelectric controls that are sensitive to levels of daylight.*
- ✓ *Consider controls that provide continuous, rather than stepped, dimming.*

Daylighting and Fenestration Design

Daylighting is the controlled admission of natural light into a space through windows, skylights or roof monitors. A high performance school should use as much daylight as possible, especially in classrooms, while avoiding excessive heat loss, heat gain, and glare.

Access to natural light may be one of the most important attributes of a high performance school. Daylight is the highest quality light source for visual tasks, enhancing the color and appearance of objects. Studies clearly indicate that daylighting can enhance student performance. Views from windows also provide a connection with the natural world and contribute to eye health by allowing frequent changes in focal distance.

A Closer Look—High Tech High, Van Nuys, CA

Los Angeles Unified School District completed High Tech High in 2004, as the only school designed specifically to train students for the "high technology careers of tomorrow." The architects, Berliner and Associates, incorporated many energy efficient day lighting strategies to maximize efficiency and comfort.

The school uses skylights and roof monitors to bring in controlled natural light and reduce reliance on electric lighting systems. The school uses high clerestories to maximize penetration of light deep into building spaces with many common areas having thermal mass flooring to take advantage of this feature. "In addition, the high north orientated side lighting in the commons and the curving configuration of the roof will allow natural light to penetrate the full width of this part of the building and provides shared light to adjacent spaces."

The school also used high performance window glazing to minimize solar heat gain and solar heat loss in the winter while maintaining excellent levels of daylight.

Source: Berliner and Associates

Daylighting can also save schools money. Properly designed systems can substantially reduce the need for electric lighting, which can account for 35%–50% of a school's electrical energy consumption. As an added benefit, waste heat from the lighting system is reduced, lowering demands on the school's cooling equipment. The savings can be as much as 10%–20% of a school's cooling energy use. And daylight provides these savings during the day when demand for electric power is at its peak and electricity rates are at their highest.

Energy Efficiency Checklist for Daylighting

Avoid direct beam sunlight and glare

- ✓ *Consider interior (shades, louvers, or blinds) and exterior (overhangs, trees) strategies to control glare and filter daylight.*

Design for diffuse, uniform daylight that penetrates deep into the space

- ✓ *Use a daylighting analysis tool to help guide the design process.*
- ✓ *Design windows to allow daylight to penetrate as far as possible into a room. Consider using light shelves (solid horizontal elements placed above eye level, but below the top of the window) to reflect daylight deep into a room.*
- ✓ *Consider skylights (horizontal glass), roof monitors (vertical glass), light from two sides, and/or clerestory windows.*
- ✓ *Lay out the room to take advantage of daylight. Consider sloped ceilings. Consider light-colored ceiling surfaces to help reflect daylight within the room.*

Integrate daylighting with the electric lighting system

- ✓ *Provide controls that turn off lights when sufficient daylight exists. Consider dimming controls that continuously adjust light levels to respond to daylight conditions.*

Building Enclosures

The building enclosure (walls, roofs, floors, and windows) of a high performance school should enhance energy efficiency without compromising durability, maintainability, or acoustic, thermal, or visual comfort. An energy-efficient building enclosure is one that integrates and optimizes moisture control, insulation levels, glazing, shading, thermal mass, air leakage control, and light-colored exterior surfaces. An energy-efficient building enclosure will reduce a school's overall operating expenses and will also help the environment. Many of the techniques employed—high performance glazing, shading devices, light-colored surfaces—are easy for students to understand and can be used as instructional aids.

A Closer Look—Oquirrh Hills Elementary School, Kearns, UT

Well-insulated metal stud and brick veneer walls, a light-colored roof with R-30 rigid insulation, and windows with low-e glass all contribute to the superior energy performance of this elementary school near Salt Lake City.

The school, completed in 1996, replaced a previous facility that had been destroyed by fire. The new building saves roughly $22,000 per year in operating costs compared to its predecessor—a result of careful design combined with high performance systems and an energy-efficient building enclosure.

Based on its experience with Oquirrh Hills, the Jordan School District has embraced high performance as a procurement goal and has gone on to build six more energy-efficient schools.

"High performance, energy smart school design means going 'beyond code'…cost effectively. That's just what the architects did at Oquirrh Hills," notes Duane Devey, Director of Energy and Utility Resources for Jordan School District.

The key to optimizing the building enclosure is an integrated approach to design that considers how all the components of the building shell interact with each other and with the building's HVAC systems. Tools to analyze these interactions are readily available and can be used to create the optimal building enclosure based on total system performance. As part of an integrated approach, consider the actions described below.

Energy Efficiency Checklist for the Building Enclosure

Specify high performance glazing

- ✓ *Specify glazing that offers the best combination of insulating value, daylight transmittance and solar heat gain coefficient for the specific application.*

Control heat gain and glare

- ✓ *Consider exterior shading devices to reduce solar heat gain and minimize glare.*
- ✓ *Consider using light-colored materials for walls and roofs to reflect, rather than absorb, solar energy.*

Consider high mass materials, like concrete or brick

- ✓ *Use the building's thermal mass to store heat and temper heat transfer.*
- ✓ *Consider adding thermal mass to increase the storage capacity and energy efficiency of the building.*

Control air leakage

- ✓ *Consider air retarder systems (also referred to as "air infiltration barriers") as a means to improve energy performance and comfort.*

Efficient HVAC Systems

A school's HVAC system provides the heating, ventilating, and air-conditioning necessary for the comfort and well-being of students, staff, and visitors. To ensure peak operating efficiency, the HVAC system in a high performance school should: use high efficiency equipment; be "right sized" for the estimated demands of the facility; and include controls that boost system performance.

The HVAC system is one of the largest energy consumers in a school. Even modest improvements in system efficiency can represent relatively large savings to a school's operating budget. With the highly efficient systems available today—and the sophisticated analysis tools that can be used to select and size them—there's no reason why every school HVAC system can't be designed to the highest levels of performance.

A Closer Look—Inderkum High School, Sacramento, CA.

The Natomas Unified School District completed Inderkum High School with the design assistance of Nacht and Lewis Architects in fall 2004. One of its key energy saving high performance features included a geo-thermal system, instead of a conventional HVAC system. Capital Engineering Consultants Inc. were responsible for this state-of-the-art feature incorporating 500 geothermal wells that sit under the campus parking lot and reach up to 275 ft deep.

The system is a "closed loop earth heat exchange" that taps into the stable temperature of the earth at about 55 degrees. It is also more efficient than a conventional water-cooled heat pump, and has improved maintainability due to the elimination of mechanical cooling towers and gas consuming boilers.

Source: Brian Maytum Nacht & Lewis Architects and Capital Engineering Consultants Inc. Photo: Steve Whittaker, copyright 2004

The key to optimizing HVAC system performance is an integrated design approach that considers the building as an interactive whole rather than as an assembly of individual systems. For example, the benefits of an energy-efficient building enclosure may be wasted if the HVAC equipment is not sized to take advantage of it. Oversized systems, based on rule-of-thumb sizing calculations, will not only cost more, but will be too large to ever run at peak efficiency and will waste energy every time they turn on. An integrated approach, based on an accurate estimate of the impact of the high efficiency building enclosure, will allow the HVAC system to be sized for optimum performance. The resulting system will cost less to purchase, will use less energy, and will run more efficiently over time.

Energy Efficiency Checklist for HVAC Systems

Use high efficiency equipment

- ✓ *Specify non-CFC-based refrigerants for systems using large chillers.*
- ✓ *Specify equipment that meets or exceeds the DOE's "Energy Conservation Voluntary Performance Standards for New Buildings."*
- ✓ *Use Energy Star-approved products.*
- ✓ *Consider recovery systems that pre-heat or pre-cool incoming ventilation air.*
- ✓ *Consider "economizer cycles" for small, packaged systems.*
- ✓ *In hot, dry climates, consider evaporative cooling.*
- ✓ *Investigate the potential for on-site cogeneration.*

"Right-size" the system

- ✓ *Consider standard HVAC sizing safety factors as upper limits.*
- ✓ *Apply any safety factors to a reasonable base condition for the building: not the hottest or coldest day of the year with maximum attendance; not the most temperate day of the year with the school half full.*
- ✓ *Select systems that operate well under part-load conditions.*
- ✓ *Monitor existing local systems to size future systems.*
- ✓ *Incorporate controls that boost system performance*
- ✓ *Consider integrated building management systems that control HVAC, lighting, outside air ventilation, water heating and building security.*
- ✓ *Consider individual HVAC controls for each classroom.*

Water Efficiency

Fresh water is an increasingly scarce resource in most areas of California. A high performance school should control and reduce water runoff from its site, consume fresh water as efficiently as possible, and recover and reuse gray water to the extent feasible.

Basic efficiency measures can reduce a school's water use by 30% or more. These reductions help the environment, locally and regionally. They also lower a school's operating expenses. While the cost savings may be modest now, since water is relatively inexpensive in most areas of the country, there is a strong potential that these savings will rise over time, especially in areas of California where water is scarce and becoming more expensive.

A Closer Look—Chartwell School, Seaside, California

Chartwell School, overlooking Monterey Bay, reflects a commitment to water conservations. Indoors, they installed plumbing fixtures with automatic sensors, and dual-flush or waterless operation. Outdoors, they planted only native landscaping and used recycled water for any needed irrigation through installation of a rainwater collection system.

The technologies and techniques used to conserve water—especially landscaping, water treatment, and recycling strategies—can be used to help instruct students about ecology and the environment. Guidelines on the use of drought-resistant plants and efficient irrigation systems are provided in the Site Planning chapter. The HVAC guidelines discuss water consumption issues related to HVAC system choices. Opportunities to save water through water reclamation, gray water systems, and low-flow devices are discussed in the chapter on other (non-HVAC) systems. The following checklist summarizes the key issues related to water efficiency.

Water Efficiency Checklist

Design landscaping to use water efficiently

- ✓ *Reduce water use.*
- ✓ *Consider innovative wastewater treatment options.*
- ✓ *Specify hardy, native vegetation.*
- ✓ *Consider using an irrigation system for athletic fields only, not for plantings near buildings or in parking lots.*
- ✓ *Use high efficiency irrigation technology (e.g., drip irrigation in lieu of sprinklers).*
- ✓ *Use captured rain or recycled site water for irrigation.*
- ✓ *"Design in" cisterns for capturing rainwater.*

Set water use goals for the school

- ✓ *Recommended goal: 20% less than the baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992 fixture performance requirements.*

Specify water-conserving fixtures and equipment

- ✓ *Specify water-conserving plumbing fixtures that exceed Energy Policy Act of 1992 requirements.*
- ✓ *Specify high efficiency equipment (dishwashers, laundry, cooling towers).*
- ✓ *Consider single temperature fittings for student toilets/locker rooms.*
- ✓ *Consider automatic lavatory faucet shutoff controls.*
- ✓ *Consider low-flow showerheads with pause control.*

Consider using recycled or rainwater for non-potable uses

- ✓ *Decrease use of potable water for sewage conveyance by using gray and/or black water systems. Opportunities include toilet flushing, landscape irrigation, etc.*
- ✓ *Consider on-site wastewater treatment, including full or partial "solar aquatics" systems on large sites.*
- ✓ *Possible applications include HVAC and process make-up water.*

Material Efficiency

Material efficiency in this manual refers specifically to two overarching goals: 1) waste reduction—including construction and demolition (C&D) source reduction, reuse, and recycling; and 2) the use of building products that are manufactured in ways that conserve raw materials, including the use of recycled content products, that conserve energy and water, that are reused or salvaged, or that can be recycled or reused at the end of the building's service life. Addressing these goals provides significant environmental benefit. According to WorldWatch, buildings account for 40% of many processed materials used (such as stone, gravel, and steel) and 25% of virgin wood harvested. These withdrawals can cause landscape destruction, toxic runoff from mines, deforestation, biodiversity losses, air pollution, water pollution, siltation, and other problems.

The checklist below summarizes key material efficiency strategies. When considering recycled content products or other materials-efficient products, be sure to consider their effect on acoustic, visual, and indoor air quality. Be aware that using certain recycled products may conflict with goals for long-term materials efficiency, since a product's recycled composite may be difficult to recycle. Avoid products that unnecessarily complicate operation and maintenance procedures, and be sure that the custodial staff receives training in proper upkeep of the products. Using these strategies can help teach students about the role of waste reduction in protecting the environment.

A Closer Look—Heroes Elementary, Santa Ana, CA

Heroes Elementary is a CHPS demonstration school project sponsored by the California Integrated Waste Management Board (CIWMB). This is the first school in Santa Ana Unified School District to meet the CHPS Criteria with an emphasis on material-efficiency. The project focuses on the use of recycled content products and construction and demolition (C&D) waste management.

Heroes school plans to meet a 50% recycled content rate, which they have included in their design specifications. They will achieve this goal through using several products derived from waste tires including tire-derived resilient flooring, playground surfaces, rubberized asphalt concrete, and parking stops. Other products include bathroom tiles made from recycled windshield glass, formaldehyde-free acoustical ceiling tiles made from newsprint, toilet partitions made from recycled plastic beverage containers, thermal insulation made from recycled glass beverage containers, 50% postconsumer recycled content paint, and low-emitting recycled content carpet.

SAUSD is one of many school districts that have adopted CHPS resolutions and plans to incorporate high performance design into all their new construction projects.

Source: CIWMB California Integrated Waste Management Board. www.ciwmb.ca.gov/GreenBuilding/CaseStudies/

Material Efficiency Checklist

Design to facilitate recycling

- ✓ *"Design in" an area within the building dedicated to separating, collecting, storing and transporting materials for recycling including paper, glass, plastics, and metals.*

Reduce the amount of construction waste going to landfills

- ✓ *Develop and implement a management plan for sorting and recycling construction waste.*
- ✓ *Consider a goal of recycling or salvaging 50% (by weight) of total construction, demolition, or land clearing waste.*

Specify salvaged or refurbished materials

- ✓ *Evaluate the potential impact of salvaged materials on overall performance, including energy and water efficiency, and operation and maintenance procedures.*

Maximize recycled content of all new materials

- ✓ *Use EPA-designated recycled content products to the maximum extent practicable.*
- ✓ *Use materials and assemblies with the highest available percentage of post-consumer or post-industrial recycled content.*
- ✓ *Set a goal to achieve a minimum recycled content rate of 25%. (See Volume III for more information.)*

Eliminate materials that may introduce indoor air pollutants

- ✓ *Use materials or assemblies with the lowest level of VOCs.*
- ✓ *Evaluate the potential impact of specified materials on the indoor air quality of the school.*

GENERAL PURPOSE DESIGN AND EVALUATION TOOLS

Appropriate design tools are discussed in the overview of each technical chapter and within each guideline. Some general design and analysis tools are addressed here because they are common to many of the technical chapters that follow. More information on design tools can be found at www.eere.energy.gov/buildings/tools_directory/.

Conceptual Design Tools

Energy-10 is an educational tool that provides an overview of the performance interactions between different design strategies during conceptual design. For more information, visit the National Renewable Energy Laboratory's Energy-10 Web site at www.nrel.gov/buildings/energy10/ or the Sustainable Buildings Industry Council Web site at www.sbicouncil.org.

Green Building Advisor™ (GBA) is a CD-ROM based software tool that can be used as a "first cut" to help designers identify building design strategies that can be incorporated into specific projects. Based on inputs provided by the user, GBA generates a list of prioritized strategies organized by categories. The software provides information on relative cost as well as case studies where the strategy has been implemented. Registered users get a user's manual and free technical support. For more information, call (802) 257-7300 or visit www.buildinggreen.com/.

Energy Analysis Tools

These are computer programs designed to predict the annual energy consumed by a building. They can be used to evaluate the energy impacts of various design alternatives and, in particular, to compare specific low-energy strategies (for example, higher insulation levels, better glazing, increased thermal mass) in terms of their impacts on overall building performance. Combined with accurate cost estimates, they can help create a high performance school that is optimized in terms of its overall energy performance, which can save money on initial construction costs as well as on long-term operating expenses.

For example, a school that combines daylighting strategies and highly efficient electric lighting in its classrooms will require less electricity to illuminate those classrooms, providing a long-term operating savings. In addition, the rooms, because they take advantage of daylight and use high efficiency lamps, may need fewer light fixtures overall to achieve a high quality visual environment, providing an upfront savings on initial costs. Finally, highly efficient lighting—and, potentially, fewer light fixtures—will result in less waste heat in each classroom. This, in turn, will allow the cooling system for the classrooms to be smaller, generating additional upfront savings.

A wide number of energy analysis tools are currently available, some appropriate for the early stages of a project, some for the later phases. A sampling of these tools is provided below. Energy performance analyses using one or a combination of these tools should be conducted during each of the following design phases: programming, schematic design, design development, construction documents, and bidding and negotiation.

Architectural Design Tools

These are used primarily during a project's programming, schematic design, and design development phases.

- *Building Design Advisor.* Contact: Lawrence Berkeley National Laboratory. Web site: www.lbl.gov/.
- *Energy Scheming.* Contact: Iris Communications. Web site: www.oikos.com/esb/37/scheming.html.
- *VisualDOE.* Contact: Architectural Energy Corporation. Web site: www.archenergy.com/products/.

Load Calculation and HVAC Sizing

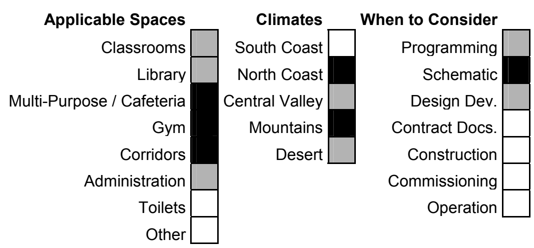
These are used primarily during a project's design development and construction documents phases.

- *EnergyPlus.* This computer program, which is being developed by the U.S. Department of Energy (DOE), is considered to be the successor to both DOE-2 and BLAST. It combines features from both programs and includes modules for the thermal analysis of windows, radiant transfer within spaces and other features. Contact: Lawrence Berkeley National Laboratory. Web site: www.lbl.gov/.
- *DOE-2.* This widely used program for analyzing the energy efficiency of buildings uses an hourly weather file and simulates energy performance during a typical year. Contact: Lawrence Berkeley National Laboratory. Web site: www.lbl.gov/. There are several Windows user interfaces that make it easier to use DOE-2, including VisualDOE, PowerDOE, and EnergyPro.
- *HAP*. Contact: Carrier Corp. Web site: www.carrier.com/.
- *TRACE*. Contact: Trane Corp. Web site: www.trane.com/.
- *BLAST.* Contact: University of Illinois. Web site: www.bso.uiuc.edu/.

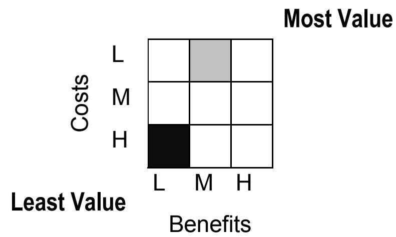
ANATOMY OF A GUIDELINE

Each guideline in Volume II follows the format outlined below. Information relevant to multiple guidelines is typically discussed in the Overview for that chapter.

- **Recommendation:** A brief description of how to apply the high performance design concept to the building feature.
- **Description:** More detailed information on the technology or design strategy.
- **Applicability chart**: Indicates the applicability of the guideline to particular spaces, climate zones, and design process steps. (See the end of this section for more information on the climate zones covered in this manual.) In the example below, the black areas indicate the guideline's strong applicability and the gray areas represent limited applicability. Unshaded areas indicate that the guideline is not applicable.



- **Applicable Codes:** Lists the codes and regulations that apply to the building feature described in the guideline. Although not listed in this document, local ordinances may also apply in some jurisdictions.
- **Integrated Design Implications:** Describes the implications that the design strategy or technology might have on other building systems, e.g., if cooling load is significantly reduced by high performance fenestration, the HVAC system might be made smaller and natural ventilation might become more viable. Discusses the phase of design when the strategy or technology might best be implemented.
- **Cost Effectiveness:** Describes the benefits and costs of the strategy/technology on both a system basis and an overall project basis. The chart below shows construction costs on the vertical scale, ranging from low to medium to high. The horizontal scale represents benefits, also categorized from low to medium to high. A black mark shows the overall project impact and a gray mark represents the system impact. In the diagram below, the system benefits are medium and the system costs low, while the overall cost is high and benefits are low.



For ranking the *system* benefits and costs:

- Low represents an increase in costs or benefits of 0%–20% over the base case system.
- Medium is a cost or benefit increase of 20%–50% over the base case system.
- High is an increase in costs or benefits of more than 50% over the base case system.

For ranking the *overall* benefits and costs:

- Low represents an increase in costs or benefits of 0%–2% over the base case system.
- Medium is a cost or benefit increase of 2%–8% over the base case system.
- High is an increase in costs or benefits of more than 8% over the base case system.

The cost scale refers only to the initial construction cost, which is a significant issue for schools and their architects. On an overall basis, low means that the incremental construction cost is small or even negligible and that the district should be able to afford the strategy/technology with the normal school construction budget. Medium cost means that the strategy/technology will cost a little more and the school construction budget will need to be supplemented or will need to realize savings from other systems, e.g., HVAC downsizing.

This section also presents general information on construction costs on a $/ft² or $/classroom basis, when possible. It identifies and quantifies operation and maintenance costs if applicable and/or possible. The section describes environmental costs or externalities that cannot be given a dollar value.

- **Benefits:** Outlines the benefits expected from the implementation of the measure including energy savings, improvements in indoor environmental quality, productivity benefits, and possible impact on average daily attendance.
- **Design Tools:** Lists any applicable design tools, including software that can be used to optimize the design, quantify the benefits, or estimate construction costs. In some cases, the section will describe a technique for using a general-purpose tool such as DOE-2 to evaluate and analyze the design.
- **Design Details:** Contains more thorough details on the design, such as rules of thumb, specific recommendations, sample specifications, or schematic diagrams.

- **Operation and Maintenance Issues:** Outlines potential operation and maintenance concerns and requirements for keeping the strategy/technology operating at optimal performance.
- **Commissioning:** Discusses the need for calibration, functional tests, static tests, commissioning plan requirements, statement of design intent, post-occupancy tests, and other issues and requirements related to ensuring that the strategy/technology was implemented as the designer intended.
- **References / Additional Information:** Provides as sampling of documents, Web sites, etc. where additional information about the strategy/technology can be found.

CLIMATES

The guidelines are developed for the five California climate regions shown here. Many of the recommendations vary depending on the climate where the school is constructed. In these cases, the recommendations, and their applicable climate zones, will be indicated in both the guideline text and the applicability chart described in the previous section

Figure 2—California Climate Regions

General Conditions

OVERVIEW

This chapter provides guidelines for preparing the general conditions portion of the construction specification. These guidelines address the responsibilities of the general contractor including:

- Guideline GC1: Sustainable Job-Site Operations Plan
- Guideline GC2: Construction and Demolition (C&D) Waste Management
- Guideline GC3: Indoor Air Quality During Construction
- Guideline GC4: Site Protection During Construction
- Guideline GC5: Contractor's Commissioning Responsibilities

The general conditions guidelines aim to ensure that the methods used to build the school and operate the construction site are environmentally sound. It is not only important to end up with a high performing school; the means to get there should be consistent with that end.

During construction, literally hundreds of opportunities exist to work toward fulfilling the environmental goals of a high performance school or, alternatively, to compromise them. To ensure the construction process is consistent with these goals, contractors should be made aware of these opportunities upfront, as part of the bidding process. Ideally, the selected contractor should have experience with some of the practices recommended in this Best Practices Manual. At a minimum, they should be aware of, and responsive to, the goals set for the project. The better contractors understand their role in achieving the high performance goals, the more likely the construction process will go smoothly.

Using Environmentally Preferable Methods during Construction

During construction, general and trade contractors have a significant role to play in making efficient use of materials, preventing future indoor air quality problems, and protecting the site from degradation. In practice, requiring that the contractor produce and implement a job-site operations plan has proven to be the most effective way to ensure that environmental goals will be given equal treatment along with other project goals.

Sustainable job-site operational costs are generally minimal, and benefits can be significant. Planning helps minimize costs and liabilities, including expensive delays, stoppages, and callbacks due to mistakes made during construction. Savings resulting from job-site waste reduction practices are well documented. Contractors familiar with sustainable job-site operations will know the benefits and understand that these are not complicated practices. Contractors unfamiliar with them, however, will assume they cost more and bid accordingly. Bid packages should contain references to existing resources to help uninitiated contractors familiarize themselves with high performance construction practices plans as well as provide tools to estimate costs and benefits more accurately.

A sustainable job-site operation will use a combination of contract language, signage, weekly job-site meetings, and incentives/rewards to educate and motivate field personnel to ensure everyone works towards the high performance goals. Brief presentations, signage that both informs and motivates by reporting progress on environmental goals, and contractor's field guides can be helpful communication aids. On most construction sites, signage and other printed instructions will need to be written so individuals for whom English is a second language can easily understand. For some construction trades, it may be beneficial to include both English and Spanish signage.

In addition, the most successful contractors identify an individual (often the safety officer) who can enforce the sustainable job-site operations plan on a day-to-day basis. With many recommended job-site practices and with a host of subcontractors, it is difficult to determine whether the recommended practices actually occur without regular in-the-field monitoring. Ideally, the same individual monitoring compliance would take an active role in training and other on-site educational efforts.

Achieving the Design Intent of a High Performance School

Perhaps the most important contribution the contractor can provide in achieving high performance goals for the school is in participating in the commissioning process. The entire point of this process is to demonstrate that the installed components of building systems meet the original design intent. (See the Best Practices Manual Volume V: Commissioning for more detailed discussions of the commissioning process.) Contractors can play a key role in effective commissioning by providing timely documentation, understanding the importance of thorough testing and tuning, paying attention to detail when correcting problems, and being responsive to the commissioning agent's recommendations and requests.

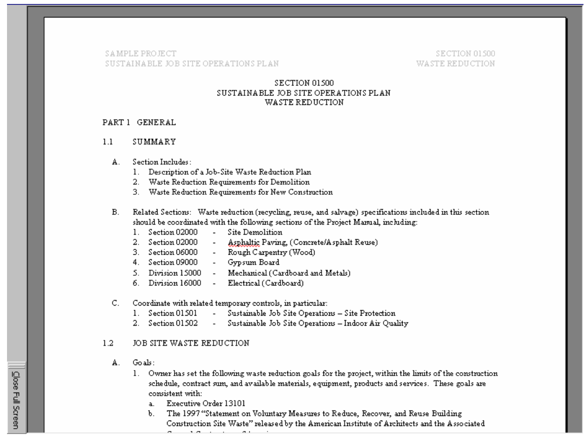
Installation schedules of a high performance school may be different from a conventional school. For example, the California Department of Health Services' "Reducing Occupant Exposure to Volatile Organic Compounds (VOCs) from Office Building Construction Materials Non-Binding Guidelines" recommends that "porous materials, such as carpets and fabric-covered office dividers…be installed last." This practice prevents the porous materials from acting as a "sink" for VOCs being emitted by wet products (paints and other finishes, for example). Proper sequencing can be spelled out in execution articles of pertinent specification sections, but may also be called out under general conditions. In addition, ventilation and flush-out requirements during and after installation will need to be specified in appropriate sections.

In addition, product substitutions (especially those made in the field due to last-minute availability problems) can contribute to losing sight of the original design intent. When substitutions in the field occur, submittals must show that these substitutions possess the environmentally preferable characteristics of the original product or material specified. A sustainable job-site operations plan should specify a method to providing documentation for substituted products, so that, in the event of replacement or repair, the information is available to the custodial staff. In addition, when dealing with non-conventional or innovative materials, it can be helpful to note information in a field log about how a product behaves during installation and pre-occupancy maintenance (such as during cleanup), as well as any other "lessons learned.

GUIDELINE GC1: SUSTAINABLE JOB-SITE OPERATIONS PLAN

Recommendation

Require a job-site operations plan that includes protocols for Job-Site Waste Reduction (Guideline GC2: Construction and Demolition (C&D) Waste Management), Indoor Air Quality (Guideline GC3: Indoor Air Quality During Construction), and Site Protection (Guideline GC4: Site Protection During Construction).



SAMPLE PROJECT
SUSTAINABLE JOB SITE OPERATIONS PLAN

SECTION 01500
WASTE REDUCTION

SECTION 01500
SUSTAINABLE JOB SITE OPERATIONS PLAN
WASTE REDUCTION

PART 1 GENERAL

1.1 SUMMARY

A. Section Includes:
1. Description of a Job-Site Waste Reduction Plan
2. Waste Reduction Requirements for Demolition
3. Waste Reduction Requirements for New Construction

B. Related Sections: Waste reduction (recycling, reuse, and salvage) specifications included in this section should be coordinated with the following sections of the Project Manual, including:
1. Section 02000 - Site Demolition
2. Section 02000 - Asphaltic Paving, (Concrete/Asphalt Reuse)
3. Section 06000 - Rough Carpentry (Wood)
4. Section 09000 - Gypsum Board
5. Division 15000 - Mechanical (Cardboard and Metals)
6. Division 16000 - Electrical (Cardboard)

C. Coordinate with related temporary controls, in particular:
1. Section 01501 - Sustainable Job Site Operations – Site Protection
2. Section 01502 - Sustainable Job Site Operations – Indoor Air Quality

1.2 JOB SITE WASTE REDUCTION

A. Goals:
1. Owner has set the following waste reduction goals for the project, within the limits of the construction schedule, contract sum, and available materials, equipment, products and services. These goals are consistent with:
a. Executive Order 13101
b. The 1997 "Statement on Voluntary Measures to Reduce, Recover, and Reuse Building Construction Site Waste" released by the American Institute of Architects and the Associated

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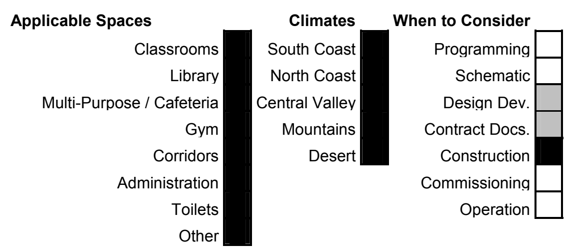
Figure 3—Sample Sustainable Job Site Operations Plan

Description

A sustainable job-site operations plan will describe goals, construction practices to achieve those goals, methods to train or otherwise communicate these goals to field personnel, and methods to track and assess progress towards those goals. For each component of the plan (waste reduction, IAQ, and site protection), these elements will be specified. In addition, the plan will specify the method of documenting compliance with these goals, including in the case of product substitutions.



Applicability

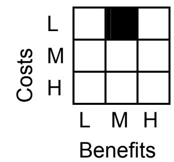
Job-site management is applicable to all spaces in schools and to all climates. While it is carried out in the construction phase, the contract documents must clearly specify the expectations of the general contractor.

Applicable Codes

There are many jurisdictions in California (at the county and city level) that have developed, or are developing, ordinances that require job-site waste management planning. (See Guideline GC2: Construction and Demolition (C&D) Waste Management for more information.) In addition, local school districts are beginning to develop IAQ policies that incorporate some operational requirements for construction. (See Guideline GC3: Indoor Air Quality During Construction for more information.) The U.S. Green Building Council's LEED Green Building Rating System (Commercial, Version 2.1) includes a provision for an IAQ construction plan as well. All jurisdictions include some requirements related to water quality protection, in particular stormwater management during construction. More communities are adopting “green building ordinances” that capture some elements of sustainable job-site operations.

Integrated Design Implications

A sustainable job-site operations plan protects the integrity of design goals to reduce waste, improve air quality, and protect the site and surrounding waterways from degradation.



Cost Effectiveness

Costs for implementing the plan will include labor for overseeing and documenting compliance, and should not be significant.

Benefits

Having a plan in place helps minimize costs and liabilities, including delays, stoppages, and residual problems in the completed school building. Proper planning is always more cost-effective than cleaning up after a mistake.

Design Tools

None.

Design Details

The requirement for a sustainable job-site operations plan would appear in the “Temporary Controls” section(s) of specifications. The more clearly a plan allocates responsibilities and expectations, the less likely the project will generate unpleasant surprises during and after construction. Ideally, the plan should specify a time requirement for when a plan must be submitted, such as within 14 days of Notice of Award and prior to applicable construction activities. In addition, it can include sample forms, references, or other resources for the contractor to help facilitate development of an effective plan. Sample specifications for the three plan components recommended in this guideline—job-site waste reduction, IAQ, and site protection—can be found in the electronic Appendix A.[3]

3 The electronic appendices are located on-line at www.chps.net/manual/index.htm or on the CD-ROM version of the Manual.

Operation and Maintenance Issues

The plan should specify a method of providing documentation for products substituted in the field, so that information is available to maintenance staff should a replacement or repair be required. In addition, when dealing with non-conventional or innovative materials, information about how a product behaves during installation and pre-occupancy maintenance (such as during cleanup), as well as other "lessons learned" noted in a field log can be helpful.

Commissioning

None.

References/Additional Information

Please see the References listed for individual components of the plan in the following guidelines: Guideline GC1: Sustainable Job-Site Operations Plan, Guideline GC2: Construction and Demolition (C&D) Waste Management, and Guideline GC3: Indoor Air Quality During Construction.

Also see electronic Appendix A for sample specifications language. This appendix includes a specification section 01500 that contains sample language that can be used in the contract documents.

GUIDELINE GC2: CONSTRUCTION AND DEMOLITION (C&D) WASTE MANAGEMENT

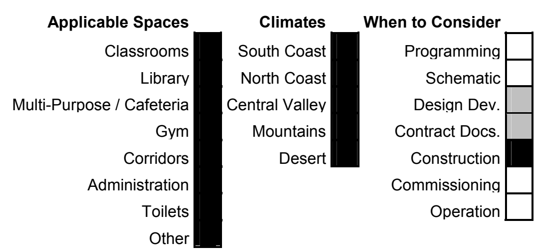
Recommendation

Require waste reduction planning and job-site practices. These guidelines recommend that a sustainable job-site operations plan (Guideline GC1: Sustainable Job-Site Operations Plan) be developed that incorporates a job-site waste reduction component. An alternative is to develop a stand-alone Construction and Demolition (C&D) Waste Management Plan.

Figure 4—Conducting a Construction Site Waste Audit (courtesy O'Brien & Company)

Description

Effective job-site waste management will reduce the amount of C&D waste generated, as well as divert materials generated through C&D processes from disposal through reuse (salvage) and recycling. This effort can be combined with a concerted use of salvaged or recycled-content building materials throughout the building project; specific materials would be called out in appropriate sections of project specifications.



C&D waste management will include the development of a waste reduction plan, identification of personnel responsible for implementing and monitoring the plan, and an outline of consequences for non-compliance. Waste management should reflect the prioritized hierarchy of "Reduce, Reuse, and Recycle, Buy Recycled" with recycling efforts occurring in concert with *source reduction* and applying only to materials that *cannot be reused*. The concept of source reduction eliminates or reduces potential waste prior to generation.

Applicability

C&D waste management is applicable in all climates and in all types of school spaces. While carried out during the C&D phase, the contract documents must clearly layout the responsibilities of the general contractor.

Applicable Codes

Because of state goals and possible sanctions, many jurisdictions at the county and city level have developed, or are developing, ordinances related to C&D waste management. In some cases, these ordinances apply only to municipally owned projects. Some ordinances exempt C&D projects below a specified dollar value or size.

Though not mandated, the CIWMB provides a model C&D waste management ordinance for cities and counties to consider adopting. The CIWMB Web site has the model ordinance at www.ciwmb.ca.gov/LGLibrary/CandDModel/.

These ordinances generally require a C&D waste management plan and implementation documentation for permitting, often providing a sample form for this purpose. In some cases, the ordinances require a minimum level of C&D materials diversion from landfills, or at the very least, a "good faith effort." In addition, at least two ordinances require deposits be held until proof of compliance with waste reduction requirements has been provided. Though schools are not required to go through the local building approval process, CHPS recommends that schools do comply and, through project specifications, require that contractors pay this deposit and/or follow any other local ordinance requirements.

For a sample of C&D-waste-related ordinances, see www.ciwmb.ca.gov/ConDemo/SampleDocs.

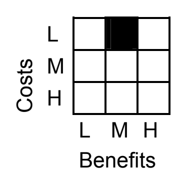
Integrated Design Implications

Some waste reduction can be designed into the building project, such as: standardized dimensioning, modular or panelized building units, and layout of openings. Specifying the use of mechanical fasteners (screws, Velcro) rather than chemical adhesives and solvents will allow components to be easily disassembled and reused.

It will be important that intent of these design details be made clear to avoid in-the-field decisions that waste materials. Contractors are excellent problem solvers, and should be encouraged to find cost-effective substitutes that they know will meet or exceed the environmental goals.

Improper handling of materials on the job site can add to construction waste. For example, materials contaminated by mildew and mold due to moisture exposure have to be discarded and replaced.

Cost Effectiveness



Costs include labor for overseeing and implementing the C&D waste reduction (or waste management) plan, rental for additional bins or other containers used for recycling or salvage, and transportation. Research indicates labor costs decrease significantly as contractors become more familiar with job-site waste reduction techniques. Some contractors keep costs down by utilizing temporary lay down areas with plywood barriers to hold recyclables, rather than renting bins or containers. Alternatively, planning ahead and ordering bins only when needed can keep down costs, since C&D materials are typically generated at predictable phases of the project. And, using recycling bins can avoid disposal costs, saving contractors and districts money.

Waste disposal/management is generally budgeted as a very small portion of overall job costs. However, the cost of purchasing materials to replace materials that are wasted is rarely taken into account. The tendency is to assume that effective waste reduction takes more time and results in higher costs, but case studies show that, if labor crews are adequately trained and a good plan is in place, costs do not increase.

Benefits

In general, C&D waste reduction should also reduce overall construction costs, especially as the practice becomes a part of every job, and the C&D recycling/reuse infrastructure matures. If revenues from waste reduction, reuse/salvage, and recycling are allocated to the contractor, the responsibility (and the incentive) for waste reduction clearly lies in the contractor's domain. Most contractors report that having a good waste reduction program in place results in a cleaner, safer site, resulting in less lost time and delay.

Environmentally, less waste means better use of limited raw materials and of the energy required to produce, transport, and dispose of building products used in the project. Also, recycling provides "stock" for new materials to be manufactured.

Design Tools

See the Waste Management specification section and the C&D Waste Management Plan of the electronic Appendix A, for sample specification language. Also see the sample specifications included in Green Spec: The Environmental Building News Product Directory and Guideline Specifications.

Design Details

Scheduling should permit salvaging and deconstruction activities, as appropriate.

Waste reduction goals (as with all other sustainable building goals) should be outlined in the Instructions to Bidders section of the Project Summary. The California Integrated Waste Management Board (CIWMB) recommends a goal of 75% diversion of C&D materials by weight. In addition, waste reduction specifications should be included in the Temporary Controls sections of General Conditions. The CIWMB recommends a 13-step C&D site recycling process (see Table 2 at the end of this guideline).

As part of identifying those materials that should be targeted for recycling or reuse in a particular project, contact the local waste authority (www.ciwmb.ca.gov/OLA/Contacts.asp) for information about building materials that can be cost-effectively recycled or salvaged in the project area. These materials (an example being gypsum drywall) should be called out for recycling in the General Conditions specifications section pertaining to waste reduction and in other pertinent sections.

Waste reduction specifications should reflect local jurisdictional requirements, but should be organized using typical CSI convention. The specifications should describe what is included in the job-site waste reduction plan, outline submittal and documentation requirements; indicate ownership of revenues resulting from waste reduction efforts; and include performance goals like minimum levels of waste reduction. The specifications should also outline remedies in the event those levels cannot be met.

If the contractor is required by ordinance or specification to be responsible for achieving waste reduction, it is not necessary to detail methods by which the contractor can achieve it. However, it is informative to contractors to include a list of proven waste reduction strategies, such as:

- A pre-C&D-waste-management meeting to discuss procedures, schedules, coordination, and special requirements for materials.
- A waste reduction provision in supply agreements specifying a preference for reduced, U-turn, and/or recyclable packaging.
- Detailed take-offs that identify location and use in the structure to reduce risk of unplanned and potentially wasteful cuts.
- Proper storage for materials to avoid water or other damage as well as outdating. Materials that become wet or damp due to improper storage shall be replaced at contractor's expense.
- Safety meetings, signage, and subcontractor agreements that communicate the goals of the waste reduction plan. Signage should be clear and easy to understand for multiple languages, through the use of graphic symbols.
- On-site instruction regarding appropriate separation, handling, recycling, salvage, reuse, and return methods to be used to achieve waste reduction goals.
- Discussion of C&D waste management during regular job meetings and safety meetings.
- Contamination protection for materials to be recycled.

Tipping fees or hauling costs are sometimes quoted by weight and sometimes by volume. The conversion from volume to weight, or vice versa, depends on the density of the material. The volume to weight conversions for most common construction and demolition materials are given at the following website, www.ciwmb.ca.gov/LGLibrary/DSG/ICandD.htm.

Operation and Maintenance Issues

Contractors should be required to provide sufficient information on product substitutions to enable the operation and maintenance staff to properly maintain, repair, and replace all products.

Commissioning

None.

References/Additional Information

California Integrated Waste Management Board Web site. In particular, see "Job Site Source Separation," a fact sheet located at www.ciwmb.ca.gov/ConDemo/Materials/SourceSep.htm. Also see the Clean Washington Center's *Recycling Plus Manual* at www.ciwmb.ca.gov/ConDemo/Links.htm. Use this resource to produce a step-by-step construction waste management and recovery plan. *Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction*. Chapter 9, Managing Job-Site Waste addresses C&D waste and is located at www.ciwmb.ca.gov/ConDemo/Pubs.htm.

California Integrated Waste Management Board, Conducting a Diversion Study: A Guide for Local Jurisdictions, www.ciwmb.ca.gov/LGLibrary/DSG.

U.S. Environmental Protection Agency, *Characterization of Building-Related Construction and Demolition Debris in the United States*, June 1998 at www.epa.gov/epaoswer/hazwaste/sqg/c&d-rpt.pdf. Provides national data that a builder may find helpful to estimate and characterize his own waste generation.

U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2.1) at www.usgbc.org.

For product substitutions, refer contractors to the CIWMB Web site. Also refer to Green Spec: The Environmental Building News Product Directory and Guideline Specifications (www.buildinggreen.com/), and the OIKOS Web site (www.data.oikos.com/products).

Table 2 – Steps to a Successful Construction and Demolition Waste Management Program

Excerpt from Designing With Vision, A Technical Manual for Material Choices in Sustainable Construction, Revised July 2000, California Integrated Waste Management Board, www.ciwmb.ca.gov/greenbuilding/pubs.htm

Step 1—Plan the project.	Each construction project and job site presents a different set of challenges. Develop a "solid resources management plan" for each project. An effective plan outlines job site waste reduction goals, identifies targeted materials, describes specific waste reduction actions to be implemented on a project, and identifies reuse, recycling, or disposal facilities to which materials will be taken. This is an extremely important part of the materials management plan. The plan should be outlined in the bid and contract specifications, as described in Step 2.
Step 2—Incorporate solid resources management in specifications.	One of the most important tools for assuring that contractors implement the goals and objectives of your waste management plan is to put it right up front in the bid package. The bid specification should outline the procedures and specifications required for salvage, reuse or recycling.
Step 3—Coordinate recycling by project phase.	Different materials are generated at different phases of the project. Use your construction schedule to coordinate recycling by project phase and by trade. A fast-paced job could decrease the amount of materials recycled, since many activities will be happening simultaneously and site recovery efforts may be placed on the back burner. Careful planning can help minimize this problem. A slow job could decrease the rate of materials collection below that which is cost-effective. This problem can be minimized if there is space to store the materials on site.
Step 4—Estimate amount of waste expected.	Estimate the types and quantities of waste that are expected from the project. See “Types of Materials Typically Recovered Successfully” on page 137 for a list of possible materials.
Step 5—Determine what is cost-effective to recycle.	Select several material types that are typically recycled, such as wood, cardboard, concrete, and metals. Though labor costs are often higher for recycling, the lower tipping fees at recycling facilities can often more than compensate. For example, concrete and asphalt recycling may cost $5 per ton, versus $35 per ton for landfilling. If the concrete recycler's location is not too much farther than the landfill, the project could save a significant amount of money. To determine the cost-effectiveness of recycling, calculate each material's cost per ton for recycling versus landfilling by estimating labor costs, transportation costs, and tipping fees. The “Economics Worksheet” in Appendix D is a convenient tool for this calculation. (Note: This worksheet is a draft and may require revisions over time. Please contact IWMB staff to suggest improvements, and/or obtain an updated version.)
Step 6—Consider hiring a recycling service.	Consider working with either (1) your hauler, (2) a professional full-service recycling contractor, or (3) a waste management consultant to help you identify what types of materials can be cost-effectively recycled from your project. See “Sample Provisions for a Full-Service Recycling Agreement With a Waste Hauler,” page 138, for information on contract language and sample provisions to use when hiring a full-service recycling contractor or hauler.
Step 7—Consider space constraints.	Most jobs have moderate to severe space constraints. Develop a plan to "stage" the job site for the most effective method for storing and collecting both recyclables and waste, and position recycling bins at the most convenient location for the various trades to use. See “Tips for Recycling Bin Use,” page 139.
Step 8—Work with haulers to plan collection.	Work with haulers to develop a plan for collecting materials. Identify "peak generation" times early in the process. Determine what types of containers are available to collect the materials. Different containers may be needed at different phases of the project in coordination with the various trades. For example, a large 40-yard (cubic yard) dumpster may be needed for wood, but only a 20-yard dumpster is needed for steel studs.
Step 9—Get “buy in” up front.	For the program to be successful, it is important to establish a high level of commitment from the contractor, subcontractors, cleanup personnel, and waste haulers up front. Some contractors have waste management training as part of their prebid, preconstruction, and safety training meetings. Hold your subcontractors accountable for implementing the solid resources management plan outlined in the bid package. Provide a package of information on the recycling program to each new subcontractor when they come on board.
Step 10—Expect a learning curve.	When dealing with contractors and subcontractors, who are inexperienced with waste reduction and recycling practices, expect some errors and inefficiencies because of the learning curve. Set recycling goals that are realistic for personnel who are learning new skills. It's better for morale to exceed the goals than to miss them.
Step 11—Reward participation.	It's important that field personnel know how their efforts are paying off. Communicate the success of the reuse/recycling program with subcontractors. One idea would be to put up a status graph to show on a monthly or weekly basis how much waste has been diverted from the landfill, and how much savings have accrued to the project because of their waste management efforts. Another idea would be to provide incentives such as t-shirts or mugs, when goals are met. Also, encourage everyone's ideas and suggestions.
Step 12—Monitor and track for quality control.	One contaminated box can really add costs to a successful recycling program. It is helpful to track on a monthly basis the type, amount and cost of all materials being recycled or landfilled from the job site. A simple tracking form is provided in the "Solid Resources Management" specification in Appendix C (Attachment B), called "Summary of Solid Waste Disposal and Diversion." This form can be used to develop a spreadsheet that gives you an up-to-date report that will identify how many clean dumpsters went off site for reuse and recycling and how many contaminated and costly dumpsters were taken to the landfill.
Step 13—Promote your success.	Put out press releases on the success of your project. Clearly identify the job site with signs that tell the public you are reducing, reusing, and recycling your waste. Let the public know you are committed to being resource efficient.

GUIDELINE GC3: INDOOR AIR QUALITY DURING CONSTRUCTION

Recommendation

Require indoor air quality (IAQ) planning and preventive job-site practices for the jobsite.

Description

Preventive job-site practices can eliminate undue health risks for workers and reduce residual problems with IAQ in the completed building and eliminate undue health risks for workers. "Healthy" job-site planning will adequately address problem substances, including construction dust, chemical fumes, off-gassing materials, and moisture. It will make sure these problems are not introduced during construction, or, if they must be, eliminates or reduces their impact. Areas of planning will include product substitutions and materials storage, safe installation, proper sequencing, regular monitoring, as well as safe and thorough cleanup.

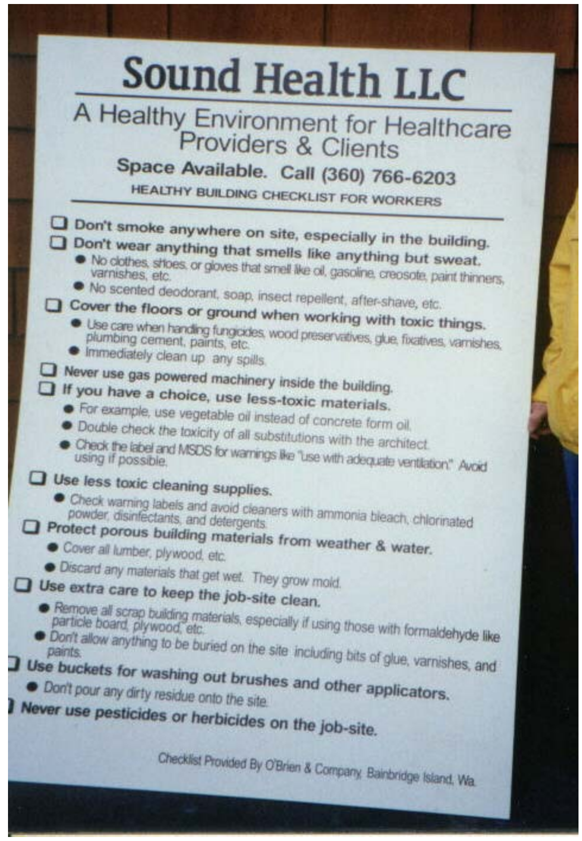


Figure 5—Healthy Job Site Signage (courtesy of O'Brien & Company)

Applicability

Maintaining healthy job-site conditions is important for all spaces and all climates. The activity is carried out in the construction and renovation phases, but must be planned in the design development and documented in contracts, maintenance plans, and policies.

Applicable Spaces	Climates	When to Consider
Classrooms	South Coast	Programming
Library	North Coast	Schematic
Multi-Purpose / Cafeteria	Central Valley	Design Dev.
Gym	Mountains	Contract Docs.
Corridors	Desert	Construction
Administration		Commissioning
Toilets		Operation
Other		

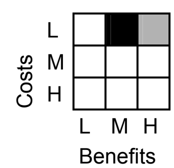
Applicable Codes and Guidelines

Local school districts are beginning to develop IAQ policies that incorporate construction/operational requirements. See for example, the Materials/Indoor Air Quality Policy for School District Buildings (Berkeley Unified School District, Berkeley, CA: 1994–1995). Check with your local jurisdiction to see if a similar policy is in place. In addition, the U.S. Green Building Council's LEED Green Building Rating System (Commercial, Version 2.1) includes a provision for an IAQ construction plan. This provision requires that the project contractor "meet or exceed the minimum requirements of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines for Occupied Buildings Under Construction, 1995."

Integrated Design Implications

When identifying "healthy" materials for use in buildings, the focus is generally on preventing problems during occupancy. This guideline implies some responsibility for air quality falls during installation, which may impact the choice of material and/or the method of installation. Also, since product substitutions may happen in the field, it is important to outline the approval process for these substitutions clearly. For materials with off-gassing potential, require specific ingredient information about the product itself (as well as any adhesives, solvents, or other products that might be used during installation or maintenance). Designing to use mechanical fasteners (screws, Velcro) rather than chemical adhesives and solvents can reduce potential problems with IAQ during construction.

Cost Effectiveness



Implementing this guideline should not necessarily add cost to the project. The one area where it might add cost is in the form of potential delays due to sequencing and ventilation requirements. However, this cost can be minimized by proper planning.

Risk managers may be reluctant to take on the added responsibility of requiring IAQ planning and preventive job-site practices. However, school districts and project architects across the country have experienced litigation related to poor IAQ resulting from improper construction activities. Addressing these issues before and during construction will reduce exposure of the school district and designers to potentially expensive litigation in the future.

Benefits

The costs of poor IAQ are difficult to quantify, but considerable. They include the sum of illness and decreased student productivity suffered by students and teachers, along with the district's cost of equipment replacement, workers' compensation claims, and in the most severe cases, litigation. Unfortunately, serious health complaints have resulted from careless acts during construction projects, such as failure to clean up spilled adhesives or neglecting to properly ventilate during and after applying sealants in an occupied building. These mistakes have led to school closures, unpleasant headlines, and costly lawsuits. Good IAQ strategies during construction will help eliminate these potential liabilities.

Design Tools

See electronic Appendix A for sample specification language.

Design Details

IAQ goals (as with all other sustainable building goals) should be outlined in the Instructions to Bidders as part of the Project Summary addition. IAQ specifications should be included in the Temporary Controls sections of General Conditions.

The specifications should describe what is included in an IAQ construction plan, outline submittal requirements, and reference the SMACNA IAQ Guidelines for Occupied Buildings Under Construction 1995, with the goals of:

- Protect the ventilation system components from contamination, or provide cleaning of the ventilation components that are accidentally exposed to contamination during construction prior to occupancy. Manufacturers and distributors of these components should have clear instructions for cleaning and sealing these components to remove any manufacturing residues and to avoid subsequent contamination by dust or fumes. Duct work and air handlers should be well-sealed until they are installed.
- Provide a minimum continuous ventilation rate of one air change per hour during construction, or conduct a building flush-out with new filtration media at 100% outside air after construction ends (following issuance of Occupancy Certificate) and prior to occupancy for seven days (one week). Systems designed to filter particulate matter must not be operated without a particulate filter in place during construction, though the filter used during construction does not need to be of the same rating as that used during occupancy (per ANSI/ASHRAE *Standard 62.1-2004*). Note that seven days is considered a minimum. IAQ specialists recommend flushing the building with 100% outside air for 30 days prior to substantial completion.

If the contractor is required by the specification to be responsible for protecting IAQ during construction, it is not necessary to detail methods by which the contractor can achieve it. However, it is informative for contractors to include a list of proven air quality protection strategies, such as:

- Use supplemental (temporary) ventilation during the installation of carpet, paints, furnishings, and other volatile organic compound (VOC)-emitting products, for at least 72 hours after work is completed. Preferred HVAC system operation uses supply air fans and ducts only, with windows providing exhaust. Use exhaust fans to pull air from deep interior locations. Stair towers and other paths to the exterior can be useful during this process. Portable floor fans are also recommended to improve pollutant removal from surface materials such as carpeting.
- Perform regular inspection and maintenance of IAQ measures, including ventilation system protection and ventilation rate. Spot check walls, duct work, and plenums before they are closed up, to ensure that debris, contamination, and mold are not present.
- Provide VOC-safe masks for workers installing VOC-emitting products (interior and exterior), which are defined as products that emit 150 grams per liter (gpl) or more. If local jurisdiction's requirements are stricter, the strictest requirement should be followed for use of VOC-safe masks.

- Provide low-toxicity cleaning supplies for surfaces, equipment, and worker's personal use. Options include several soybean-based solvents and cleaning options (SoySolv), and citrus-based cleaners.
- Wet sand gypsum board assemblies. Exceptions should be clearly defined and include full isolation of space undergoing finishing or closure of all air system devices and ductwork. Additional conditions can be set.
- Use safety meetings, signage, and subcontractor agreements to communicate the goals of the construction IAQ plan.

The IAQ construction plan is also a good opportunity to proscribe unacceptable behaviors that represent a potentially negative impact on long term IAQ, such as smoking, using chew tobacco, or wearing contaminated work clothes.

Operation and Maintenance Issues

Contractors should be required to provide information on product substitutions sufficient to enable operation and maintenance staff to properly maintain and repair low-emitting or otherwise "healthy" materials.

Commissioning

None.

References/Additional Information

U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2.1) at www.usgbc.org. Also see Carpet and Rug Institute (CRI) guidelines for carpet installation. The Painting Contractors Union (New York City local) has reportedly developed guidelines for ventilation during painting.

U.S. Environmental Protection Agency. www.epa.gov/iaq/schools/tfs/renovate.html. A checklist for IAQ issues at all stages of construction.

For product substitutions, refer contractors to the CIWMB Web site. Also refer to Green Spec: The Environmental Building News Product Directory and Guideline Specifications (www.buildinggreen.com/), and the OIKOS Web site (www.data.oikos.com/products).

GUIDELINE GC4: SITE PROTECTION DURING CONSTRUCTION

Recommendation

Require best management practices for site protection during construction.

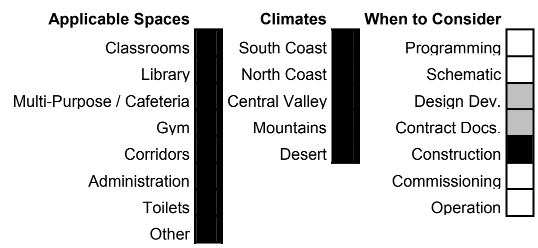
Figure 6—Silt Fencing for Sedimentation Control (courtesy of O'Brien & Company)

Description

An effective job-site protection plan will describe construction practices that eliminate unnecessary site disturbance, minimize impact on the site's natural (soil and water) functions, and eliminate water pollution and water quality degradation.

Primarily it will include protocols for:

- Construction equipment operation and parking.
- Topsoil and vegetation protection and reuse.
- Hazardous materials management.
- Installation and maintenance of erosion control and stormwater management measures.



Applicability

This guideline applies to all climates and spaces.

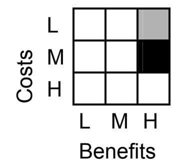
Applicable Codes

All jurisdictions include some requirements related to water quality protection, in particular stormwater management and erosion control during construction. Local policies may govern other construction activities covered in this guideline. Please check with the local jurisdiction.

Integrated Design Implications

The plan should be integrated with stormwater management and erosion control measures (see the Site Planning chapter). In addition, a requirement to submit ingredient information about in-field product substitutions to avoid degradation of water quality on the site is important.

Cost Effectiveness



This guideline recommends going beyond typical site practices. The project architect needs to evaluate the risk of erosion problems to determine whether redundant erosion control measures are cost effective. Least-toxic pest and weed control is quite cost effective, as it can provide savings and an increased level of safety for students who will be using the school grounds.

Benefits

Construction delays and work stoppages due to erosion control failure are avoided. Water quality in surrounding waterways and groundwater supplies are protected. Health risks to students due to residual toxicity on the site can be reduced.

Design Tools

See electronic Appendix A for sample specification language.

Design Details

Site protection (as with all other sustainable building goals) should be outlined in the Instructions to Bidders as part of the Project Summary. In addition, site protection specifications should be included in the Temporary Controls sections of General Conditions. The specifications should describe what is included in a site protection plan, outline submittal requirements, and recommend strategies, including:

- Regular inspection and maintenance of site protection measures. At a minimum, inspection of all erosion and sedimentation measures after a heavy rainfall, which is defined as 0.5 in. in less than 24 hours.
- Redundant mechanisms for site protection of any critical or sensitive areas, as identified in the site plan. Silt fencing fabric and other temporary site protection measures should be selected to last for the life of the project.
- Measures to ensure that detergent does not get into soil and sediment separators.
- Posted protocol for construction vehicles regarding parking and access on the site.
- Rocked heavy construction vehicle entrance and tire wash.

- Posted clean-up procedures for spills to prevent illicit discharges.
- Measures to minimize risk of the toxic release of hazardous wastes, including paints and other finish products, solvents, adhesives, and oils as follows:
- Avoid overstocking.
- Adopt a first-in, first-out policy.
- Label containers properly.
- Control access to storage areas and routinely inspect containers.
- Inspect all containers upon receipt. Reject leaking or damaged containers.
- Topsoil preparation, planting, and maintenance using Integrated Pest Management (least-toxic) protocol. Least-toxic products for controlling pests and insects in detention ponds and for soil prep. No chemical weed eradication.
- Safety meetings, signage, and subcontractor agreements that communicate the goals of the site protection plan.

Operation and Maintenance Issues

Operation and maintenance staff should be informed that least-toxic products have been used for soil preparation and for controlling pests and insects in detention ponds. Also, contractors should be required to provide information on product substitutions sufficient to enable operation and maintenance staff to properly maintain site protection measures.

Commissioning

None.

References/Additional Information

Ross Middle School. Ross School District, CA. Completed in 1999. For more information contact Dana Papke, DPapke@CIWMB.ca.gov.

U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2.1) at www.usgbc.org. Also see the Environmental Protection Agency (EPA) publication: Stormwater Management for Construction Activities, Chapter 3.

For product substitutions, refer contractors to the CIWMB Web site. Also refer to Green Spec: The Environmental Building News Product Directory and Guideline Specifications (www.buildinggreen.com/), and the OIKOS Web site (www.data.oikos.com/products).

GUIDELINE GC5: CONTRACTOR’S COMMISSIONING RESPONSIBILITIES

Recommendation

Require that the contractor and subcontractors provide the commissioning agent (CA) with information needed to facilitate the commissioning process and to coordinate activities with the CA as needed.

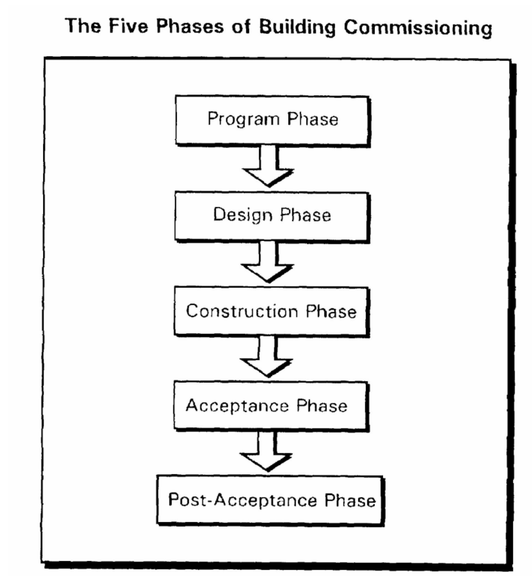
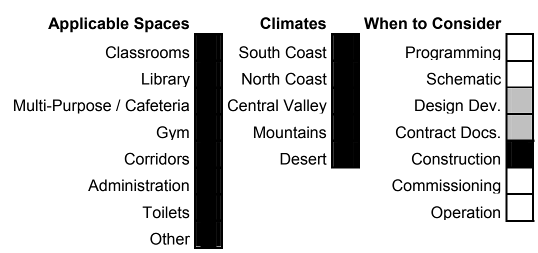


Figure 7—Commissioning Phases

(from Building Commissioning Guide; see References/Additional Information)

Description

Commissioning is a systematic, documented process including visual examination and functional performance testing to demonstrate that installed components or systems, as well as the building overall, meet the intent of the original design. A CA is someone qualified to provide an independent inspection of the building or site/landscape component or system being commissioned. This guideline recommends that the contractor be required to coordinate with the CA and provide information as needed to optimize commissioning results. Contractors will be involved in fine-tuning and correcting systems when commissioning indicates this is needed. See the CHPS Volume V on Commissioning for more information.



Applicability

This requirement is applicable to all climates and spaces. It is implemented in the construction phase, but needs to be considered in both the design development and contract documents phase.

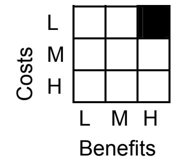
Applicable Codes

None.

Integrated Design Implications

None.

Cost Effectiveness



Costs for this aspect of commissioning are minimal. Overall, commissioning has the potential for producing savings in avoided delays and other startup problems.

Benefits

Requiring contractor coordination will facilitate effective commissioning. Commissioning can provide tremendous economic benefits as well as improve building performance.

Design Tools

None.

Design Details

Commissioning goals (in addition to all high performance building goals) should be outlined in the Instructions to Bidders as part of the Project Summary. A requirement that the contractor coordinate with the CA should be included in General Conditions. (A separate commissioning agreement will be drawn up between the district and the CA.) Other commissioning requirements for the contractor will appear in pertinent sections, including mechanical and electrical. (If the contractor is responsible for hiring the CA, a special section incorporating commissioning requirements should be written, and the "coordination" aspect of this guideline would be part of the agreement between the contractor and the CA.)

The contractor should be informed of the types of systems that will be commissioned, the types of information that may be required, and his responsibilities in terms of correcting problems that are identified. Types of systems to be commissioned may include:

- HVAC plant.
- Air and water delivery system.
- Energy management system.
- Electrical and lighting system.

- Fire/life safety system.
- Data networks/communications.
- Security system.
- Irrigation system.
- Kitchen equipment.
- Building envelope.
- Renewable energy system.
- Fume hoods.
- Science lab gas delivery system.
- Emergency power supply.
- Plumbing.

Frequently it is difficult to enforce the requirement that the contractor finish all commissioning tasks prior to Substantial Completion. A practical solution is to provide an incentive to complete the work, by applying a penalty if such tasks are not performed by "functional" completion. Exceptions would be seasonal or "approved deferred" testing and controls training. Functional and substantial completion should be defined in the general conditions of the construction contract.

During construction, building systems are installed, undergo pre-functional performance tests, and are placed into operation. Once construction is completed, all building systems should be operating as designed, both individually and collectively, and are ready for functional performance testing. The contractor assists in all aspects of the commissioning process, including documentation; pre-functional testing; start-up and initial checkout; initial controls checkout; testing; adjusting and balancing (TAB); functional testing for individual systems and integrated systems; verification; training of operation and maintenance personnel; and operation and maintenance manual development and review. In practice, some of the system checks included in full commissioning are performed, but rarely documented.

Operation and Maintenance Issues

The contractor will be required to provide documentation and information for the commissioning process that will be incorporated into an operation and maintenance plan or manual.

Commissioning

None.

References/Additional Information

U. S. Department of Energy's Federal Energy Management Program (FEMP), in cooperation with the General Services Administration (GSA), developed the *Building Commissioning Guide* as part of GSA's facility commissioning program to ensure that construction of new facilities meets the requirements. Chapter 10 of this document includes an extensive list of additional resources related to building commissioning. www.femp.gov/

A Web site dedicated to providing access to documents dealing with the Guidelines for Total Building Commissioning is being developed under the auspices of the National Institute of Building Sciences. The site is maintained by the Florida Design Initiative and is organized around the individual technical guidelines that will comprise the complete set of Guidelines for Total Building Commissioning. http://sustainable.state.fl.us/fdi/edesign/resource/totalbcx.

Site Planning

OVERVIEW

This chapter provides the following guidelines:

- Guideline SP1: Optimum Building Orientation
- Guideline SP2: Landscaping to Shade HVAC Equipment, Buildings, and Paved Areas
- Guideline SP3: Safe and Energy-Efficient Transportation
- Guideline SP4: Landscape Design and Management
- Guideline SP5: Impervious Surfaces
- Guideline SP6: Native and Drought-Tolerant Plants
- Guideline SP7: Landscaping Soil, Amendments, and Mulch
- Guideline SP8: Water-Efficient Irrigation Systems
- Guideline SP9: Stormwater/Groundwater Management and Drainage Materials
- Guideline SP10: Gray Water Systems
- Guideline SP11: Space for Recycling

Site planning is a fundamentally important aspect of high performance school design. The choices and decisions made during site selection and site planning affect all subsequent design decisions and mistakes can be very difficult or costly to correct later in the design process. All aspects of high performance design—from energy and water efficiency, to acoustic comfort and environmental impacts—are affected. Furthermore, every site and district will face unique constraints. Some districts have the luxury of choosing between optional sites while other districts have just one option. It is important to remember that regardless of what site is chosen, and whether it is urban or rural, the site can be developed wisely to incorporate ideas that support the high performance goals of the entire project.

Open spaces at schools typically fall into two categories: hard surfaces and lawn. Districts can and should move beyond this approach to create more vibrant and environmentally responsive site designs. Even if the opportunities for a particular site seem modest, there are better ways to pave a parking lot, water a soccer field, and manage stormwater than are typically practiced.

Site selection and design can either support or detract from the overall performance of the building. Table 3 summarizes some of the benefits associated with wise site planning.

Sustainable Site Planning Process

Sustainable site planning is adaptable to all school sites. It balances ecological, social, and economic needs and emphasizes long-term, cost-effective strategies over now short-term results. It should be an open process and include the input of the school staff and local community.

Figure 8—Playground Separation

Berkeley, CA. Good separation between growth and high-use play areas have created a complex and vibrant playground. Photo courtesy Wolfe Mason Associates.

Site selection is crucial in the sustainability of school design, and districts must balance cost, student demographics, and environmental concerns during the site selection process. The school's environmental impact can be reduced when the district can select sites, being conscious of ecosystem protection, careful building orientation, and a design that controls urban heat islands can significantly lower.

Figure 9—Boulders and Mulch

Berkeley, CA. Boulders add interest and alternative play areas for these children. Mulch filled cutouts protect tree roots from mowing damage. Photo courtesy Wolfe Mason Associates.

When selecting a site, maintaining the health of students should be the first concern. Sites must not contain toxins, pollutants, or safety hazards that will impact student health, such as:

- Hazardous agents, including industrial, agricultural, and naturally occurring pollutants such as asbestos and heavy metals.
- Nearby facilities which might emit hazardous air emissions, or handle hazardous or acutely hazardous materials.
- Other objects that are potentially harmful near a school, such as hazardous pipelines, high voltage power-line easements, railroad tracks, adverse levels of traffic noise, and airports.

The district should also address issues of land use and open space, including:

- Developing sites that are centrally located for the student population. Both schools and parents spend significant time, energy, and money transporting students to and from school. Cars driven by parents, guardians, or the students themselves are the largest resource users and producers of transportation-related pollution. Centrally located sites mean that cars do not have to travel as far and encourage more students to walk or bike to school.
- Develop joint-use agreements with community organizations to share parts of the school buildings, parks, or recreation space. As part of a growing trend, schools are being integrated with a variety of organizations, from laundromats and coffee shops, to police stations and park districts. Benefits include better campus security, improved community relationships, and reduced site acquisition and construction costs.
- Avoiding development on prime farmland, public parkland, flood zones, and on habitats for threatened or endangered species.
- Preserve undeveloped lands. By not developing on greenfields, which are sites that have not been previously developed, or have been restored to park or farm use, urban redevelopment can reduce environmental impacts.
- Promoting alternative transportation, by locating the school close to public transportation and creating bike facilities.

Once a site is selected, use educational specifications and the schematic design to address areas of the site targeted for conservation, development, or natural enhancement. Select and specify environmentally preferable site materials—building products that use raw materials efficiently and do not introduce pollutants or degradation to the project site or atmosphere, and building systems that conserve water and energy. (For additional information about materials, see the Interior Surfaces chapter.) All stakeholders should meet to review the baseline data and discuss the opportunities and constraints based upon the initial site analysis and program. These stakeholders help define the project's "vision," which guides development of the plan. Their involvement is essential throughout the planning and design process. The plan, developed by the design team and approved by the community, might include many, or all, of these principles:

- Identify and protect existing natural features and ecosystems.
- Repair and restore damaged natural areas and create habitat to promote biodiversity.
- Respect and incorporate historic, cultural, and artistic resources.
- Stormwater management to reduce pollution and the load on local infrastructure.
- Create healthy landscapes that evolve over time and survive intensive use.
- Develop a responsible maintenance and management program that incorporates an objective monitoring and evaluation strategy.

- Provide a strong link to the surrounding neighborhood and become an active part of the community.

Design Goals and Guidelines

Site planning activities for a high performance school seek to achieve one or more of the following three primary goals:

- Protect and/or restore the site.
- Incorporate the site's natural features to achieve high performance.
- Select environmentally preferable products.

Protect and Restore the Site

The natural functions of a site (hydrologic, geologic, and micro-climatic) can be seriously disrupted by the construction and operation of a building. The design of a high performance school considers ways that natural site features can be protected—perhaps even restored—through the design, development, and construction processes. For example, preserving natural vegetation reduces overall disturbance to the site. Soil amendments help restore the health of disturbed soils. And designing to reduce impervious surfaces mitigates stormwater runoff caused by construction and protects the hydrologic functions of the site.

Site protection and restoration objectives include:

- Minimizing disturbance to the site.
- Mimicking (or restoring) natural processes in disturbed areas.
- Protecting water quality.

Incorporate the Site's Natural Features to Achieve High Performance

A high performance school responds to the site. Building placement, orientation, massing, and layout decisions made early in the school design process can profoundly affect the energy impacts of the building. These decisions also bear on the resulting indoor environment since they either capture or lose opportunities for daylighting and natural ventilation. Other implications include acoustic comfort, safety, and visual quality. The design of a high performance school incorporates the site's natural advantages and features to achieve the school's high performance goals.

In addition, the high performance school site and building should "teach" environmental protection concepts. Site design will take into consideration opportunities for outdoor classrooms and environmental learning projects. With careful planning and coordination with school staff, such projects can be identified and then facilitated during construction. For example, stream restoration by students and staff can take place more easily if a culvert has been removed during construction. Or a wetland graded during construction can be planted as part of lessons about the natural ecosystems.

Figure 10—Landscaping Zones

Bloomington, MN. Natural landscaping materials separate landscaping zones of local plants, including native grasses that do not require mowing. Photo courtesy Wolfe Mason Associates.

Site planning objectives that fall into this category include:

- Reduce the demand for water.
- Reduce energy demand.
- Select environmentally preferable materials.

A steadily increasing number and variety of environmentally preferable products are available for sitework and landscaping. Salvaged materials, originating from both on-site and off-site, should also be used where possible. These products include landscaping accessories made with post-consumer and post-industrial recycled materials (parking stops, bike racks, tree cuffs, grates, landscaping ties, planters, outdoor furniture, and lighting and sign posts), recycled concrete asphalt aggregate for fill or road base, concrete made with fly ash, and recycled content soil amendments.

Specific examples include:

- Synthetic surfacing for exterior sports surfaces, playgrounds, and other surfaces. Made from 84% to 98% post-consumer rubber from used tires.
- Fencing with made with recycled plastic or salvaged wood or metal.
- Running track surfaces made with 100% recycled rubber/tires.

While maintenance will vary by product, in most cases, maintenance needs are reduced compared to conventional products. For example, recycled plastic lumber is more durable and requires less ongoing maintenance than wood.

In addition, the selection of environmentally preferable materials can also serve as a teaching tool. Prominent interpretive signage can inform students, staff, parents, and the community about environmentally preferable materials and their attributes.

Table 3 summarizes the site planning goals and objectives just described, and shows the correspondence of these objectives to the guidelines provided in this chapter.

Table 3—Site Planning Goals and Relationship to Guidelines

Goals		SP1: Optimum Building Orientation	SP2: Landscaping to Provide Shade to HVAC Equipment, Buildings, and Paved Areas	SP3: Safe and Energy-Efficient Transportation	SP4: Landscape Design and Management	SP5: Impervious Surfaces	SP6: Native and Drought-Tolerant Plants	SP7: Landscaping Soil Amendment and Mulch	SP8: Water-Efficient Irrigation Systems	SP9: Stormwater Management, Groundwater Management, and Drainage Material	SP10: Rainwater Collection Systems	SP11: Gray Water System
Protect and Restore the Site	Minimize Disturbance to the Site						●			●		
	Mimic Natural Process.					●		●		●		
	Protect Water Quality							●		●		
Incorporate the Site's Natural Features to Achieve High Performance	Reduce Water Demand				●		●	●	●		●	●
	Reduce Energy Demand	●	●	●								
Select Environmentally Preferable Materials					●	●		●		●		

Resources

Architects, Designers and Planners for Social Responsibility (ADPSR) West Coast. 1998. *Architectural Resource Guide.* Contact: ADPSR, PO Box 9126, Berkeley CA. Tel: (510) 273-2428. Resources and information on green and healthy buildings, including many sources for materials in California.

Barnett, D.L. 1995. *A Primer on Sustainable Building.* Snowmass, CO: Rocky Mountain Institute. An excellent overview of issues and benefits of sustainable building. www.rmi.org.

Center of Excellence for Sustainable Development, U.S. Department of Energy, Energy Efficiency and Renewable Energy Network (EREN). Provides web pages on green building and green development. www.sustainable.doe.gov.

Crowther, R.L. 1992. *Ecological Architecture*. Boston: Butterworth Architecture. Primer on ecological design, emphasizing the importance of holistic building design and its integration with natural systems. Includes design guidelines for design, landscaping and planning.

King County, Washington. *Construction and Landscaping Materials Specifications*. www.metrokc.gov/procure/green/const.htm.

Los Angeles, City of. *Sustainable Building Reference Manual.* Contact: Nady Maechling. Tel: (213) 473-8226. Contains local information and resources.

Lyle, J.T. 1994. *Regenerative Design for Sustainable Development*. New York: John Wiley & Sons. One of the seminal books on the theory, design and construction of regenerative systems and the practical application of ecological design.

Marsh, W. M. 1991. *Landscape Planning: Environmental Applications.* New York: John Wiley & Sons. A definitive reference for landscape architects, planners and designers on the definition and application of environmental design principles to landscape and site planning.

Maryland State Department of Education. *Conserving and Enhancing the Natural Environment, A Guide for Planning, Design, Construction, and Maintenance on New & Existing School Sites* and *Building Ecology and School Design*. 1999. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager: (410) 767-0097

Mason, Gary et al; *An Ecosystem-based Approach to Planning Communities: An Ecosystem Manager's Workbook*, USDA Forest Service, Center for Urban Forestry, 1994, 1996, 1998.

Moore, Robin C. and Wong, Herb H.1997. *Natural Learning: Creating Environments for Rediscovering Nature's Way of Teaching*, MIG Communications.

Rocky Mountain Institute.1998. *Green Development: Integrating Ecology and Real Estate.* New York: John Wiley & Sons.

Second Nature: Adapting Los Angeles's Landscape for Sustainable Living. 1999. Published by TreePeople.

Sorvig, K. 1996. *Sustainable Building Technical Manual*. Washington DC: Public Technologies Inc. Chapter 7, Site Materials and Equipment, offers a concise, valuable overview that highlights design considerations for soil amendments, plant materials and management, paving materials and materials for site construction and furnishings.

Spurgeon, Richard. 1988. *Ecology: A Practical Introduction with Projects & Activities.* Osborne Publishing Ltd.

For additional information about environmentally preferable materials, see the Material Selection and Research section in the Introduction to Volume II.

Acknowledgments

The following resources were particularly useful for developing this chapter on site planning:

Sustainable Building Task Force. The Sustainable Building Task Force was formed by a number of California agencies to institutionalize sustainable building practices into state construction projects. The task force meets on a monthly basis to discuss strategies for implementing sustainable building practices in all future and current state buildings, including those leased by the State. See www.ciwmb.ca.gov/GreenBuilding/TaskForce/ for more information and links to member agencies.

Santa Monica, City of. 1999. *Santa Monica Green Building Design and Construction Guidelines.* Available on-line at http://greenbuildings.santa-monica.org/main.htm.

Partnership for Resource-Efficient Schools. 1998. *Recommended Best Management Practices Promoting Energy Efficiency, Resource Conservation, and Environmental Quality.* A publication of the Seattle Public Schools Building Excellence Program and the City of Seattle (Solid Waste Utility, Water Department and Seattle City Light). The following Web site provides information about the Partnership for Resource-Efficient Schools project and a link to download the Best Management Practices manual: www.cityofseattle.net/util/rescons/susbuild/partnership.htm

BUILT GREEN™ Handbook. 1999. BUILT GREEN is a program of the Master Builders Association of King and Snohomish Counties (MBA) in partnership with King County, Washington and Snohomish County, Washington. www.builtgreen.net/.

GUIDELINE SP1: OPTIMUM BUILDING ORIENTATION

Recommendation

When site conditions permit, orient buildings so that major windows face either north or south. Position classrooms so that light and air can be introduced from two sides. Solar orientation should guide the placement of building and site features. Reduce the impact of exterior noise sources by locating noise sensitive areas, such as classrooms, away from noise producers, like roadways, train tracks, etc.

Figure 11—Well-Oriented Entrance

Oakland, CA. Orientation plays a key role in the landscaping and daylighting design; low walls, building materials, and varied landscaping create a rich and inviting entrance. Photo courtesy Wolfe Mason Associates.

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	■
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	▒
Gym	■	Mountains	■	Contract Docs.	
Corridors	■	Desert	■	Construction	
Administration	■			Commissioning	
Toilets	■			Operation	
Other	■				

Description

Space heating and cooling accounts for nearly 20% of all energy consumption in the U.S. Optimal orientation of the building creates opportunities to utilize the potential contributions of the sun, topography, and existing vegetation for increased energy efficiency by maximizing heat gain (or minimizing heat loss) in winter and minimizing heat gain in summer. In the case of existing buildings, arrangement of interior spaces, strategic landscaping, and modifications to the building envelope can mitigate unfavorable orientation.

Applicability

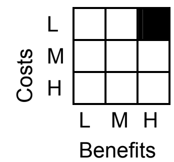
All climates. Primarily for new buildings and site planning, with some applicability to retrofitting existing buildings for greater efficiency.

Applicable Codes

None.

Integrated Design Implications

Knowledge of the existing site soils, vegetation, and microclimate are critical to understanding how to best arrange site elements to create the least disruption to the site and orient structures and spaces appropriately. Integrate existing site features; proposed landscape design; orientation, height and finish of walls; architectural design; impervious surfaces; location of heating and cooling equipment. Refer to: Guideline SP2: Landscaping to Shade HVAC Equipment, Buildings, and Paved Areas and Guideline SP3: Safe and Energy-Efficient Transportation.



Cost Effectiveness

Cost is generally low or negligible. Resulting cost savings will be demonstrated during building operation with lowered heating and cooling requirements.

Benefits

Reduced energy consumption will result in cost savings for heating and cooling. The arrangement of interior and outdoor spaces with thoughtful solar orientation allows optimal natural lighting and user-friendly spaces. Studies have shown that students in classrooms with the most daylighting have a 21% improvement in learning rates over students in classrooms with poor natural light.[4] Volume I has more discussion on this research chapter for more information on this research.

Design Tools

Pacific Gas & Electric and Southern California Edison offer use of heliodons for accurate modeling of shading in and around buildings. Contact their energy centers for more information. A physical model is mounted on the heliodon and a simulated sun shows shadows and solar exposure for different times of the day and the year. Most are coupled with a video camera for recording the test.

A sun angle calculator is a handy tool for studying sun position for different times of the day and year. It can be used to determine the required distance between buildings needed for adequate solar exposure and for determining the effect of shading obstructions such as adjacent buildings.

Computer software such as DOE-2 or Ecotect demonstrate the effects of orientation on the energy consumption of the building. Ecotect and other software display the effects of the sun over time, similar to a heliodon.

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[4] Heshong Mahone Group and New Building Institute. "Re-Analysis Summary: Daylighting in Schools, Additional Analysis." On behalf of the California Energy Commission Public Interest Energy Research (PIER) Program, February 2002.

Design Details

Consider stretching buildings in east-west orientation to maximize north-south daylighting opportunities. Single-story designs offer toplighting daylight strategies for all spaces.

Solar angles, soils, and topography determine plant species and distribution, as well as vulnerability of the land to erosion by runoff. The extent of disruption to the site during construction can be minimized with careful orientation of buildings and site elements. Align long buildings and parking areas parallel to landscape contours.

Building orientation can have a significant impact on the acoustical performance of a building. Locating classrooms or otherwise protecting them from sources of noise is the primary goal. Mass walls or berms of earth, which break the line-of-site between the noise source and the receiver (e.g. classroom), can reduce sound intrusion. A single row of trees or shrubs will be ineffective in reducing sound. Since windows are frequently the “weakest link” acoustically in a building structure, double glazed windows are often the only alternative to controlling exterior noise. Normal double paned windows with ¼ in. or ½ in. airspace are not effective acoustically. To be effective acoustically, the outer pane should be laminated glass and the airspace between the two panes of glass should be increased. Thicker laminated glass is needed to control exterior traffic and/or aircraft noise, which contain substantial low frequency energy. Sound Transmission Coefficient (STC) is a single number determined in accordance with ASTM standard E413 which indicates the level of sound transmission.

Operation and Maintenance Issues

None.

Commissioning

None.

References/Additional Information

American Institute of Architects Research Corporation. *Solar Dwelling Design Concepts.* Washington, DC: U.S. Department of Housing and Urban Development, 1976.

Baccomb, John Douglas. “Using Energy-10 to Design Low Energy Buildings.” National Renewable Energy Laboratory, 1999. A summary report that describes Energy-10 and presents a detailed worked example carrying a particular building from pre-design through preliminary design. www.nrel.gov/buildings/energy10/resources.html.

Buffo, John, et al. “Direct Solar Radiation on Various Slopes from 0 to 60 Degrees North Latitude.” U.S. Department of Agriculture Forest Service Research Paper PNW-142, 1972, 74pp.

DeChiara, Joseph. *Site Planning Standards.* McGraw-Hill, Inc. 1978.

Harris, Charles. *Timesaver Standard for Landscape Architecture: Design and Construction Data.* McGraw-Hill, Inc. 1998.

Land Design/Research, Inc. *Energy Conserving Site Design Case Study*, Burke Center, Virginia. Washington, DC: U.S. Department of Energy, 1979, 60pp.

Marsh, W.M. *Landscape Planning: Environmental Applications.* John Wiley & Sons, New York. 1991.

Marsh, William M., and Dozier, Jeff. *"The Radiation Balance." Landscape: An Introduction to Physical Geography*. Reading, MA: Addison-Wesley, 1981, pp. 21-35.

Sizemore and Associates. *Methodology for Energy Management Plans for Small Communities.* Washington, DC: U.S. Department of Energy, 1978.

Sterling, Raymond, et al. *Earth Sheltered Community Design.* New York: Van Nostrand Reinhold, 1981, 270 pp.

Durant Road Middle School, Wake County, NC utilized many recommendations from this guideline.

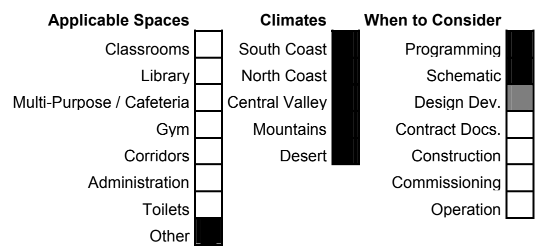
GUIDELINE SP2: LANDSCAPING TO SHADE HVAC EQUIPMENT, BUILDINGS, AND PAVED AREAS

Recommendation

Shade HVAC equipment from direct sun. Ensure landscaping does not block air circulation to or from the building. Use landscaping to shade windows on the east- and west-facing building facades. Use landscaping or shade structures to shade paved areas to reduce the heat island effect.

Figure 12—Arbors and Trellises

Berkeley, CA. Arbors and trellises provide shade to ground and building surfaces for this daycare center. Photo courtesy of Wolfe Mason Associates



Description

Shading HVAC equipment from direct sunlight can significantly lower the cooling demand. Landscaping can greatly reduce the impacts of heavy radiation loads on the roof, and east and west exposure in summer. In temperate regions, site planning and design should seek to promote shade and evaporative cooling in warm periods, and block winds and promote heat gain in cool periods, without disrupting favorable summer wind patterns. In hot, arid regions, plan to balance daily temperature extremes by storing energy, increasing humidity, and diverting desiccating winds.

Applicability

All climates.

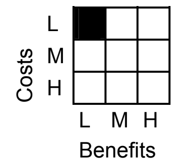
Applicable Codes

Some communities in California have a 51% shade canopy requirement for parking lots.

Integrated Design Implications

Integrate landscaping, HVAC design, parking lot design, lighting design, irrigation, and preservation of existing plants with building design and orientation. Wind and moisture patterns should be considered during site planning in conjunction with goals to provide building shade. Design coordination will be needed so that trees and lighting are placed without conflicting with the shade or footcandle requirements. Refer to Guideline SP1: Optimum Building Orientation; SP3: Safe and Energy-Efficient Transportation; SP5: Impervious Surfaces; HVAC guidelines; as well as guidelines in the Building Enclosure and Insulation chapter.

Cost Effectiveness



Costs will vary depending on the type and extent of vegetation or shading structures used. Costs are minimal for HVAC shading, particularly if incorporated into overall HVAC system and landscaping design. Consult with a qualified HVAC engineer regarding opportunities for downsizing systems due to decreased system load.

Benefits

Lower energy costs from reduced solar loads on building. Shading HVAC equipment lowers demand for electricity and reduces heat islands.

Design Tools

Charts illustrating distance required between buildings or landscaping to avoid shadows and minimum spacing required to assure adequate light penetration. Solar path, latitude, and altitude charts should also be utilized.

Design Details

Building orientation should be closely integrated with landscape design. Planting deciduous trees on the southeast, southwest, and west side of the building will reduce solar gain in summer during the morning and afternoon. Deciduous vines on arbor structures will provide shade, particularly when used adjacent to the building on the south or west face, sheltering the interior from summer midday sun while allowing solar penetration in winter. Plant low branching deciduous trees on the west side to keep low afternoon sun off west and north walls in summer.

Consider the use of vines against south- and west-facing walls to reduce reflected and absorbed heat and light. This can reduce the temperatures in courtyards and outdoor spaces as well as adjacent buildings and interior spaces.

In urban environments, the site context may include solar windows (gaps between buildings) and shadow corridors (elongated zones which block the sun), which should be considered during site design to maintain sunlight to structures.

Parking lots and paved areas can reflect sunlight and absorb heat that raises temperatures. Shading with trees, shade structures or structures with vines can help lower temperatures.

Locate HVAC equipment so that it is shaded from afternoon sun during the cooling season. Plant trees so that at maturity their canopies shade the unit and the adjacent area during the entire cooling season.

Operation and Maintenance Issues

Design criteria and maintenance guidelines will be needed so that trees shading parking lots and other paved areas can grow to full maturity without excessive pruning. However, care must be taken to avoid contaminating HVAC equipment with leaves or other organic debris. Maintenance must keep plantings from growing too dense and preventing the proper circulation of air around the unit.

Commissioning

None.

References/Additional Information

DeChiara,Joseph. *Site Planning Standards*. McGraw-Hill, Inc. 1978.

Harris, Charles. *Timesaver Standard for Landscape Architecture: Design and Construction Data*. McGraw-Hill, Inc. 1998.

Marsh, W.M. *Landscape Planning: Environmental Applications.* John Wiley & Sons, New York. 1991.

Parker, D.S. "Measured Impacts of Air Conditioner Condensor Shading." The Tenth Symposium on Improving Building Systems in Hot and Humid Climates. Fort Worth, TX, 1996. Archived at www.fsec.ucf.edu/~bdac/pubs/PF302/PF302.htm, 12/15/2000.

Parker, J.H. "The Impact of Vegetation on Air Conditioning Consumption." Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, CA, pp. 45-52, 1989.

GUIDELINE SP3: SAFE AND ENERGY-EFFICIENT TRANSPORTATION

Recommendation

Locate schools and design school sites to encourage use of safe, energy efficient transit alternatives and to discourage single-use automobile transportation.

Incorporate safe and effective parking and storage for bicycles, skateboards, rollerblades, and scooters, if applicable.

Figure 13—Child Cycling

Designing bike and pedestrian paths and facilities for shared vehicle transportation helps to reduce morning traffic.
NREL/PIX 09075

Applicable Spaces	
Classrooms	□
Library	□
Multi-Purpose / Cafeteria	□
Gym	□
Corridors	□
Administration	□
Toilets	□
Other	■

Climates	
South Coast	■
North Coast	■
Central Valley	■
Mountains	■
Desert	■

When to Consider	
Programming	■
Schematic	■
Design Dev.	■
Contract Docs.	▒
Construction	▒
Commissioning	□
Operation	■

Description

Strategies for encouraging the use of safe, energy-efficient transportation alternatives include providing safe bike and pedestrian paths, and providing facilities for shared vehicle transportation (carpools, vanpools, mass transit).

Applicability

All climates.

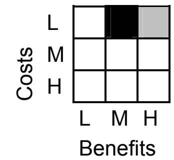
Applicable Codes

Applicable municipal codes.

Integrated Design Implications

This guideline should be addressed in the site selection and site planning stage. Also incorporate these strategies into the building and site design stages, especially when looking at access, circulation, and parking lot design. Be sure to locate parking lots and other sources of pollution away from fresh air intake ducts to preserve indoor air quality.

Cost Effectiveness



Costs will vary with strategies selected. In most cases, additional costs are minimized when integrated early into site/building design. Added costs will be offset by reduction in parking lot size.

Benefits

Reduced automobile use, reduced traffic congestion, improved urban air quality, improved sense of community, and more efficient use of site (if parking lot size is reduced).

Design Tools

IESNA. 1980. RP-8 Roadway Lighting, Chapter 4, Pedestrian Walkway and Bikeway Lighting Design, Illuminating Engineering Society of North America (IESNA), New York. This document contains guidelines for the design of fixed lighting for roadways, bikeways, and pedestrian paths.

Design Details

- Pedestrian- and bike-friendly features include pedestrian paths and walkways, bike paths, safe and accessible bike storage, and showers/changing facilities.
- Good lighting is critical for safe walkways in the early morning and at night. Provide effective lighting onto walkways in accordance with illuminance levels and cut-off angles as specified by IESNA RP8. Most outdoor areas around schools will not need lighting. Pathways leading to multi-purpose or joint use areas of the school facility are an exception.
- High schools and many middle schools have shower facilities already incorporated into the design. Making these facilities accessible to students, teachers and staff who use their bikes to commute to the school encourages bike use. A smaller shower and changing area can be added for cyclists in elementary and middle schools that do not have shower facilities for the student population in general.
- Building design can encourage carpooling and vanpooling by giving priority to shared transportation, and by making waiting areas convenient and safe.
- Locate carpool and vanpool parking spaces closer to the building entrance than other single-use automobile parking.
- Post prominent signage to identify the location of carpool and vanpool parking and pick-up areas.
- Provide safe and comfortable waiting areas to encourage carpool and vanpool commuters. Consider amenities such as sunshades, rain canopies, seating, and bulletin boards.

Safety Cautions

- Ensure commuter safety with building lobbies that view waiting, pick-up, and drop-off areas, occupied windows that overlook them, good lighting, and if necessary, prominent surveillance cameras. Eliminate potential hiding places for potential criminals.
- Ensure that sheltered areas are visible from the street and/or parking areas, sidewalk, and school building.
- Avoid creating small, dark courtyards that winter sun never reaches.
- Heavy and massive arcades and other features can obscure visibility and affect pedestrian safety.

Note: The cost premium for providing for environmentally safe and energy-efficient transportation may be offset by grants offered by various agencies.

Operation and Maintenance Issues

None.

Commissioning

None.

References/Additional Information

Bicycle Federation of America. Comprehensive coverage of a host of policy, planning and design guidelines supporting bicycle use. Internet Resource Center. www.bikefed.org/. April 1999.

Cox, E. (April 1999). Long Term Bike Parking. Useful overview of design considerations for long-term bicycle storage offering essential and optional features for caged facilities, bike rooms, bike lockers and shower and clothes locker rooms. www.jps.net/cbc/longbikepark.html.

Woodhull, J. 1992. *How Alternative Forms of Development Can Reduce Traffic Congestion.*" Sustainable Cities; Concepts and Strategies for Eco-City Development, Ed. Bob Walter, et al., Eco-Home Media, Los Angeles. Offers alternative approaches to traffic planning concentrating on "access" rather than mobility. Covers densification, parking, and development patterns, and offers solutions for pedestrian-friendly, transit-oriented development.

GUIDELINE SP4: LANDSCAPE DESIGN AND MANAGEMENT

Recommendation

Develop a landscape plan based on an ecological approach, emphasizing plant diversity, natural lawn care, and resource conservation. Use this plan to guide site preparation, site design, and ongoing care of the site. Include objective plans, tasks, standards, and requirements that provide information about how to create a healthy and attractive landscape.

Figure 14—Creeping Red Fescue

Castro Valley, CA. Creeping red fescue covers this difficult to maintain site and does not require mowing. Grass is also appropriate for pedestrian traffic and general use. Photo courtesy of Wolfe Mason Associates.

Applicable Spaces		Climates		When to Consider	
Classrooms		South Coast	■	Programming	■
Library		North Coast	■	Schematic	■
Multi-Purpose / Cafeteria		Central Valley	■	Design Dev.	▒
Gym		Mountains	■	Contract Docs.	▒
Corridors		Desert	■	Construction	
Administration				Commissioning	
Toilets				Operation	■
Other	■				

Description

Every site has an ecological dynamism that involves all the physical elements of the landscape. A high performance approach to landscape design and management should be guided by four basic principles that respect this dynamism: resource conservation, diversity, connectivity, and environmental responsibility.

- *Resource Conservation*. Identify, use, and recycle available natural and physical resources that do not degrade the ecosystem. This principle should also be applied to site and landscape accessories.
- *Diversity*. Maintain a healthy natural system that gives primary consideration to habitat, species, and genetic diversity.
- *Connectivity*. Maintain networks of natural resources and interconnecting habitats to maximize healthy ecological functions.
- *Environmental Responsibility*. Protect, restore, and manage resources to maintain a healthy ecosystem in perpetuity.

To apply these principles to landscape care, it's important to understand the difference between landscape *maintenance* and landscape *management*. Maintaining a landscape implies that the landscape deteriorates and needs to be returned to a "correct" condition by the maintenance crew. This static vision belies the natural dynamism of the landscape. Seeking to simply maintain landscapes works against the dynamic tendencies of nature, resulting in great expense of time, energy, and money.

Management, on the other hand, acknowledges the constant change of nature. To manage a landscape is to work with the basic tendency of nature to change. Management based on ecological principles does not try to always return the landscape to a single, static state. Management—as opposed to maintenance—recognizes the dynamic qualities of landscapes and takes advantage of interconnected elements such as water, soil, beneficial organisms, and pests.

Applicability

All climate regions.

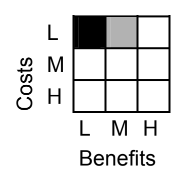
Applicable Codes

Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495, www.owue.water.a.gov/docs/WaterOrdIndex.cfm, or applicable local ordinances.

Integrated Design Implications

Planning for landscape management should be integrated and coordinated with Guideline SP6: Native and Drought-Tolerant Plants and Guideline SP7: Landscaping Soil, Amendments, and Mulch. All landscape planning should also take into account irrigation system parameters to help maximize water efficiency (see Guideline SP8: Water-Efficient Irrigation Systems).

Cost Effectiveness



Costs will vary depending on the extent of the site and scope of management plan. Native grasses save money on maintenance with reduced or eliminated mowing schedules. Recycled-content landscaping products are comparable in cost to conventional options.

Benefits

High performance landscape design and management, which seeks to bring the designed landscape into a closer adherence with the region's natural systems, provides a high level of benefit. A well-designed and implemented landscape management plan results in water conservation, soil improvement, the use of less intensive practices to manage plants, and the preservation, enhancement, or creation of habitat. The use of recycled content products helps alleviate waste disposal problems, and reduces energy use and consumption of natural resources during manufacturing.

Landscape management, including natural lawn care practices, can help make the school grounds healthier for students and staff, protect beneficial soil organisms, and protect the environment through reduced use of water, pesticides, fertilizers, and pollution-producing mowers and maintenance equipment.

Properly designed earth berms with a hearty groundcover and mulch can shield the school from nearby roadways, train tracks, etc. However, landscaping, trees, and shrubs cannot be used to reduce the level of exterior noise at the building façade.

Berms on steep slopes with turf can cause water runoff issues, so irrigation schedules need to be closely monitored with short run times to avoid runoff.

Design Tools

To identify high performance landscape and site planning strategies, consider consulting with a landscape professional that has expertise in ecological approaches to vegetation management.

Design Details

Key Elements of a Landscape Management Plan

A landscape management plan needs to take into account three different functions: management of the vegetation, including lawn care; management of the site's infrastructure; and management of those responsible for its care. A landscape management plan should contain the following components:

- *Management vs. Maintenance*: Briefly discuss the basis of an ecological approach, the concept of maintenance vs. management, and the principles of ecosystem-based management.
- *Vegetation Types and Locations*: Discuss the concept of vegetation types, including diversity of vegetation. Also describe the landscape management zones, and list and describe the types of vegetation to be included in each zone. Provide standards that describe the desired condition of each vegetation type. Vegetation types include trees (young, street, native, ornamental, naturalized, riparian); shrubs (ornamental, naturalized, riparian, native); perennials; vegetables; meadow; lawn; groundcover; vines; and weeds and undesirable plants.
- *Infrastructure Standards*: Discuss standards for infrastructure care to achieve the desired condition.
- *Designating Responsibility*: Discuss who is responsible for each aspect of the landscape management, and delineate responsibility on a site map.

- *Sustaining the Landscape*: Describe the general tasks necessary to implement the landscape management specifications, including a yearly calendar of tasks as well as monthly task checklists to monitor the work and the health of the landscape.

Establishing Landscape Management Zones

A high performance design should divide a landscape into management zones based on each zone's differing design intents and maintenance requirements. In general, three landscape management zones exist:

- *Ornamental Zone*: The more traditional landscape areas next to buildings, parking areas, streets, and other public use facilities. This zone creates strong identity and focus for the schools. The landscape in this zone is typically designed to be organized, attractive, and lush. This zone requires the highest level of management to maintain a visually pleasing and healthy appearance.
- *Natural or Native Zone*: Existing natural areas on, or adjacent to, the site that are to be preserved, enhanced, or expanded.
- *Buffer Zone*: The interface areas between the other two zones. The management goal is to provide a visually pleasing landscape that bridges the ornamental zone and the native, or more natural, areas.

Natural Lawn Care

Lawns are typically the most intensively managed type of vegetation on a school site. A high performance approach to lawn care starts with lawn placement at the site. Lawn can be divided into different zones, based on how it will be used and how it needs to be cared for. Typically, three standards of care should be considered:

- *High Intensity*: Requires uniform species composition, high irrigation demands, high synthetic fertilizer use, and regular pesticide and herbicide use. Used when primarily concerned with having uniform green grass year round with no weed, pest, or soil organisms.
- *Medium Intensity*: Allows for more diverse species composition, less demanding irrigation, moderate organic fertilizer use, and integrated pest management approach. Green is important, but not essential year round. Building soil structure over time is an important goal.
- *Low Intensity*: Diverse species composition and/or sparse coverage is tolerable. Alternatives to lawn are considered, with other vegetation taking precedence over lawn.

Plants depend on soil organisms to recycle nutrients, protect them from disease, and build loose fertile soil. Overuse of soluble fertilizers and pesticides can disrupt this ecosystem and contribute to landscape and lawn problems like thatch buildup and soil compaction. Ecological approaches to landscape management and natural lawn care practices can help make lawns healthier for students and staff, protect beneficial soil organisms, and protect the environment.

A natural approach to lawn care produces lawns that stay healthy and are easier on the environment. Strategies include soil preparation/amendment, choosing groundcovers or no-mow lawn varieties; minimizing turf areas; "grass cycling" (leaving clippings to decompose quickly, releasing valuable nutrients back into the soil); mowing at the proper height, minimal use of pesticides; applying smaller amounts of fertilizers at regular intervals; appropriate watering; and accepting an appropriate threshold for some weeds.

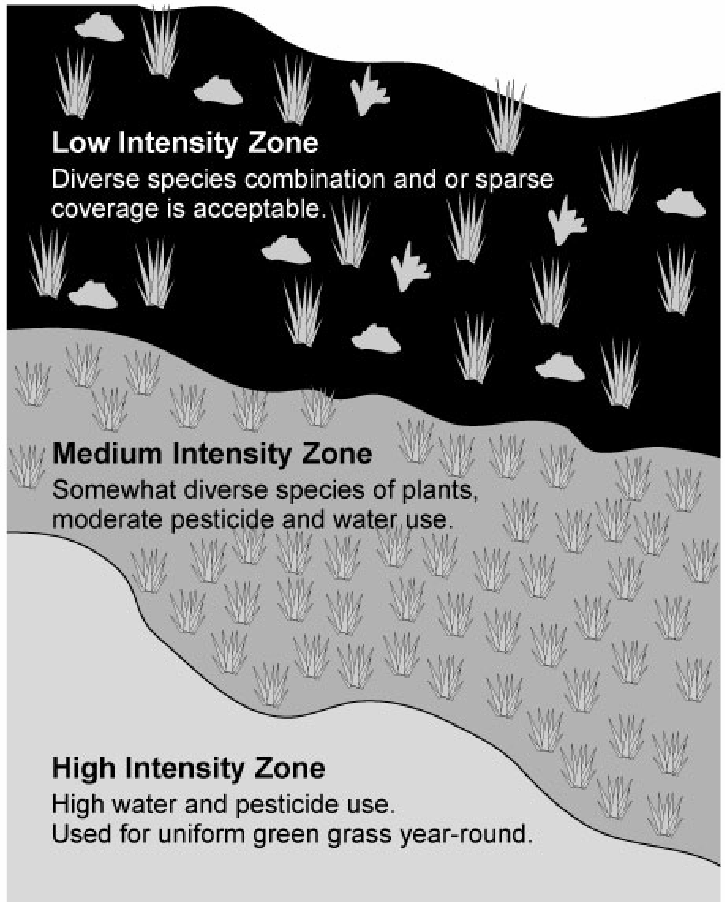


Figure 15—Landscape Management Zones

Operation and Maintenance Issues

Consider a variety of alternatives to traditional school staff for maintenance. For example, Conservation Corps or job training programs for restoration and habitat areas.

Landscape management is a different approach from conventional landscape maintenance. Planning, education, and training are key to a program's success. Each school district should develop and implement a written landscape management policy and program.

Commissioning

None.

References/Additional Information

California Department of Water Resources. 1416 9th Street, Room 1104-1, Sacramento, CA 95814. Tel: (916) 653-6192. Fax (916) 653-4684. Web site: www.dwr.water.ca.gov/.

California Integrated Waste Management Board. Database of Recycled-Content Providers: www.ciwmb.ca.gov/rcp.

Clean Air Lawn Care, South Coast Air Quality Management District. Available on-line at www.aqmd.gov/monthly/garden.html.

Cook, Tom and Roy L. Goss. *Construction and Maintenance of Natural Grass Athletic Fields*. Washington State University Cooperative Extension, Publication PNW0240. This bulletin provides the basis for development and maintenance of high quality fields for different purposes under different conditions. It is well illustrated with line drawings and color photographs plus data tables specific to different areas of the Pacific Northwest. Explains construction, establishment, drainage, irrigation, maintenance, and some troubleshooting. Rev. 1992. 28 pages. $2.25. To order, call (800) 723-1763.

Craul, Phillip J. *Urban Soil in Landscape Design.* John Wiley & Sons, Inc. 1992.

Hunter, Charles D. *Suppliers of Beneficial Organisms in North America.* California Environmental Protection Agency, Department of Pesticide Regulation, Environmental Monitoring and Pest Management Branch. 1997.

Los Angeles County Department of Public Works. *The Natural Approach to Lawn Care.* Available on-line at www.smartgardening.com/grassrecycling.htm.

Olkowski, William et al. *Common Sense Pest Control.* The Taunton Press. 1991.

People's Park Landscape Management: Vegetation and Infrastructure Program. A program developed for the University of California, City of Berkeley and the Park/Community Advisory Group. This program uses an ecological approach to the renovation and care of the landscape. Information available from Wolfe Mason Associates at www.wolfemason.com.

Profiles: A Special Report on Grounds Care. A report of grounds maintenance challenges at Georgetown University, Washington, DC, the University of Texas Southwestern Medical Center in Dallas, and the Orange County Public School District in Orlando, Florida. Available on-line at www.facilitiesnet.com/fn/NS/NS3m9li.html.

Ross Middle School, Ross, CA (Marin County)—Uses recycled content landscaping products. Sun shades and landscape benches are made from certified sustainably harvested Ipe or Angico. Concrete mix design replaces 50% of cement with fly ash.

Santa Barbara County Waste Management Board: Recycled Content Providers: www.lessismore.org/htdocs/text_only/important_info/recycled_products.html.

GUIDELINE SP5: IMPERVIOUS SURFACES

Recommendation

Minimize impervious surface areas to reduce stormwater runoff. Use material-efficient products for installed pervious and impervious surfaces.

Figure 16—Porous Parking Lot

Student and Staff Parking at Dominican University, River Forest, Illinois. Made with Gravelpave porous paving, manufactured by Invisible Structures, Inc., Aurora, CO (www.invisiblestructures.com). A porous base course was constructed on top of existing site soils to leave tree roots undisturbed. 15" deep concrete curbs were installed with forms to curve around tree bases. The final top 1 in. of rings, grid and fabric were anchored in place to receive the gravel. Photo reprinted with permission from Invisible Structures, Inc.

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	■
Library	□	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	□	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	□
Administration	□			Commissioning	□
Toilets	□			Operation	□
Other	■				

Description

Impervious areas, such as roofs, driveways, sidewalks, and streets, increase stormwater runoff by preventing the infiltration of surface water into the ground. This increased stormwater runoff results in increased erosion, higher flow rates, higher ambient temperatures, and increased sediment and pollution of waterways. As stormwater flows over buildings, parking lots, and play fields, it collects pollutants, such as oil, litter, and dirt. These waterborne pollutants often discharge directly into waterways. Conversely, pervious surfaces reduce peak stormwater runoff and treat stormwater pollutants. In addition, impervious surfaces create higher ambient temperatures on the site compared to pervious or vegetated alternatives.

Strategies to limit impervious surfaces on the building site include:

- Using pervious (or porous) pavement systems in lieu of impervious asphalt or concrete. Examples:
- Porous asphalt, paver blocks, or large aggregate concrete for parking and high use bicycle and pedestrian areas.
- Lattice blocks that permit grass growth for fire lanes and overflow parking.
- Crushed stone or brick for lightly used pedestrian paths.

- Minimizing the amount of paving by designing for multiple uses. Uses can include access, parking, pathways, meeting places and game courts. Surfacing materials can vary depending on intensity of use, e.g., access roads paved and parking gravel; turf block for emergency access; decomposed granite for secondary paths. All surfacing materials can utilize porous paving techniques.
- Retaining or substituting vegetation in lieu of hard surfaces.

Note: One limitation of porous pavement is its tendency to clog if improperly maintained. Once it is clogged, it is difficult and costly to rehabilitate and often must be completely replaced. Clogging can be prevented most easily by not installing it in areas where erosion is a concern and by waiting until all other phases of construction are complete and vegetation is stabilized to install the pavement. The substrate needs to be designed to drain efficiently to prevent clogging. Other concerns include the lack of expertise of pavement engineers and pavement contractors. Also, some studies indicate that porous systems have slightly higher deformation in porous pavement compared to conventional.

Another issue is that the surface of pervious concrete is rougher than normal concrete and may not be suitable for play areas where children may stumble and fall.

- Designing to distribute runoff from impervious surfaces over large vegetated areas prior to reaching a stormwater conveyance system. This reduces the flow velocity, removes pollutants, and promotes groundwater infiltration.
- Installing a vegetated roof.
- Using natural or constructed wetlands to provide on-site retention and treatment of stormwater.
- Minimizing the building footprint through design. (Note: Minimizing building footprint usually means building "up" rather than "out." For schools, this may not be desirable because of conflicts with higher priority goals, such as daylighting and natural ventilation.)

Where impervious surfaces are necessary, use materials efficient materials. Examples include:

- Rubber modified asphalt or recycled concrete asphalt.
- Recycled aggregate for base coarse of new parking lots and roadways.
- Concrete made using fly ash, a byproduct of coal combustion, to replace a portion of the Portland cement.

Figure 17—Vegetated Roof

Reprinted with permission from Sarnafil (Source: www.sarnafilus.com/GreenRoofs.htm)

Applicability

All climates.

Applicable Codes

State Water Resources Control Board, Storm Water Program, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone

(916) 341-5536 for general inquiries, (916) 341-5537 for construction related issues, stormwater@dwq.swrcb.ca.gov, or www.swrcb.ca.gov/stormwtr/index.htm.

The California Environmental Resources Evaluation System (CERES) Web site, www.ceres.ca.gov/index.html, features the California Land Use Planning Network with a broad array of data types from diverse sources, including selected, but fully scanned and searchable, county and city zoning ordinances.

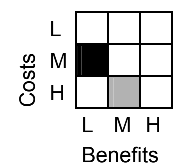
Applicable landscaping codes.

Setting up a new concrete and asphalt recycling plant requires certain state and local permits, such as air, water, and zoning.

Integrated Design Implications

Strategies to minimize impervious surfaces should be integrated with decisions about landscaping design; shading of the building, site, and heat rejection equipment; building orientation and design (footprint); roofing selection; stormwater management; parking lot and paving design; building layout; vegetated roof design; and parking lot design.

Cost Effectiveness



Minimizing paved areas means less paving material overall, which translates into lower initial cost.

The cost of pervious paving systems will vary depending on the system used. For example, porous (no fines) concrete may be comparable to conventional pavement. (This material requires a contractor familiar with the process, however.) Grid types, pavers, and brick systems have significant a cost premium over asphalt or concrete. Cost associated with pervious paving is offset by its dual purpose as a stormwater system. Less land is needed for this type of system, as a separate area for detention, retention, or infiltration is not necessary.

Benefits

Minimizing impervious surfaces helps preserve the hydrological and geological functions of a developed site by maximizing the area available for soils and vegetation to receive and treat surface water and facilitates groundwater recharge. The flow, velocity, and quantity of surface water is decreased overall, reducing the sediment and pollutant load on local waterways as well as the burden on municipal water management systems.

Ancillary benefits include reduced heat local heat build-up (heat islands) from the shading and cooling effects of vegetation, vegetated roofing, and whitetopping. These translate into reduced cooling loads and energy consumption. Several pervious pavement systems are manufactured with recycled content and so are also material efficient. Impervious paving that uses recycled concrete aggregate for base or fly ash in concrete is also material efficient.

Design Tools

Applicable state and local stormwater and surface water management design manuals.

Pervious Paving

As of this writing, no California guidelines or specifications for porous pavement exist. Guidance documents used in Washington State include:

- Interim Guidelines for the Construction of Portland Cement Pervious Pavement or "No Fines" Concrete, a working document of the Washington State Aggregates and Concrete Association, soon to be updated. Contact the California Cement Promotion Council for more information.
- *BMP T3.40, Porous Pavement,* from the *Final Draft, Stormwater Management Manual for Western Washington, Volume V*, *Runoff Treatment BMPs*. Washington State Department of Ecology, Water Division. August 1999, revised August 2000. This document can be downloaded at www.ecy.wa.gov/biblio/9915.html or call (360) 407-6614.

Recycled Concrete Asphalt for Base

Many local jurisdictions use California Department of Transportation (Caltrans) Standard Specifications. In Southern California, the Greenbook is commonly used for road projects. Where recycled aggregate is allowed, it must also, of course, meet the same grading and quality specifications as virgin aggregate.

Caltrans Standard Specifications, July 1995, covers aggregate base and aggregate subbase in Sections 25 and 26. These sections do not mention recycled aggregate. However, Caltrans SSPs do allow "reclaimed asphalt concrete, Portland cement concrete, lean concrete base, cement treated base," or "glass" in Class 2 and 3 aggregate base, and also in Class 1, 2, and 3 aggregate subbases.

The Greenbook is a public works specification book commonly used in the Los Angeles area. The Greenbook includes standardized specifications for crushed concrete and asphalt in three of its four aggregate base categories in Section 200-2, "Untreated Base Materials":

- Crushed aggregate base (CAB) does NOT include recycled aggregate. CAB may sometimes be specified where recycled base (CMB or PMB) would also meet requirements.
- Crushed miscellaneous base (CMB) allows recycled aggregate. The Greenbook states that CMB "shall consist of broken and crushed AC or PCC and may contain crushed aggregate base or other rock."
- Processed miscellaneous base (PMB) also allows recycled aggregate. The Greenbook states that PMB "shall consist of broken or crushed AC, PCC, railroad ballast, glass, crushed rock, rock dust, or natural material."

- Select subbase is the Greenbook's only aggregate subbase category. It allows recycled aggregate.

Whitetopping

American Concrete Paving Association (ACPA), Whitetopping, State of the Practice. Publication EB210P. This engineering bulletin covers of all aspects of concrete overlays on existing asphalt pavement. Its five chapters include: Introduction (uses and benefits), History and Performance, Design Practices (conventional whitetopping), Construction Practices, and Ultra-Thin Whitetopping (UTW). The last chapter presents the interim procedure for determining the load-carrying capacity of UTW based on research and performance surveys. 1998. $25.00. Order from the ACPA, www.pavement.com/.

Design Details

Effective surfaces are those, pervious or impervious, that are connected via sheet flow (shallow or concentrated surface flow) or discrete conveyance (such as drainage ditch) to a drainage system. *Effective impervious surface* is a measure of the performance of the lot with respect to stormwater flows, which provides a way of monitoring impact due to construction. Methods to minimize runoff can be expressed: (1) prescriptively, such as using pervious surfaces, or (2) performance-based, such as providing zero effective impervious surface (no net increase in runoff). Specific strategies will depend upon the specific site and local requirements.

Where impervious pavement must be used, specify the use of recycled asphalt, concrete manufactured with fly ash for paving, and/or rubberized asphalt pavement. In hot climates, look for opportunities to whitetop asphalt surfaces with heat-reflecting white concrete.

For concrete work, use reusable steel forms, expansion joint filler with recycled content, and least toxic release methods.

When using porous paving or on-site bio-filtration swales, it is critical that sub-base soils are tested so that designs are sufficient to process the stormwater flow.

Utilize surface stormwater flow wherever possible. Introduce oil/water separators at catch basins.

Note that design considerations should assume a minor loss in porosity in the first four to six years.

Avoid compaction of site soils in adjacent areas during construction to retain infiltration and water holding capacity of existing soils.

Operation and Maintenance Issues

For bio-swales and constructed wetlands, the design intent is to create a self-sustaining system that requires little maintenance. Monitoring and maintenance as the landscape matures provide educational opportunities. As bio-swales and constructed wetlands provide wildlife habitat, mowing and thinning plants should be minimal unless soils testing shows that impurities from runoff are high. In that case, mowing and thinning will aid in removal of toxins that may accumulate in the vegetation.

In parking areas, prune plants as needed to maintain sight lines and the desired aesthetic. If storm drains are used, clear as needed to prevent blockages. Avoid soil compaction in vegetated areas.

For porous asphalt and concrete, vacuum with a hydrovac to maintain or restore porosity by removing sediment from the paving surface. If areas become deformed by traffic, drill compacted areas to restore porosity. Keep underdrains, overflow drains, and edge drains clear.

Grassed paving systems need to be mowed. Tall grasses create a less-permeable surface. If this type of system is perceived as unmaintained, it may discourage potential users. During the dry summer season tall grass that is not watered has a higher potential to catch fire from contact with hot automobile exhaust systems. The durability of the system depends on soil type and climate, however maintenance is decreased with the use of appropriate groundcover plants in lieu of lawn. Some groundcovers can take foot traffic but lawn, in turf block or grids, is best used where there is auto traffic.

Unit pavers on a permeable subgrade settle after the initial installation, and therefore require that a joint-filler material be swept in. Permeability decreases over time as the joints become compacted.

The systems mentioned above are conducive to "spot fixes", should replacement of small areas be required due to damage. It should also be noted that maintenance is reduced where snow removal is significant, as snow melts faster on permeable surfaces.

Longevity of the system depends on the type of system used, the amount of use it receives, and the appropriate match of system to site.

Commissioning

None.

References/Additional Information

California Cement Promotion Council, Dave Holman, phone (925) 838-0701 or dholman@best.com.

California Integrated Waste Management Board. *Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction*. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix E sample specifications for: Section 02145, Erosion Control; Section 02230, Base Course; Section 02513, Asphaltic Concrete Paving. *Designing with Vision* can be downloaded in four parts from www.ciwmb.ca.gov/GreenBuilding. Chapter 8 is in Part D. Revised July 2000.

California Integrated Waste Management Board. Database of Recycled-Content Providers: www.ciwmb.ca.gov/rcp.

California Integrated Waste Management Board. Recycled Aggregate, A CIWMB Fact Sheet, CIWMB publication #431-95-052. Also available to download from www.ciwmb.ca.gov/publications/condemo/43195052.doc.

California Stormwater Best Management Practice Handbook: Construction Activities. Prepared for Stormwater Quality Task Force. Camp Dresser and McKee, Larry Walker Associates, Uribe and Associates and Resources Planning Associates. 183p. 1993.

International Erosion Control Association. Provides technical assistance and an annual Erosion Control Products and Services Directory. (800) 455-4322. www.ieca.org/.

Richman, T., et al. Start at the Source: Residential Site Planning and Design Guidelines: Manual for Stormwater Quality Protection. Bay Area Stormwater Management Agencies San Francisco. Brief, information-dense design guide to stormwater runoff reduction and treatment, oriented toward biological and landscaping methods. Many illustrations and diagrams. 1997.

Ross Middle School, Ross, CA (Marin County). Most rain leaders empty into landscaped areas: this allows percolation back to water table, reduces peak storm flows and flooding, and filters pollutants out of stormwater; site design includes pervious surfaces where possible.

Southern California Rock Products Association | Southern California Ready Mixed Concrete Association, www.scrpa.com/.

State Water Resources Control Board, Water Recycling Programs, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone (916) 341-5536 for general inquiries, (916)341-5537 for construction related issues, stormwater@dwq.swrcb.ca.gov, Web site: www.swrcb.ca.gov/stormwtr/index.html.

Stormwater and Urban Runoff Seminars—Guide for Builders and Developers, NAHB, Edited by Susan Asmus, Washington DC, (800) 368-5242 x538 or www.nahb.com/.

Stockdale, E.C. *Freshwater Wetlands, Urban Stormwater, and Nonpoint Pollution Control: A Literature Review and Annotated Bibliography*. 2nd Ed. WA Dept. of Ecology, Olympia, WA. 1991.

Strecker, E.W., J.M. Kersnar, E.D. Driscoll & R.R. Horner. *The Use of Wetlands for Controlling Stormwater Pollution*. The Terrene Institute, Washington, DC. April 1992.

U.S. Environmental Protection Agency. *Natural Wetlands and Urban Stormwater: Potential Impacts and Management*. EPA843-R-001. Office of Wetlands, Oceans and Watersheds, Washington, DC. February 1993.

U.S. Environmental Protection Agency. *Stormwater Management for Construction Activities: Developing Pollution Prevention Plans And Best Management Practices: Summary Guidance*. EPA#833-R-92-001, Office of Wastewater Management, 401 M St. SW, Mail Code EN-336, Washington DC, 20460. October 1992. (800) 245-6510, (202) 260-7786 or www.epa.gov/owm/sw/construction/.

GUIDELINE SP6: NATIVE AND DROUGHT-TOLERANT PLANTS

Recommendation

Use vegetation that is drought-tolerant and native to the school's climate area. Preserve existing vegetation, especially groups of plants or significant specimens wherever possible. Design for plant survival since many landscape areas in schools can be destroyed by intensive use.

Figure 18—Native, Perennial Grasses

Davis, CA. These groupings of native, quick growing perennial grasses require little irrigation and thrive in high use areas. Photo courtesy of Wolfe Mason Associates.

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	□
Library	□	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	□	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	■
Corridors	□	Desert	■	Construction	■
Administration	□			Commissioning	□
Toilets	□			Operation	■
Other	■				

Description

Native vegetation is adapted to regional climate conditions. They are easy to establish, are drought-tolerant (require little or no irrigation once established), and are naturally disease-resistant and pest-resistant. Planting for minimal water use is also referred to as "xeriscaping" or "drought-tolerant" landscaping. Existing vegetation is the easiest and most cost-effective way to landscape the site. It also provides historical connection to the surrounding neighborhood.

Plant survival can be increased by using tough plants that can take foot traffic such as plants grown from corms or bulbs. Good examples include *Dietes vegeta, Acanthus mollis, Phorium sp.,* and many of the grasses, reeds and sedges. These tough plants should anchor corners and edges of planted areas. Also raised beds, curbs, and temporary but artistic barriers can help protect plants into maturity. Prepare designs and management programs that layer plant types; use a mixture of sizes at initial plantings; and plan for plant succession.

Applicability

This guideline applies to all climates, but is especially important in the central valley, southern coastal, and desert climates.

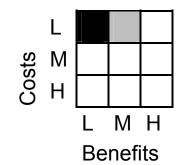
Applicable Codes

Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495 (www.dpla.water.ca.gov/cgibin/urban/conservation/landscape/ordinance/index).

Integrated Design Implications

Drought-tolerant landscaping should be integrated/coordinated with Guideline SP2: Landscaping to Shade HVAC Equipment, Buildings, and Paved Areas and Guideline SP4: Landscape Design and Management. All landscape planning should also take into account irrigation system parameters to assist in the goal of maximum efficiency. See Guideline SP8: Water-Efficient Irrigation Systems.

Cost Effectiveness



Costs are competitive with, or only slightly higher than, conventional landscape design. Additional cost benefit occurs if reusing existing vegetation.

Benefits

The use of drought-tolerant, native species conserves water (thereby reducing water costs), provides lots of attractive planting options, presents minimal disease and pest problems, thrives with little fertilization, requires low pruning and maintenance, provides wildlife habitat, and saves valuable landfill space. If retaining native vegetation in a landscape (rather than removing them and then replanting), added benefits include excellent erosion, sediment, dust, and pollution control.

Design Tools

Landscaping for minimal irrigation also requires careful planning of plant groupings, the “right plant, right place” concept, soil considerations, and other landscape design practices. The use of landscape professional with expertise in native and drought-tolerant vegetation for the school’s climate region is recommended.

Irrigation Water Needs of Landscape Plants in California, www.dpla.water.ca.gov/urban/conservation/landscape/wucols/index.html.

Landscape Auditors certified by the Irrigation Association (703) 536-7080, Web site: www.irrigation.org/.

Design Details

- Add language into construction specs to protect existing plants, especially trees and root systems.
- Soils are often disturbed during construction activities, and native vegetation may not thrive in degraded soils. Unless soil amendments are used to restore disturbed soil, it may be more appropriate to use water-efficient, non-native vegetation. See Guideline SP7 for using soil amendments.
- Clearly define planting zones by intended use, e.g., lawns for play; tree groves for shade and habitat; shrub masses for buffering and screening; etc.
- Introduce plants to increase habitat, e.g., butterflies and hummingbirds.
- Create a diversity of landscape areas, e.g., ponds, meadows and groves; community gardens; vines and perennials, etc.

Operation and Maintenance Issues

Native, drought-tolerant plants are usually hardier and more pest-resistant, requiring less fertilizer and pesticide use. Use organic, slow release fertilizers and integrated pest management for pest control. See Guideline SP12 on integrated pest management.

Recommend that the landscape contractor specify in the maintenance contract that new landscaped areas be maintained for a two to three year plant establishment period. Monthly findings on plant establishment should be reported to owner.

Commissioning

None.

References/Additional Information

California Department of Water Resources. 1416 9th Street, Room 1104-1, Sacramento, CA 95814, Phone: (916) 653-6192, fax: (916) 653-4684, www.dwr.water.ca.gov/.

California Landscape Contractors Association (CLCA). Phone: (916) 448-2522, fax: (916) 446-7692, or Web site (with an on-line contractor search) at www.clca.org/index.html.

California Native Plants Society, www.cnps.org/index.htm.

City of Fort Collins. (March 1999). Xeriscape: a New Kind of Landscaping.
A summary of environmentally responsive landscaping resources, including a list of very low, low and moderate water consumption. www.ci.fort-collins.co.us/utilities/water/conserv/xeriscap.htm.

City of Santa Barbara. (March 1999). Water Conservation Program: Landscaping. An excellent and visual orientation to water-conserving landscaping on the Southern California coast. www.ci.santa-barbara.ca.us/departments/public_works/water_resources.

Managing a Waste-Efficient Landscape, and on-line publication of the California Integrated Waste Management Board, Web site: www.ciwmb.ca.gov/organics/Landscaping/KeepGreen/Manage.htm.

Marsh, W. M. 1991. Landscape Planning: Environmental Applications. John Wiley & Sons, New York. A definitive reference for landscape architects, planners and designers on the definition and application of environmental design principles to landscape and site planning.

Peterson Nature Area, Peterson Middle School, Sunnyvale, California. Contact: Bryan Osborrne, Peterson Middle School, bryosborne@mail.telis.org, Santa Clara Unified School District, (408) 720-8540. Web site: www.peterson.scu.k12.ca.us/~bosborne.

WaterWiser—a program of the American Water Works Association operated in cooperation with the U.S. Bureau of Reclamation. The Web site provides information and resources including links for all aspects of outdoor and indoor water conservation, recycled water collection and reuse, irrigation, landscaping, and efficient fixtures and appliances. AWWA number is (202) 628-8303. www.waterwiser.org/.

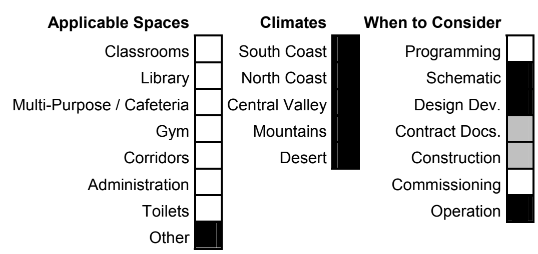
GUIDELINE SP7: LANDSCAPING SOIL, AMENDMENTS, AND MULCH

Recommendation

Use organic soil amendments to help restore the health of disturbed soils. Where feasible and appropriate, use soil amendments and mulch with recycled content.

Figure 19—Mulching

Davis, CA. Mulch areas 3–4 inches deep prevent weed growth, protect soil, and prevent irrigation from washing it into other areas. Mulch can be walked on and used to replenish the soils of high use areas.
Photo courtesy of Wolfe Mason Associates.



Description

The appropriate use of organic soil amendment will offset degradation in soil health due to construction activities, reduce runoff, help treat stormwater pollutants, and help ensure establishment of vegetation. Where feasible, use high quality soil amendments and mulch from shredded bark, which adheres better to the soil.

Applicability

All climates.

Applicable Codes

Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495 www.dpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/index.

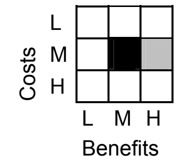
Applicable local ordinances (for example, City of Palo Alto. Landscape Water Efficiency Standards. March 15, 1993).

Integrated Design Implications

Soil amending should be integrated/coordinated with Guideline SP2: Landscaping to Provide Shade to HVAC Systems, Buildings, and Paved Areas; Guideline SP4: Landscape Design and Management; and Guideline SP6: Native and Drought-Tolerant Plants.

Cost Effectiveness

Medium.



Benefits

Research at the University of Washington has shown that, compared to traditional lawn installations, landscape grown on composted-amended soils:

- Uses less water for irrigation.
- Requires less fertilizer and pesticide.
- Covers and "greens up" more quickly.
- Has improved appearance.
- Reduces stormwater runoff..

Design Tools

Appropriate use of soil amendments requires site soil testing and analysis to determine type and amount of amendment.

Design Details

Key steps in creating and maintaining healthy soil and amendments include:

- Minimize disturbance of existing soil.
- Test the horticultural suitability of existing soil.
- Strip and save suitable existing soil for re-use in landscape areas.
- All existing soil in areas to be planted that have been degraded and compacted from building construction must be scarified before planting. In general and depending on soil type, planting soils can not be compacted more than 80% so that air and water can percolate through the soil cross section.
- Incorporate organic soil amendments from composted green waste to help restore the health of disturbed soils.
- Use a minimum 3 in. to 4 in. layer of mulch at all planting areas to help retain soil moisture and discourage weed growth. Some types of mulch can also take foot traffic.

Urban development often involves clearing, removing topsoil, cuts, and fills. Once the work is done, the remaining soil is often much less healthy than the original, native soil.

Since soil is different on every site, it may be useful to hire a soil scientist to examine the chemical and psysical properties of the soil and make soil recommendations based on this analysis. Although this adds expense, it may be more cost-effective to improve soil quality before investing in landscaping that cannot survive in existing soil conditions.

Table 4—Characteristics of Healthy vs. Disturbed Urban Soil

Healthy Native Soil	Disturbed Urban Soil
Stores water and nutrients—Contains a rich, diverse makeup of organisms, organic matter, and pores. Healthy soil acts like a giant sponge, storing and slowly releasing water, oxygen, and nutrients to plants as needed.	*Compacted*—The removal of topsoil exposes subsoil that is often compacted. Heavy construction equipment can further compact soils. These dense layers resist plant root penetration and lack pores needed for adequate aeration. As a result, the soil is less able to absorb, retain, and filter (purify) groundwater.
Regulates water flow—Maintains the natural water cycle by slowly discharging to streams and lakes and recharging aquifers.	*Reduced storage capacity*—Because subsoil are less able to retain water, more stormwater ends up as runoff, disrupting the natural water cycle and degrading the health of nearby streams and waterways.
Neutralizes pollutants—Soil rich in organic matter contains microorganisms that can immobilize or degrade pollutants.	*Poorer quality*—The subsoil layer generally contains less organic matter and fewer nutrients than rich topsoil. This soil is less able to immobilize or degrade pollutants.

The result is increased erosion and stormwater runoff, as well as higher flow rates, higher temperatures, and increased sediment in nearby streams result from disturbed urban soil. In addition, developed sites with poor soil typically require more irrigation, pesticides, and fertilizers to establish and maintain landscaping. Increased water usage as well as pesticide/fertilizer runoff causes further habitat damage.

Operation and Maintenance Issues

Vegetation grown on amended soils establishes more quickly and requires less ongoing maintenance compared to vegetation grown on un-amended, disturbed urban soil.

Commissioning

None.

References/Additional Information

The California Compost Quality Council (CCQC). A collaboration of compost producers, scientists, farmers, landscape contractors, and recycling advocates formed to administer compost quality guidelines in California. The CCQC operates an independent verification program through which compost producers can assure consumers that quality claims have been verified. CCQC, 584 Castro Street, San Francisco, CA 94114, phone (415) 863-1048 or Web site: www.crra.com/ccqc/ccqchome.htm.

Compost and Mulch Sources List from the California Integrated Waste Management Board. Listings for Northern, Central, and Southern California. Web site: www.ciwmb.ca.gov/organics/SupplierList/ListCent.htm.

Landscape Architects Technical Committee (LATC). Under the purview of the California Architects Board, the LATC was created by the California Legislature to protect the health, safety, and welfare of the public by establishing standards of licensure and the enforcing of laws and regulations which govern the profession of landscape architecture. It is one of the numerous boards, bureaus, commissions, and committees within the Department of Consumer Affairs responsible for consumer protection and the regulation of licensed professions. State of California, Department of Consumer Affairs, California Architects Board, Landscape Architects Technical Committee, 400 R Street Suite 4000 Sacramento, Ca 95814, phone (916) 445-4954, fax (916) 324-2333, Web site: www.latc.dca.ca.gov/index.htm.

U.S. Composting Council. This non-profit organization is involved in research, public education, composting and compost standards. Their website has links to composting resources throughout the country. Web site: www.compostingcouncil.org/.

GUIDELINE SP8: WATER-EFFICIENT IRRIGATION SYSTEMS

Recommendation

Install drip or other low-volume, water-efficient irrigation and/or systems connected to humidity sensors, where appropriate.

Figure 20—Drip Irrigation

Photo reprinted with permission from Rain Bird Sprinkler Mfg. Corp. www.rainbird.com/drip/index.htm

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	□
Library	□	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	□	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	■
Corridors	□	Desert	■	Construction	■
Administration	□			Commissioning	□
Toilets	□			Operation	■
Other	■				

Description

Supplemental irrigation accounts for most water use at schools during the summer and a significant amount during the spring and fall. Maximizing the water efficiency of irrigation systems supports healthy and attractive landscapes and sports fields.

Applicability

All climates.

Applicable Codes

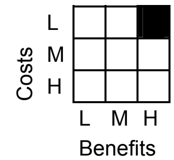
Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495 (www.dpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/index), or applicable local ordinances.

Integrated Design Implications

Irrigation system design and installation should be closely coordinated with other landscape planning and water management activities. See Guideline SP4: Landscape Design and Management, Guideline SP6: Native and Drought-Tolerant Plants, and Guideline SP7: Landscaping Soil, Amendments, and Mulch.

Note: The soil should be amended and blended prior to installing the irrigation systems to avoid damage to the system.

Cost Effectiveness



Drip systems and micro-emitters have become very cost effective when evaluated against water restrictions and rising water costs.

Benefits

Benefits include significantly reduced irrigation water consumption, reduced utility costs and increased water conservation. Conventional spray heads deliver only 55% to 65% of the water to the ground; the rest is blown away or evaporates, depending on weather conditions. In contrast, drip irrigation is up to 95% efficient. Plants establish and thrive better with drip irrigation since water is delivered to the root zone, where it is needed. Water-efficient irrigation systems are also *waste*-efficient—water and fertilizer are used only where needed, preventing nutrient-consuming and waste-generating weed growth in other areas and reducing costs associated with managing and disposing of undesired plant growth.

Design Tools

None.

Design Details

- First, aim to eliminate the need for an irrigation system entirely. An effective stewardship program combined with drought-tolerant plants (Guideline SP6) might eliminate the need for an in-ground system.
- Where an in-ground system is required, the design and installation should be completed by a certified irrigation specialist and should conform to local ordinances. The ordinances include specifics about efficient irrigation.
- Systems should be installed to avoid runoff, low-head drainage, overspray, or other similar conditions where irrigation water flows onto adjacent property, non-irrigated areas, or impervious surfaces. Some irrigation systems can be connected to humidity sensors to keep from operating when humidity is high or when it is raining.
- Consider special problems posed by irrigation on slopes, in median strips, and in narrow hydrozones. Installation should provide easy access to sprinkler heads for inspection and maintenance.
- Use irrigation zones to group plants with similar water needs close to a water source, which limits the scope and impact of an in-ground irrigation system.
- Where possible, use the minimum amount of polyvinyl chloride (PVC) products. PVC is highly toxic during manufacture and disposal. Unfortunately the alternatives, such as copper or clay piping, tend

to be more expensive. If substitution for virgin PVC is not an option, the system should be designed to use the minimum length of piping possible.

- Consider using irrigation systems made with recycled-content plastic, tire-derived rubber, and other recycled-content materials. See the California Integrated Waste Management Board's Recycled Content Product Database at www.ciwmb.ca.gov/rcp/.
- Preserve established vegetation to minimize irrigation needs. Avoid killing existing vegetation with too much water from new irrigation systems.

Operation and Maintenance Issues

Requires regular monitoring to ensure system is operating properly. Develop a monthly schedule to visually inspect and monitor irrigation system(s) performance during irrigation season. Performance evaluation should be based upon original design intent, irrigation audit report, and water budget goals.

Commissioning

Work with the commissioning agent and certified irrigation auditor to ensure compliance with the design documents. In addition to checking for proper irrigation equipment and installation, check the system for adherence to specified performance criteria and operation parameters as designed. Verify that maintenance personnel are trained and proficient in the ongoing programming and adjustments for the irrigation system.

References/Additional Information

California Department of Water Resources. 1416 9th Street, Room 1104-1, Sacramento, CA 95814, Phone (916) 653-6192, fax (916) 653-4684, www.dwr.water.ca.gov/.

Costello, L. R. and K. S. Jones, A Guide to Irrigation Water Needs of Landscape Plants in California, University Of California Cooperative Extension. 1999 Edition. On-line at www.dpla.water.ca.gov/urban/conservation/landscape/wucols/index.html.

Drip Irrigation for Every Landscape and All Climates, by Robert Kourik, Metamorphic Press, PO Box 1841, Santa Rosa, CA 95402.

Hawn, Joellyn. "Process Changes to Improve Commercial Landscape Viability." *New England Real Estate Journal*, May 31-June 6, 1996.

Irrigation Association, various publications, including *Common Obstacles to Irrigation Efficiency* and *Drip Irrigation Technology*. Available on-line at www.igin.com/irrigation/irrigation.html.

Landscape Water Management Principles, Version 1.01. Cal Poly ITRC, San Luis Obispo, CA, 1994.

Netdim Irrigation Inc. 1998. *Techline Design Manual.* Netafim Irrigation, Inc. Landscape Division. Fresno, CA. A technical primer for designing drip irrigation systems.

WaterWiser is a program of the American Water Works Association operated in cooperation with the U.S. Bureau of Reclamation. The website provides information and resources including links for all aspects of outdoor and indoor water conservation, recycled water collection and reuse, irrigation, landscaping, and efficient fixtures and appliances. Web site: www.waterwiser.org/. AWWA number is (202) 628-8303.

GUIDELINE SP9: STORMWATER/GROUNDWATER MANAGEMENT AND DRAINAGE MATERIALS

Recommendation

Manage stormwater with systems that slow water velocity, maximize its use for irrigation, and filter pollutants. Use material-efficient options for on-site drainage systems. Groundwater should be managed separately from surface water.

Figure 21—Boulder Bridge

Berkeley, CA. A boulder bridge spans a surface swale in the edible garden at King Middle School. The swale allows water to percolate back into the soil and eliminates the need for pipes. Students grow produce and sell it at local markets to raise funds for schools groups. Photo courtesy of Wolfe Mason Associates.

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	□
Library	□	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	□	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	■
Corridors	□	Desert	■	Construction	■
Administration	□			Commissioning	□
Toilets	□			Operation	■
Other	■				

Description

Stormwater management is vital to the safety and ecological health of a school site. Site planning and design should strive to balance water on the site and make effective use of the water for water supply and irrigation.

Water should always be absorbed and captured with the remainder moved slowly across the site into natural features wherever possible. Trying to move water quickly to gutters, downspouts, catch basins, and pipes increases water quantity and velocity, which requires the design of large and expensive drainage infrastructure. Options for material-efficient drainage include:

For fill:

- Recycled concrete aggregate.
- Crushed concrete.
- Glass.

For pipes:

- EPS with recycled content.

In areas where the water table is high, construction can cause groundwater to seep to the surface. In these cases, level spreaders should be used to pipe the discharge from curtain drains to trickle discharge onto fields or wetlands, in lieu of the stormwater system. It is important to manage groundwater separately from stormwater to prevent possible contaminants from destroying groundwater quality.

Applicability

All climates.

Applicable Codes

State Water Resources Control Board, Storm Water Program, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone (916) 341-5536 for general inquiries, (916) 341-5537 for construction related issues, e-mail: stormwater@dwq.swrcb.ca.gov, or www.swrcb.ca.gov/stormwtr/index.htm.

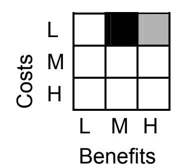
The California Environmental Resources Evaluation System www.ceres.ca.gov/index.html features the California Land Use Planning Network with a broad array of data types from diverse sources, including selected, but fully scanned and searchable, county and city zoning ordinances. www.ceres.ca.gov/index.html.

Applicable specifications for fill and drainage materials.

Integrated Design Implications

Building design (especially roofs), site grading, erosion control, and bank stabilization need to be considered. Where applicable, the groundwater management system design should be integrated with the design of site built stormwater system for greatest cost savings.

Cost Effectiveness



On-site capture, absorption, and slowing of surface runoff usually has a lower first cost and ongoing maintenance expense. By managing groundwater separately from stormwater, the complexity and size of site-built stormwater systems can potentially be reduced, decreasing overall construction costs. Costs for environmental preferable products are comparable to, or less than, conventional materials. For example, recycled aggregate base is less expensive than virgin aggregate in the Los Angeles area. There also may be an economic advantage to crushing concrete and asphalt demolition debris on-site, where the material can be used as base or sub-base. The economy of on-site crushing depends on several variables including the amount of rubble stockpiled, the capacity of the crushing equipment available (tons per hour), local tipping fees for the inert materials, the haul distance to local inert landfills, and the total cost of importing virgin or recycled aggregate base to the construction site.

Benefits

Capturing and absorbing stormwater is good water conservation. It also can improve the health of on site soils, vegetation, and habitat areas. Use of recycled-content products helps alleviate waste disposal problems, reduces energy use, and lowers consumption of natural resources during manufacturing.

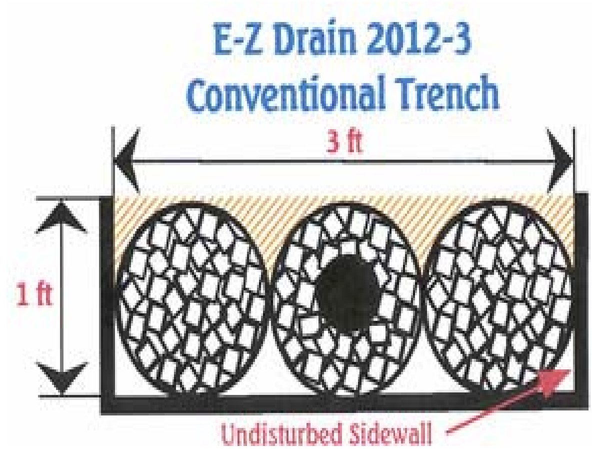


Figure 22—Cross-Section of Trench

The basic unit of E-Z Drain is a 10 foot length of 4-inch perforated corrugated plastic pipe surrounded by EPS aggregate held in place by a cylindrical shaped polyethylene netting either 10 or 12 inches in diameter. Made from 60% to 100% recycled EPS. Illustration reprinted with permission from E-Z Drain Company. www.ezdrain.com

Design Tools

None.

Design Details

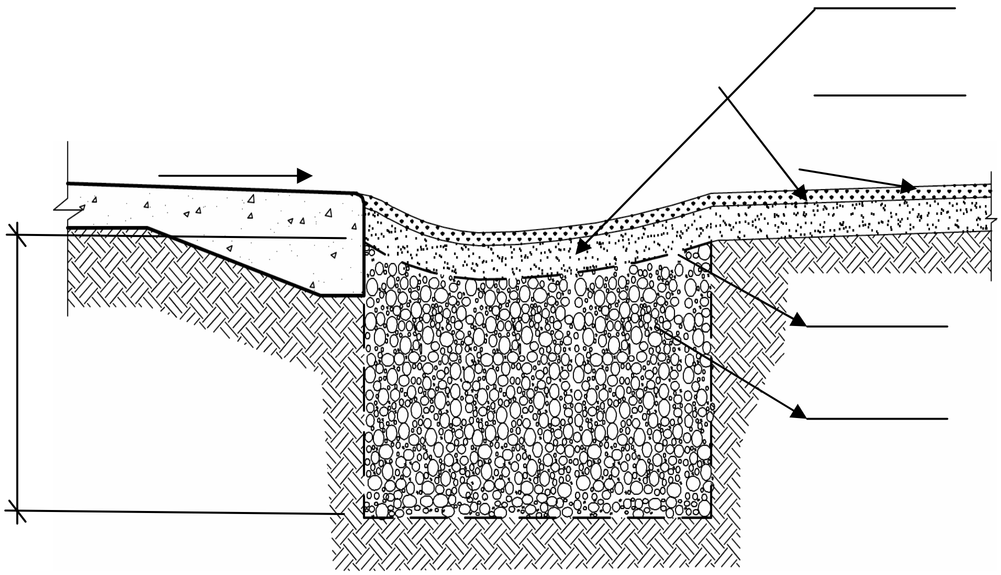
Stormwater management should begin with capture in cisterns, ponds, etc. and absorption into groundwater aquifers, landscape areas, etc. Excess water from green roofs and pervious paving should be filtered through vegetated areas or filters.

Any remaining water to runoff should be slowed down and spread slowly over the entire surface of roofs and paved areas before entering bioswales and surface runoff channels, such as brooks and creeks.

If pipes and catch basins are used, use perforated pipe and filters wherever possible.

Natural boulders can be effective as energy dissipaters or as checkdams, creating riffles and pools in the channels.

Use green roofs and bioswales at buildings. Use site grading with bioengineered banks and channels, energy dissipaters, and check dams. Broken and excess masonry and concrete are good inert fill materials under sidewalks and driveways. If space permits, excess concrete can be crushed on-site and used as aggregate on another part of the site or on another construction job.



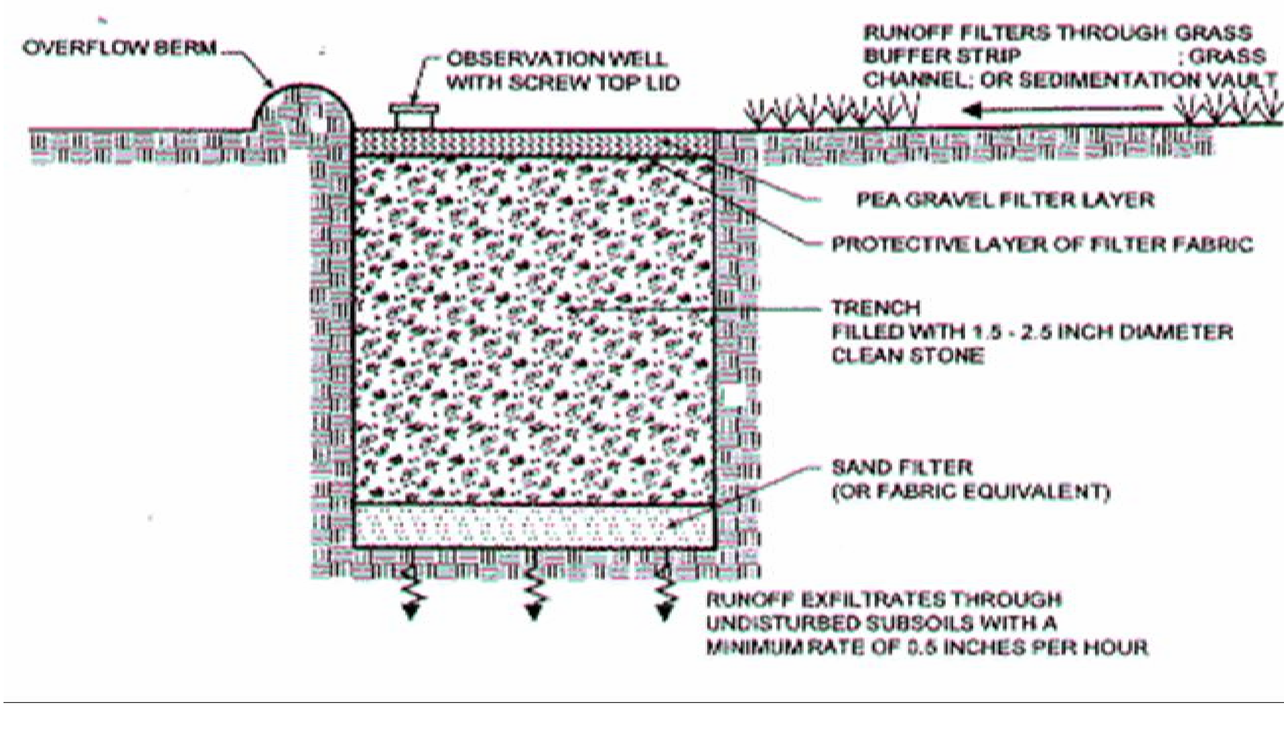


Figure 23—Detail Drawings of Stormwater Filtration Swale and Infiltration Trench

Operation and Maintenance Issues

Most traditional site maintenance programs at schools are limited trash pickup and “mow and blow” cleanup. Local conservation corps, youth job training programs, community and experienced gardeners, and neighborhood groups are good sources to help augment the school maintenance staff. They can help nurture a variety of landscapes, especially natural waterways and riparian corridors, ponds, meadows, and native planting beds.

If using level spreaders for groundwater management, they should be inspected after every runoff event to ensure proper function.

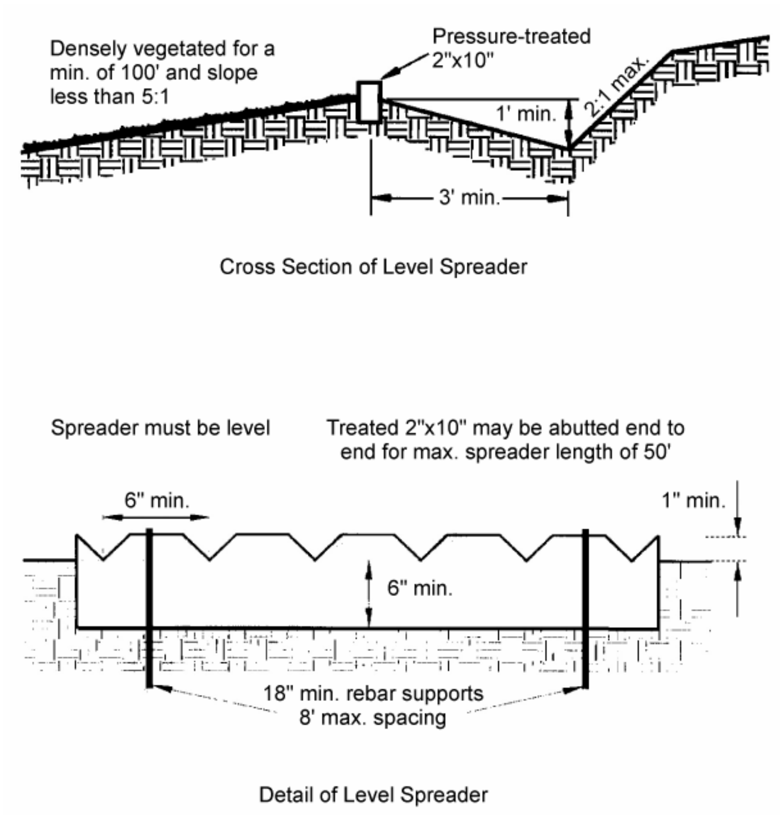


Figure 24—Level Spreader, Cross Section & Detail

(Source: Washington State Department of Ecology, Stormwater Management Manual for Western Washington, Volume II, Construction Stormwater Pollution Prevention)

Commissioning

None.

References/Additional Information

Blackberry Creek Restoration at Thousand Oaks School, Berkeley, CA. Designed by Wolfe Mason Associates with the Waterways Restoration Institute, Oakland and Berkeley, CA.

California Integrated Waste Management Board. Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix E sample specifications for: Section 02045, Rock Crushing Operations. Chapter 8 is in Part D. Revised July 2000. Designing with Vision can be downloaded in four parts from www.ciwmb.ca.gov/GreenBuilding.

California Integrated Waste Management Board. Database of Recycled-Content Providers: www.ciwmb.ca.gov/rcp.

California Integrated Waste Management Board. *Recycled Aggregate* Fact Sheet, CIWMB publication #431-95-052. Also available to download from: www.ciwmb.ca.gov/publications/condemo/43195052.doc.

International Erosion Control Association. Provides technical assistance and an annual Erosion Control Products and Services Directory. (800) 455-4322 or www.ieca.org/.

Kids in Creeks Program for School Teachers. Aquatic Outreach Institute, Richmond, CA.

Sonoji Sakai Intermediate School, Bainbridge Island School District, Bainbridge Island, Washington uses level spreaders to slowly distribute groundwater to the adjacent field and wetlands.

Stream Corridor Restoration: Principles, Processes and Practices developed by 14 Federal Agencies. Available at www.usda.gov/streamrestoration/.

State Water Resources Control Board, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone (916) 341-5536 for general inquiries, (916) 341-5537 for construction related issues, e-mail stormwater@dwq.swrcb.ca.gov, or www.swrcb.ca.gov/index.html.

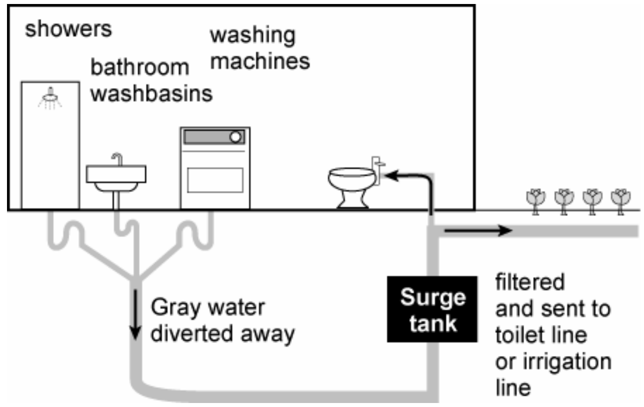
Stormwater and Urban Runoff Seminars—Guide for Builders and Developers, NAHB, Edited by Susan Asmus, Washington DC, (800) 368-5242 x538 or www.nahb.com/.

Stormwater Management For Construction Activities: Developing Pollution Prevention Plans And Best Management Practices: Summary Guidance. EPA#833-R-92-001, October 1992, U.S. Environmental Protection Agency Office of Wastewater Management, 401 M St. SW, Mail Code EN-336, Washington DC, 20460. (800) 245-6510, (202) 260-7786 or www.epa.gov/owm/sw/construction/.

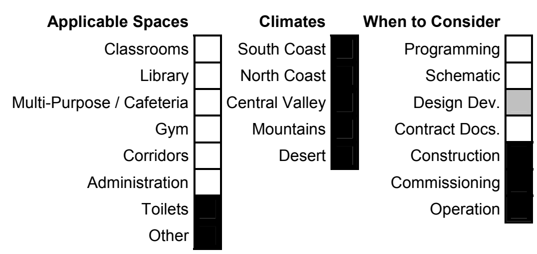
GUIDELINE SP10: GRAY WATER SYSTEMS

Recommendation

Use gray water systems for drought-resistant landscape irrigation and for flushing toilets.



Gray water systems can recycle up to 50% of the selected waste water from a school to use for irrigation and/or flushing toilets.



Description

Gray water is untreated “used” water that is not contaminated by toilet waste. The California Gray Water Standards define it to include used water from showers, bathroom washbasins, and water from washing machines. It does not include wastewater from dishwashers, kitchen sinks, or laundry water from soiled diapers. Gray water systems filter, sterilize, deodorize, and recycle this used water to be used for irrigating landscapes or flushing toilets.

Gray water systems have three major components: the drain-line plumbing, the surge tank and other equipment associated with it, and the delivery system. Surge tanks allow quicker inflow of water from the source than outflow to drainfields. The example schematic shown here from Appendix J of the California Plumbing Code identifies the components of a gray water system where gray water is delivered to the landscape.

Plumbing work is required to divert the gray water from the existing drain lines. All drain lines from gray water sources should link to a common channel that connects to the surge tank. The surge tank contains filters, vents, valves, and pumps. Sand and settling (sedimentation) filters are most commonly used in large applications. Pumps deliver the gray water to toilets and the landscape (if drip irrigation is used).

Gray water composition varies depending on the water source, plumbing system, and user-specific variables (like cleaning products). At regular concentration levels, few components in gray water will damage trees and shrubs. Few detrimental soil changes will occur from well-managed gray water systems. Gray water contains high levels of grease, fibers, and particles (like dry skin), and is 5°F to 10°F warmer than non-gray water. Gray water does increase the number of soil organisms, but only slightly. Most harmful soil effects actually result from over-watering and prolonged saturation of the soil.

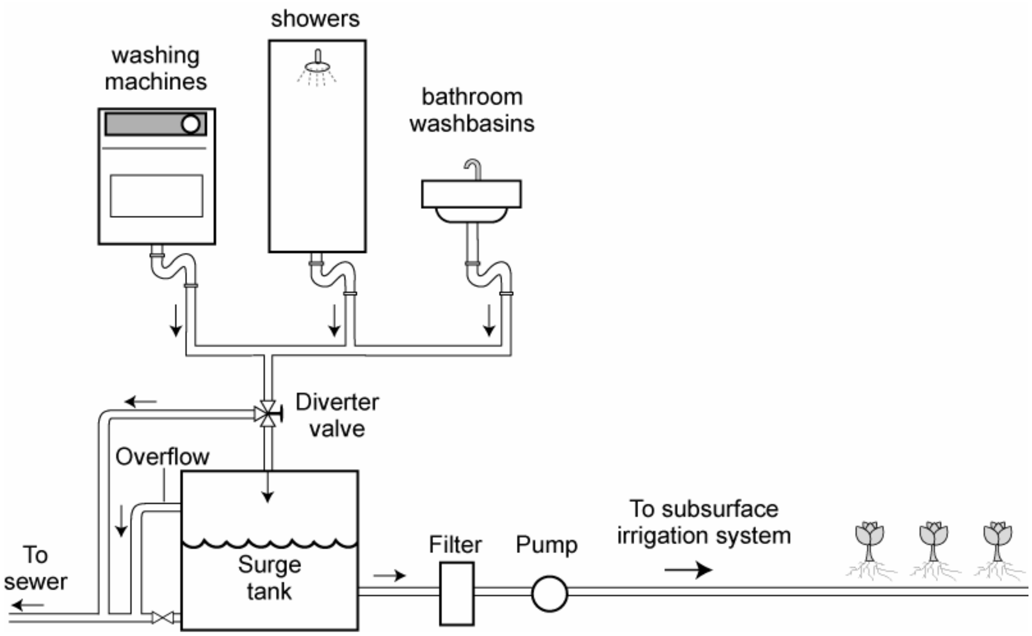


Figure 25—Example Schematic of Gray Water System

Applicability

- They are appropriate wherever supplemental irrigation is normally required.
- They are applicable for all climate types, although their uses may be limited in severely cold climates. However, in colder weather conditions, gray water can be drained into leaching trenches that are deep enough to resist freezing, but shallow enough to keep the nutrients within the root zones of surface plants. Freezing can be prevented by applying a mulch over the subsurface leaching trenches. Drought-prone climates will especially benefit from a reliable, year-round source for irrigation.
- Do *not* use gray water for plants with limited root areas or on hydroponic plants. Acid-loving trees and shrubs (azaleas, begonias, and rhododendrons) may be affected because gray water is alkaline. Do *not* use gray water on edible plant parts.

Applicable Codes

In 1992, a law legalizing gray water use in the cities and counties of California was passed. The California Department of Water Resources (CDWR) was directed to adopt standards for gray water use. The CDWR standards define gray water as "untreated single-family residential wastewater from all sources, excluding toilet, kitchen sink, and dishwasher." It also restricts the use of gray water to subsurface (varies between 8 in. to 12 in. depending on the soil type) applications. California does not require gray water sampling, monitoring, and treatment.

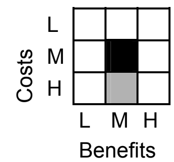
However, cities and counties in California can accept or reject the state's gray water standards or establish their own, using the state's standards as a base. They even can decide to ban gray water use altogether.

- All sub-surface drip irrigation must take place at least 9 in. below the soil surface.
- All piping, pumps, and fixtures associated with gray water systems should be clearly labeled along the entire length of the installation.

Integrated Design Implications

Integrated gray water systems for new constructions are cost effective, although retrofitting is not a major issue either. Plumbing installation and surge tank location require consideration early in the design process.

Cost Effectiveness



Installation costs for gray water systems can range from several hundred dollars to more than $5,000 for small systems. Generally, systems will have an initial cost between $8/gallon to $15/gallon of stored gray water. The annual operating costs are between $0.15/gallon and $0.25/gallon of capacity.

Table 5—Types of Systems Currently Available

System Type	Source of Gray water	Features	Cost
Low-Tech Owner or Professional Installation	Washing machine only.	200 micron mesh filter. 55-gallon garbage can with locking lid.	$400–$800
Medium-Tech	Uses all gray water sources.	Sump pump to PVC tubing. Subsurface drip irrigation. 200-micron mesh filter. (2) 55-gallon storage tanks.	$1,000–$1,500
Fully Automated Professional Installation	Uses all gray water sources.	Automatically back-washed sand filter. 250-gallon storage tanks. Pumps at both source and tank/filter. Three-way valve, backflow preventers. Microprocessor controls all flows. Backed by potable water.	$2,500–$5,000

Benefits

- Promotes conservation and reduces water bills by reusing water from baths and sinks that would have otherwise gone down the drain. At least 30% of total “used” water is reutilized by such systems.
- Drought-proof landscaping. More than half the indoor water can be recycled, ensuring a constant source of water even during shortages. Also the nutrients in the gray water may benefit plants. Valuable plant nutrients, such as phosphorous and potassium, are often found in gray water that can result in healthier plants and in the reduced application of fertilizers. By leaving the soil surface drier, it may also make for a healthier landscape by reducing disease and pests.

- Using gray water improves the efficiency of applied water because it is delivered to the plants underground, eliminating runoff, over spray, and evaporation.
- The community benefits from gray water use because it reduces the amount of wastewater that is discharged to the local treatment facility. This has the potential to reduce wastewater treatment costs, and may even postpone or avoid the need for flow-related expansions of the facility. Local water and wastewater agencies also experience reduced pumping costs.

Design Tools

One of the toughest challenges in designing the gray water system is laying out the irrigation system and determining the size of the area to be irrigated. The homeowner or designer must decide which plants can be irrigated with gray water. The size of the irrigated area is determined by the soil type, volume of gray water produced, and by the summer water requirements of the plants. A good rule of thumb is to expect 2 gallons to 2.5 gallons of water to effectively irrigate 1 ft^2/day. Estimate the total daily water requirement and assume that only 50% of this estimate will make it into the gray water storage.

Design Details

- Plumb "used" water from bathroom sinks, showers, and clothes washers separately from other wastewater. Kitchen sinks may be included if there are no in-sink garbage disposals. This water should drain by gravity into a surge tank.
- Surge tanks should have tightly fitted covers, vent stacks, and overflow drains attached. It should also have a one-way valve to prevent backflow. Install the tank such that the outflow can be gravity driven. If this is not possible, use pumps for delivering water for irrigation. Overflow pipes that redirect water to septic tanks or sewer lines are very important when the field gets saturated.
- The water in the surge tank should be filtered.
- Locate the distribution piping 9 in. below the soil surface to provide adequate decomposition and minimize health risks. Use dual pipes that consist of 1in.-perforated pipes with 5/16 in. holes at 6 in. intervals lodged in pipes of larger diameters with slits at the bottom.
- Provide several independent drain areas with valves for alternate distribution.
- Use a check valve between the pump and outflow piping to restrict the gray water flow in one direction.
- It is a good practice to label and mark all piping, fixtures, and pumps that comprise a gray water system.

Operation and Maintenance Issues

The success of gray water systems is completely dependent on careful operation and periodic maintenance. The following guidelines should be strictly followed for health and safety reasons.

- Paint thinners, paints, or pesticides should never be washed down the drain, and substances such as ammonia and chlorine should find their way into gray water plumbing in very limited quantities only. Drains in schools must be clearly labeled with bilingual signs.
- While most detergents can be used with gray water systems, there are several important exceptions and several cautions. Products that contain boron should not be used. Boron has been shown to be very toxic to most plants. Use biodegradable soaps as much as possible.
- If salt buildup in the landscape is a concern (it should be in most cases), it is better to use liquid detergents than powdered detergents. Powdered detergents contain excessive amounts of sodium.
- Chlorine is extremely toxic to plants, but it has not generally been a problem in gray water irrigation. This may be because chlorine breaks down fairly rapidly and its effects may also be dissipated or diluted in the soil. Having some residual chlorine present in the surge tank to minimize bacteria buildup also appears to be a benefit. Chlorine bleach may damage plants if it touches the foliage.
- Gray water should not be sprayed, allowed to puddle, or run off property.
- Gray water should be rotated with fresh water to leach out any harmful build-up. Biodegradable soaps appear to have the least harmful effects.

Commissioning

For safety reasons, involve a soil engineer (or other experts) to assess available soil and the feasibility of the system based on soil quality. All purchased equipment should be accompanied by detailed installation information and all equipment should be professionally installed.

References/Additional Information

California Department of Water Resources. *Gray Water Guidelines.* www.owue.water.ca.gov/docs/graywater_guide_book.pdf.

Guiding Principles of Sustainable Design (Chapter 8), National Park Service. www.nps.gov/dsc/dsgncnstr/gpsd.

U. S. Environmental Protection Agency, Office of Water, www.epa.gov/OW.

Water Alliance for Voluntary Efficiency (WAVE), www.es.epa.gov/partners/wave/wave.html.

WaterWiser—The Water Efficiency Clearinghouse. www.waterwiser.org/.

GUIDELINE SP11: SPACE FOR RECYCLING

Recommendation

Provide a dedicated, easily accessible space for the collection and storage of recyclables.

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	■
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	▒
Gym	▒	Mountains	■	Contract Docs.	□
Corridors	▒	Desert	■	Construction	□
Administration	■			Commissioning	□
Toilets	□			Operation	□
Other	■				

Description

Recycling is the practice of recovering used materials from the waste stream and then incorporating those same materials into the manufacturing process. Recycled materials conserve natural resources and save energy because they require less processing than “virgin” materials. To close the recycling loop it is important to buy products containing recycled content.

Schools typically generate about 6 lbs. of waste per classroom per day. Much of this waste can be recycled instead of deposited in a landfill. Recycling has become commonplace in California with curbside recycling standard in many communities. The majority of people are likely to recycle when it is convenient. By providing easy access for collection of recyclables a considerable portion of solid waste can be diverted from landfills.

At a minimum, recycling should include paper, corrugated cardboard, glass, plastic and metals. Localized collection points should use a maximum of 20-25 gallon containers, preferably wheeled for easy transportation. Recycling containers should be located near waste receptacles so that the opportunity for recycling is as convenient as disposal. The centralized collection point should make use of front loader bins with ramps to facilitate the transfer from the 20-25 gallon containers. In allocating space for the centralized collection point of recyclables, it is important to involve the local hauler who will be providing waste management services to the school site. Space allocation needs can vary depending upon collection strategies used by the hauler such as co-mingled or source separated collection of recyclables.

Organic materials account for 30% of the overall waste stream in California. Providing easily accessible areas to collect and store organic materials to the students, teachers and staff can help to ensure a significant portion of solid waste can be diverted from landfills and transformation facilities. Composting, mulching, and grasscycling are a few techniques to conserve water, minimize waste, and help replenish the earth with nutrients and minerals.

Applicability

All climates.

Applicable Codes

State law requires all cities to adopt a local ordinance. If local jurisdictions did not adopt a model ordinance than the Model Ordinance developed by the state becomes the de facto ordinance for all new construction (www.ciwmb.ca.gov/publications/localasst/31000012.doc).

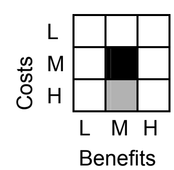
Davis RISE Partnership

The Davis Unified School District and the Davis Waste Removal agency are showing that Recycling is Simply Elementary (RISE). The Davis RISE program helps the school district to allocate space for recycling when they build new schools. The program has shown how to cut waste disposal costs nearly in half at almost all of the participating schools. Before the program started, the district spent over $23,000 bimonthly for solid waste removal at their elementary schools. After a year, they were able to cut these costs down to just over $14,000. They were able to accomplish these cost savings by modifying the pick-up frequency and the number of solid waste bins. This program offers a great example for cost savings related to recycling. See www.davisrise.org for more information.

Integrated Design Implications

The California Integrated Waste Management Board conducted a School Waste Reduction Survey in 2003, which includes information about the barriers to implementing waste reduction programs. More than 50% of the schools responding (and in all size ranges) said that storage space for recycling was a barrier to implementing a program. It is important to start working with the local recycling coordinator and hauler right away to ensure that the space is designed appropriately for the size and types of bins needed.

Cost Effectiveness



Recycling costs vary according to region, distance to landfill/transfer/recycling station and a bunch of other factors. Some schools don't pay for recycling because the local haulers are able to generate revenue from the sale of recyclables. Other schools have a contract with the hauler for a specific amount to remove the recyclables from the campus, which is part of the solid waste disposal services. Some schools haul their own recyclables off-site.

Benefits

Recycling saves natural resources and diverts waste from landfills. It is rare for there to be a cost premium for disposal of recyclable materials and in many cases there is a cost savings as recyclables

Total Cost for Trash Disposal in California Schools

An article titled, "Learning life's lessons from the box," by Michelle Hatfield, staff writer at the Santa Maria Times, found that "California's public schools spend more than $175 million a year on trash disposal, money that could instead be spent on educational programs."

have value. Schools can take advantage of this value by collecting and selling recyclables as fund raisers.

Composting, and especially worm composting, make for a rich topic for scientific investigation and discovery that can be integrated into the school's science curriculum.

Design Tools

Local recycling centers and waste haulers can provide the details of local programs and requirements.

> ***School Waste Reduction Survey***
>
> *The California Integrated Waste Management Board conducted a School Waste Reduction Survey in 2003, which includes information about the barriers to implementing waste reduction programs. More than 50% of the schools responding (and in all size ranges) said that storage space for recycling was a barrier to implementing a program. It is important to start working with the local recycling coordinator and hauler right away to ensure that the space is designed appropriately for the size and types of bins needed. For more of the survey results, please see www.ciwmb.ca.gov/Schools/WasteReduce/Survey/Default.asp.*

Design Details

- Papers should be collected in classrooms while cans and bottles can be collected in common or eating areas.
- Recycling bins should be located near waste receptacles to make recycling as convenient as disposal. Provide adequate signage to prevent contamination of bins.
- Centralized collection and composting areas can produce odors and should be located away from air intakes and operable windows.
- Include the recycling coordinator and the local hauler in the planning. Some areas allow co-mingled recyclable materials while other areas require that the recyclables be separated before collection. Materials that need to be separated include paper, cardboard, glass, plastics, metals.
- Size the collection bins according to amount of materials collected and frequency of scheduled pick up.
- Design the collection and storage area to be shielded from view and easily accessible to the local hauler. The design should also take into consideration the prevention of illegal dumping from the local community.
- Composting bins should be located close to a water source in case they become too dry. Good drainage is also important in order to avoid standing water and the build-up of anaerobic conditions. Other considerations include avoiding exposure to high winds which may dry and cool the pile, and to direct sunlight which may also dry out the pile. The pile should not touch wooden structures or trees because it may cause them to decay. There should be space nearby for temporary storage of organic wastes.

Operation and Maintenance Issues

Recycling bins should be emptied regularly to prevent overflow and diversion of recyclables to the trash. Rinse items contaminated with food waste since these can often attract pests. Annually evaluate the recycling and waste management program to verify that service levels are appropriate.

Commissioning

None.

References/Additional Information

CIWMB recycling space allocation guide. www.ciwmb.ca.gov/Publications

Cornell Composting: Composting in Schools. http://compost.css.cornell.edu/schools.html

U.S. EPA Composting. www.epa.gov/epaoswer/non-hw/composting/

U.S. EPA Recycling. www.epa.gov/epaoswer/non-hw/muncpl/recycle.htm

Locate local recycling information. www.earth911.org

Interior Surfaces and Furnishings

OVERVIEW

This chapter provides the following guidelines:

- Guideline IS1: Carpeting
- Guideline IS2: Resilient Flooring
- Guideline IS3: Ceramic Tile / Terrazzo
- Guideline IS4: Concrete Flooring
- Guideline IS5: Wood Flooring
- Guideline IS6: Bamboo Flooring
- Guideline IS7: Gypsum Board
- Guideline IS8: Acoustical Wall Panels and Ceilings
- Guideline IS9: Paints and Coatings
- Guideline IS10: Casework and Trim
- Guideline IS11: Interior Doors
- Guideline IS12: Toilet Partitions
- Guideline IS13: Acoustics—Reverberation Time

The selection of interior finishes and furnishings affects a number of high performance goals including the following:

- *Health and indoor air quality*. Low-emitting materials can be selected to reduce chemical emissions that can be a source of indoor air pollution.
- *Visual comfort*. The surface reflectance of materials affects the efficiency of lighting systems, especially when recommended indirect/direct lighting systems are used.
- *Acoustic comfort*. Interior surfaces can absorb sound and reduce the reverberation time in classrooms and other school spaces.
- *Material efficiency*. The materials represented by interior surfaces and finishes are a quite significant and present opportunities to reduce waste (including construction and demolition waste); conserve raw materials and other resources used in the manufacturer, delivery and assembly in buildings; minimize maintenance; and be durable so they don't need to be frequently replaced.
- *Building as a teaching tool*. Since intherior surfaces and finishes are so visible, they can be labeled or other wise identified to communicate sustainable design principals to students.

Guidelines are presented in this Overview that provide advice on choosing among the various product categories for flooring, wall and ceiling finishes, other interior surfaces, and their associated coatings and adhesives. Once you have settled on a product such as carpet, then detailed guidelines are provided on how to specify the most high-performing product available.

While many other characteristics, including acoustical performance and visual appearance, factor into product decisions, selecting material efficient products that do not degrade indoor air quality are the main goals addressed in these guidelines. Evaluating resource efficiency and volatile organic compound (VOC) emissions is an emerging science with many uncertainties. No material or product is going to completely satisfy all the criteria. Choosing materials and products requires some professional judgment as to which of the criteria should be given the greatest weight.

Life-Cycle Assessment

Life-Cycle Assessment (LCA) is a procedure for assessing the impact of a product over its entire life. LCA considers the environmental impact from the very beginning of a product's life when resources are extracted from the earth and/or when materials from other products are collected and recycled to become raw materials for the manufacturer of the product. It considers the human labor and natural resources (especially nonrenewable resources such as energy) that are used in the manufacturer of the product. It considers possible health impacts to workers. It considers the impact of delivering the product to the building construction site and assembling it into the building, including human labor, natural resources, and waste at the construction site from discarded packaging or unused product. After the product is installed in the building, LCA considers human labor, energy and other resources needed to maintain it (the use phase in LCA parlance). LCA also factors in what happens to the product at the end of its useful life.

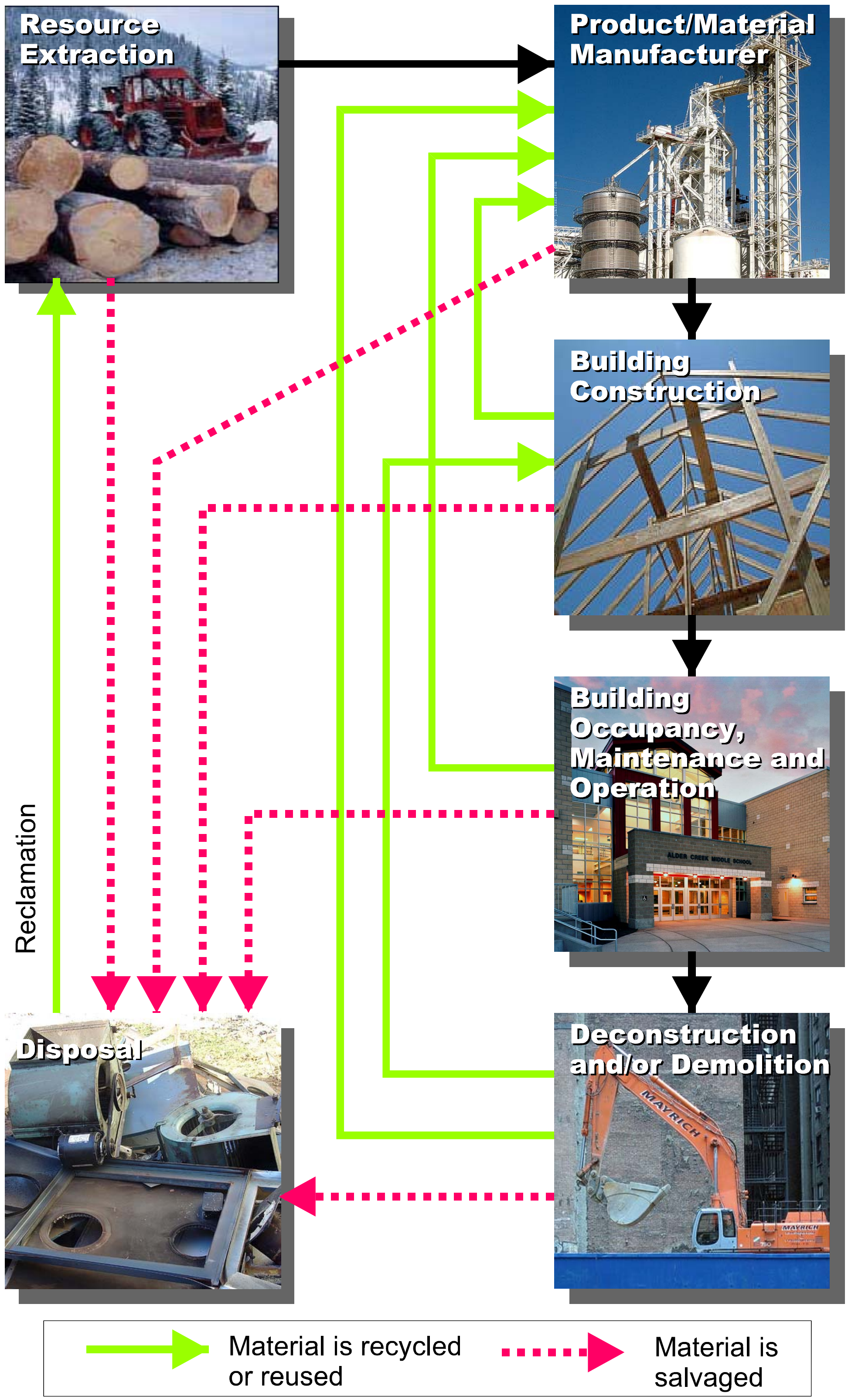


Figure 26 – Life-Cycle of Building Materials

The durability of the product and its useful life are also considered as well as its performance in its intended application. Performance includes the impact of the product on indoor environmental conditions such as visual comfort (the surface reflectance if the material is used on a ceiling or upper wall), thermal comfort (its insulating ability or surface temperature), acoustic comfort (its ability to absorb sound and reduce reverberation time), and/or indoor air quality (any chemicals that are emitted from the material). Of paramount importance is the durability of the material, its maintenance requirements, and its service life (how frequently will the product need to be replaced). LCA does not end there, however. It also considers what will happen to the product when it needs to be replaced (will it find its way into a landfill or will it be disassembled and recycled to provide a natural resource for new products?). This is why the term “cradle to cradle” is sometimes used to describe the period of time considered in LCA.

At each phase of a product’s pre-life, life, and post-life, natural resources are used, some of which may be non-renewable. Human labor is used and some persons involved in the manufacturer, delivery, assembly, or deconstruction of the product may be exposed to unhealthy or dangerous situations. The product may have positive or negative environmental impacts at any phase of its life.

Additional Information on LCA

The Sustainable Products Purchasers Coalition
www.sppcoalition.org

American Center for Life Cycle Assessment
www.lcacenter.org

International Organization for Standardization
www.iso.ch

Building for Environmental and Economic Sustainability (BEES)
www.bfrl.nist.gov/oae/software/bees.html

U. S. Environmental Protection Agency Environmentally Preferable Products.
www.epa.gov/epp

U. S. Life-Cycle Inventory Database Project
www.nrel.gov/lci

Athena
www.athenasmi.ca/

Life-Cycle Assessment for Buildings: Seeking the Holy Grail Environmental Building News, March 2002
www.buildinggreen.com

LCA is an emerging science. At present it is less of a quantitative methodology and more of a way of conceptualizing the resource use and environmental impact of using products. The goal of some LCA researchers is that all the impact factors related to the use of a product be rolled up into one figure of merit that designers or product specifiers can use to make comparisons and selections. Before this can happen, and not all agree that it can, a number of issues have to be addressed. The following are examples:

- *Availability of data*. The materials and resources used to manufacturer materials are considered proprietary by many manufacturers and data is not widely available.
- *Uncertainty about the future*. Even if a product is designed so that it can be maintained with non-toxic cleaning materials or so that it can be recycled when its life is over, what is the probability that this will happen? If the probability can be assessed how is it accounted for in the LCA?
- *Lack of standards*. Many product attributes such as reflectance, noise absorption, and insulating value can be measured and standards for making these measurements are widely accepted. Test standards and protocols are still needed, however, for many other important product attributes such as durability and service life.

- *Methodology issues*. There are a number of issues still to be resolved with regard to LCA methodologies, including the following:
- *Discounting future impacts*. In life-cycle cost analysis, future benefits and costs are discounted. Should a similar procedure be applied to LCA?
- *Applying weights*. How do you apply weights that place a relative value for factors as disparate as human live or global warming?

Progress is being made toward addressing these issues and LCA may emerge as a useful option in the future. Athena and the National Renewable Energy Laboratory are working to develop a life-cycle inventory database that would provide data. Also the Sustainable Products Purchasers Coalition, a network of government and private agencies and organizations is working to pressure manufacturers to provide data needed for LCA.

US LCI Database Project

The US LCI Database Project is a public/private research partnership dedicated to the creation of a publicly available LCI database of commonly used products and processes. The underlying intents are to support cost-effective LCA work by others; to facilitate the development of environmentally-oriented decision support systems and tools; to provide regional benchmark data for assessing company, plant or new technology data; and to provide a firm foundation for subsequent LCA tasks such as life cycle impact assessment.

A number of efforts are underway that address the methodology issues including research at Athena and the National Institute of Standards and Technology (NIST). NIST supports the Building for Environmental and Economic Sustainability (BEES) software, a tool that helps in the selection of building materials which take into account environmental and economic considerations. The ISO (International Organization for Standardization) has developed Standard 14040 that also provides guidance for LCA.

The literature on LCA, in particular the ISO standards, recognize four steps to be performed when doing a life-cycle assessment:

- *Scoping Phase*. In this phase, the purpose and goals of performing the LCA are identified and product phases to be considered are defined. Understanding the decisions that are to be informed by the LCA will often help define the precision and detail of information that needs to be collected in subsequent phases.
- *Inventory Analysis*. In this phase, information is collected on the materials, energy, water and labor used in each phase of the product's life.
- *Impact Analysis*. In this phase, information collected in the previous phase is combined and analyzed and aggregated into a series of environmental indicators such as embodied energy, greenhouse gas emissions, and water pollution.
- *Interpretations and Conclusions*. In this phase, the indicators developed in the previous are weighed and interpreted and recommendations are reached.

Current Ratings Systems for Materials

At present, CHPS, LEED™ and other high performance building rating systems are unable to use LCA and instead rely on setting criteria for individual product performance features. Credits are offered by either CHPS or LEED™ for low-emitting materials (part of the indoor environmental quality group of credits) as well as material credits for the storage and collection of recyclables, site waste management, building reuse, resource reuse, recycled content, rapidly renewable materials, certified wood, and locally manufactured products.

While imperfect, the system of individual credits serves to focus attention on a few of the important issues related to material efficiency and impact on human performance. While credits are not offered for some important features such as durability, the credits that are offered are a good first start.

CHPS, with its 2006 rating criteria, takes another step toward integrating the material attributes with the Environmentally Preferable Products (EPP) approach. The Combined Attributes Alternative is intended to offer more flexibility and give designers more options in specifying materials. It also allows EPP materials to be considered cumulative.

Product Suppliers

Some building material suppliers are making significant efforts to incorporate sustainable goals in their processes and operations and in their products. Companies serious about this commitment will provide detailed information about their product's performance. When investigating products, it is always recommended that the design team consult with the manufacturer's technical rather than sales staff.

Material Safety Data Sheets

Material Safety Data Sheets (MSDS), which must be prepared by product manufacturers, can provide some information and in particular can help "red flag" problem ingredients that may be toxic or emit significant VOCs. For example, the Health Hazard Rating (0 is low, 5 is high) found on an MSDS provides some indication of whether a product is appropriate for indoor school environments. MSDSs are often incomplete, however. Generally they do not include information about environmental attributes other than toxicity of regulated ingredients. MSDSs are primarily useful for eliminating building materials that may cause serious environmental problems.

Product Certification

Product certification programs can help identify environmentally preferable products. Many product suppliers have increased the credibility of their environmental claims by obtaining industry or independent certifications of their products' environmental attributes. Independent programs provide the most objective documentation, and include:

- EnergySTAR. A program of the federal government, manufacturers are allowed to use the Energy STAR label only if the product meets certain energy efficiency levels set by either the U.S. EPA or U.S. Department of Energy. Tel: (888) STAR-YES. Web site: www.energystar.gov/.
- *Green Seal.* Green Seal standards are based on environmental protection. They focus on reduced air and water pollution, reduced consumption of energy and other resources, protection of wildlife and habitats, reduced packaging, quality, and performance. Tel: (202) 588-8400. Web site: www.greenseal.org/.
- *Scientific Certification Systems.* Scientific Certification Systems is a nonprofit organization that assesses products based on a life-cycle or “cradle to grave” evaluation. Their Environmental Report Card gives detailed information about the environmental burdens associated with the production, use and disposal of the product. Tel: 800-ECO-FACTS. Web site: www.scs1.com/.
- *Forest Stewardship Council.* A product bearing the Forest Stewardship Council (FSC) trademark is made with wood certified to have come from a forest that is well managed according to strict environmental, social and economic standards. Look for FSC-certification as opposed to self-certification of forest management practices. FSC is an international nonprofit association working in partnership with industry and other groups to improve forest management worldwide. Tel: (802) 244-6257. Web site: www.fscus.org/. Also see Smart Wood, a U.S.-based program of the Rainforest Alliance, accredited by the FSC for the certification of forest management. Tel: (802) 434-5491. Web site: www.smartwood.org/.

Environmentally Preferable Product Directories

There are several good directories that identify environmentally preferable product options. Some focus on a product category (for example, recycled content products), while others cross categories.

- The CHPS Low-Emitting Materials Products List has products that have been chamber tested and certified according to the Department of Health Services Standard Practice and are acceptable for use in a typical classroom. See www.chps.net.
- Architects/Designers/Planners for Social Responsibility (ADPSR), Northern California chapter. Architectural Resource Guide. Organized by CSI, this guide lists sustainable, less polluting, local, and recycled building products as well as related information and a recommended reading list. Available as hard copy or CD. Web site: www.adpsr-norcal.org/.
- California Multiple Awards Schedule (CMAS). Schools can now directly purchase products listed on CMAS, part of the state’s procurement system. This allows direct purchases without going through the bidding process, saving time and offering economy of scale. Products are less expensive than if purchased through other means, but schools are encouraged to negotiate prices further. Schools may issue a purchase order directly to the supplier, while sending a copy of it to this address: CMAS, 1500 5th St. Suite 116, Sacramento, CA 95814. For assistance call the CMAS information line at (916) 324-8045. Web site: www.pd.dgs.ca.gov/(select CMAS).

- *Guide to Resource Efficient Building Elements (GREBE).* 1998. Edited by T. Mumma. Contact: Center for Resourceful Building Technology, Box 100, Missoula, MT 59806. Tel: (406) 549-7678. Web site: www.crbt.org/introduction.html. Resource book on resource-efficient building systems. Updated regularly.
- *GreenSpec: The Environmental Building News Product Directory and Guidelines Specifications.* 1999. Published by E Build, Inc., Brattleboro, VT. Tel: (802) 257-7300. Web site: www.buildinggreen.com/. *GreenSpec* is organized in standard CSI divisions.
- California Integrated Waste Management Board's Web site provides a "Recycled-Content Product Directory" at www.ciwmb.ca.gov/RCP/. The database is searchable by product type and provides links to manufacturers. The CIWMB also sponsors many Buy Recycled programs. Information on these programs can be found at www.ciwmb.ca.gov/BuyRecycled/.
- Sustainable Products Purchasers Coalition (SPPC). Web site: www.sppcoalition.org/.
- The Ecoproducts Directory. Web site: www.ecoproducts.com/index.htm.
- U.S. EPA's *Comprehensive Procurement Guidelines (CPG).* The CPG program promotes the use of products that contain recycled materials. Web site: www.epa.gov/epaoswer/non-hw/procure/index.htm. The products page, www.epa.gov/epaoswer/non-hw/procure/products.htm, provides an online list of construction, landscaping and other categories of products. The Web site briefly describes each of the listed products. You also can view EPA's recommended recycled content ranges and a list of manufacturers, vendors and suppliers for each item.

Environmentally Preferable Product Evaluation Tools

The following resources provide methodologies or suggestions for evaluating products:

- BEES (Building for Environmental and Economic Sustainability) software helps analyze the environmental and economic performance of some building products. The software is downloadable at www.bfrl.nist.gov/oae/software/bees.html.
- *Environmental Resource Guide*. 1996. Edited by Joseph A. Demkin. Offers a methodology for preparing life-cycle assessments of building materials, materials comparisons, and case study information about how high performance buildings have worked in practice. The ERG was funded by EPA and. published by AIA in 1992 as an AIA publication, and was subsequently republished by John Wiley & Sons.
- *Environmental Building News* (EBN). Brattleboro, VT. Tel: (802) 257-7300. Web site: www.buildinggreen.com/. The leading green building professional journal. Offers excellent articles, product reviews, book reviews and resources.

Material Efficiency

Material efficient interior building products is an important CHPS high performance goal. There are a number of attributes of material efficiency including recycled content, product recyclability and reusability, embodied energy, durability, and the impact of mining and manufacturing. Structural materials that also provide the finish surface, such as concrete masonry units or brick, can also be efficient products. Understanding material efficiency is complex and involves making professional EPP decisions that weigh one attribute against another. For example, one type of flooring may be made from rapidly renewable resources, but is not very durable. Another flooring type is highly durable, but cannot be recycled. Weighing these pros and cons of products can make it difficult to determine which products are most environmentally preferable.

California state law recognizes environmentally preferable products. Public Resources Code (PRC) 42635 (enacted by Senate Bill 373 in the 2001-2002 session) defines an "environmentally preferable product" as one that promotes healthy indoor environments for children and uses environmentally preferable materials and systems (e.g., uses less energy during manufacture and use; contains more recycled content; results in less potential waste; poses less harm to indoor air quality; consumes less water; can be recycled or reused) relative to similar products with similar functions.

What Makes a Product Material Efficient?

In a high performance school, materials are selected for several characteristics beyond the traditional issues of performance, price, availability,

Designing for Disassembly and Deconstruction
The Chartwell School, Seaside, California

The Chartwell school in Seaside, California (Monterey county) is designed so that it can be efficiently disassembled at the end of its life. The design process began with a methodical analysis of likely and typical construction materials and components to assess the ease of recovering materials and the relative value of the materials after recovery. This analysis was used to guide material selection. Wood was selected for the structural framing, since it is widely used in California and has a high economic value.

Since it is difficult to salvage materials from typical wood construction, the Chartwell School uses connectors that enable easy disassembly, but still meet seismic and other structural design requirements. Similarly, the wood siding is fastened with clips that are screwed into the backing for ease of disassembly.

Another strategy was to separate building services (plumbing, electrical, etc.) from the wood framing to reduce holes in the framing and increase the wood's value as a salvaged material and to enable easier disassembly. Not only does the wood have more value when it is salvaged, but there is better access to the buildings services which typically need to be replaced or modernized every 15 years or so.

Windows are detailed for disassembly so that they can be easily replaced without damaging adjacent finishes or weather tightness. When the windows need to be replaced, the job can be accomplished over the summer break with minimal disruption to the operation of the school.

The Chartwell School received an EPA grant to research these and other disassembly strategies.

Photos courtesy EHDD Architecture and © Gerald Ratto and aesthetics. Designers should look for environmentally preferable materials that are:

- *Durable.* Offers (proven) longer service life compared to other options in a given product category.
- *Healthy.* Does not introduce toxics or polluting emissions into the building.
- *Made with recycled content.* Includes materials that have been recovered or otherwise diverted from the solid waste stream, either during the manufacturing process (pre-consumer), or after consumer use (post-consumer).
- *Salvaged or reused.* Includes materials that are refurbished and used for a similar purpose; not processed or remanufactured for another use.
- *Recyclable.* Can be collected, separated, or otherwise recovered from the solid waste stream for reuse, or in the manufacture or assembly of another package or product. Movable, refinishable, and reusable.
- *Responsibly produced.* Extracted, harvested or manufactured in an environmentally friendly manner (includes certified wood products).
- *Environmentally benign.* Includes or introduces no, or low amounts of, known pollutants to the natural ecosystem (includes non ozone-depleting or toxic materials).
- *Low in embodied energy.* Does not require significant amounts of energy to produce or transport the material (includes locally manufactured or extracted options in a given product category). Manufactured close to the project site to reduce transportation energy use.
- *Produced from rapidly renewable material.* Includes material that is grown or cultivated and can be replaced in a relatively short amount of time (defined by the type of material).
- *Made with industrial byproducts*. Includes material that is created as a result of an industrial process (flyash, for example).
- *Marketed in an environmentally responsible manner.* Includes products packaged in minimal, reusable, recycled content and recyclable containers.Purchased from a manufacturing source that embraces sustainability as corporate policy, which is reflected in the operation of the production plant.

Take Back Programs

It is difficult for designers or contractors to assure what will happen to materials at the end of the service life, but one option is to specify products from manufacturers that have take back programs. With take-back programs, a manufacturer agrees to recover and recycle a product at the end of its life.

Preference should be given to manufacturers that have such programs. Design teams may include requirements in the construction specifications. The following are examples of take back programs.

Tandus offers a reclamation and recycling program for vinyl-backed carpet at their Tandus Center for Environmental Innovation in Dalton, Georgia

Armstrong offers a recycling program for acoustical ceiling tiles. According to a Newsbrief in the October 2000 issue of Environmental Building News, "The company now pays the freight (within the lower 48) on trailer loads—30,000 ft² or more—of approved tiles, has streamlined the process of recycling, and gives great guidance on job-site practices for efficient removal and "packaging" of the tiles for transport.

Costs of removal for recycling have proven to be very competitive with disposal costs.

Reduce, Reuse, Recycle, Buy Recycled

Interior finishes are important from a resource conservation perspective because they are used in large amounts and because they wear, requiring periodic maintenance and/or replacement. Material efficiency for building products should be approached in high performance school design according to the hierarchy of “Reduce, Reuse, Recycle.”

Reduce. Waste prevention is the highest priority within the material efficient hierarchy and encompasses several components, including:

- *Dimensional Planning*. Techniques like dimensional planning reduce the amount of waste generated at the construction site. This form of waste prevention includes designing a building using: standard dimensions, a minimal structural footprint, and modular or preconstructed panels and elements. Standard dimensions take into account the standard sizes of major building materials, such as wallboard and carpet, when designing the size of a space. For example, wallboard is generally manufactured in 4 ft by 8 ft sheets, and a standard carpet roll measures 12 ft wide. One potential standard dimension for a space would be 8 ft by 12 ft, because that would reduce the number of cut-offs and scraps produced when installing these major building materials. Including pre-constructed panels and elements into plans is also known as designing for flexibility and adaptability, which prevents waste when remodeling spaces. For more details on dimensional planning, See 8.3 of the CIWMB publication, “Designing with Vision…A Technical Manual for Material Choices in Sustainable Construction” (July 2000).
- *Design for Disassembly.* This concept factors in the possibility for a product and its parts to be reused, remanufactured, or recycled at the end of their “useful life,” reducing the amount of demolition waste generated. Additionally, these materials, which are typically considered a “waste,” can be another building’s raw material/resource.
- *Avoiding Unneeded Materials*. Material reduction can also be achieved by avoiding unneeded materials as a means to conserve raw resources. An example of this concept is the elimination of finish materials such as ceilings, or staining and sealing and polishing concrete instead of applying a second layer of resilient flooring over concrete slab. It is also important to select products that contain minimal packaging.
- *Durability*. Specifying products with high durability (which includes low maintenance requirements) can reduce waste, since building materials that have been discarded after a short service life account for much of the content in landfills.

Reuse is defined as using a material over again in its current form without breaking it down into a raw material. Designs can promote the reuse of materials by specifying salvaged and refurbished materials and structures. Commonly salvaged materials include lumber, pipes, steel, fencing, wood flooring, doors, windows, stone flooring and wall panels, appliances, lighting fixtures, and decorative accessories. Existing buildings and structures can be reused during renovations and redevelopments.

Recycle and Buy Recycled. Since it can be quantified, recycled content is one of the most common indicators of material efficiency. Recycled content products create markets for the tons of materials that people recycle. However, it is important to understand the distinction between recycled content products and those that are recyclable. Preferred products are those that both contain recycled content and are also recyclable at the end of their service life. However, when choosing between specifying a product that contains recycled content and one that could be recycled, the recycled content product should always take precedence. While recyclability of a product is important, it does not reduce the consumption of raw materials, nor does it promote completion of the cycle for existing materials that have already been diverted from the waste stream. The designer, in collaboration with the client, should set recycled content goals for all building materials. Guidance on post-consumer recycled content is provide by the State Agency Buy Recycled Campaign (SABRC). See more information below

The term “recycled content” can refer to two types of recycled materials: post-consumer and secondary (also known as post-industrial). Post-consumer recycled content is “a finished material which would have been disposed of as a solid waste, having completed its life-cycle as a consumer item.”[5] Secondary, or post-industrial, recycled content is defined as “fragments of finished products or finished products of a manufacturing process, which has converted a resource into a commodity of real economic value, but does not include excess virgin resources of the manufacturing process.”[6] The California SABRC program only recognizes post consumer recycled content.

The CHPS Criteria (Best Practices Manual Volume III) offers credits for the use of products with recycled content. Credits are offered through either a prescriptive or a performance approach. Under the prescriptive approach, points are offered for the use of major materials. The Criteria identifies recycled content targets for major material categories such as insulation, carpet, and flooring. The targets were adapted from the EPA Comprehensive Procurement Guidelines 2000 Buy Recycled Series. A “major” material is defined as those covering more than 50% of a building’s surface or serving a structural function throughout the majority of the building. While this option may be the easiest to follow, the finite list of materials from which to select can be limiting. Under the performance approach, points are offered using the weighted average of postconsumer recycled-content value. This approach is based on the cost of recycled content products.

The CHPS Criteria has a more performance based option called the *Combined Attributes Alternative*. This option considers not just recycled content but other material efficiency properties, including recycled content, rapidly renewable materials, organically grown materials, certified wood, and the use of salvaged materials. With this option, points are earned for specifying a minimum amount of qualifying materials (in terms of project value), that meets one or more of the material efficiency properties.

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5 California Integrated Waste Management Board.

6 Ibid.

State Agency Buy Recycled Campaign (SABRC)

> ***SB 1106***
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> *The SABRC program was amended in 2005 through Senate Bill 1106. The emphasis of the program was shifted to post consumer recycled content. Each state agency is required to document that at least 50% of reportable purchases meet the standards for post consumer recycled content.*

The State Agency Buy Recycled Campaign is a good starting point for setting recycled content goals. The State Agency Buy Recycled Campaign is a joint effort between the Department of General Services (DGS) and the California Integrated Waste Management Board (CIWMB) to implement state law requiring California agencies to purchase products with recycled content.

While the SABRC is not directly applicable to California schools, significant effort went into developing the program, and as such, it is a useful tool for school designers to avoid having to reinvent the wheel. For further information, refer to the CIWMB Web site: www.ciwmb.ca.gov/BuyRecycled/StateAgency/.

The SABRC identifies product categories of recycled content materials, including include paper products, printing and writing papers, compost, mulch, glass, oil, plastic, paint, tires, tire-derived products, antifreeze, and metal.. State agencies are required to report on the procurement and levels of recycled content in each category to keep a record of each item's recycled content certification. While this law does not apply to California's schools, it can provide a model for recycled content goals.

Table 6—Recycled Content Categories Applicable to Construction Projects

Source: SB 1106.

Product Category	Minimum Post-Consumer Recycled Content Requirement
Paper products	30%
Printing and Writing Paper	30%
Recycled Compost, Cocompost, and Mulch	80%
Glass products (windows, fiberglass insulation, tile)	10%
Plastic products (plastic lumber, carpet, entry mats, signage, and other building products)	10%
Paint	50%
Tire-derived products	50%
Recycled metal products	10%

Indoor Air Quality

Indoor air quality is one of the key goals of a high performance school and it can be significantly affected by the selection of interior surfaces and finishes. Since most of the occupants in schools are children or adolescents with still-developing respiratory systems, the importance of IAQ is heightened. The metabolic rates of children are significantly greater than adults causing them to breathe more air and as result absorb and retain more toxins. In addition children's immune systems are less effective.

The U.S. Environmental Protection Agency (EPA) documents that Americans spend more than 90% of their lives indoors, and that pollutant concentration inside buildings is two to five times greater than outdoors. News reports and scientific inquiries have brought increased attention to the symptoms and causes of poor IAQ. Symptoms range from mild discomfort (sick building syndrome) to more severe illness and permanent injury (building related illnesses and multiple chemical sensitivity). Health effects include headaches, fatigue, memory problems, eye irritation, and coughs.

There are four principles in designing good IAQ:

- *Source control*: Reduce and/or eliminate the source of contaminants in buildings.
- *Ventilation control*: Provide adequate ventilation to dissipate the contaminants in buildings.
- *Building commissioning*: Building commissioning is a process used during the design, construction, and post-occupancy phases of a project to ensure that the project is built and performed as designed, and that the systems and equipment function as intended.
- *Building maintenance*: Buildings require regular scheduled maintenance and cleaning to ensure that they perform throughout their life as they did when first constructed. Using environmentally friendly cleaning agents will reduce the opportunity for air contamination during the building's life.

The emphasis of this chapter is source control. Ventilation control is addressed in the HVAC chapter; commissioning is addressed in CHPS Best Practices Manual Volume V: Commissioning and building maintenance is addressed in CHPS Best Practices Manual Volume IV: Maintenance and Operations.

According to a 2005 report to the California Legislature[7], "Source control is the prevention or reduction of emissions at the source. It is the most effective and reliable approach to reducing indoor pollution because it keeps pollutants from entering and spreading throughout a building." The report also suggests that one action that should be taken to reduce indoor pollution is to establish emission limits and require emissions testing of building materials and some consumer products. Designers should seek to reduce or eliminate potential sources of indoor air pollution by selecting the lowest odor, least toxic, lowest emitting, most moisture-resistant, and most durable materials that can be safely installed and maintained. The CHPS Low-Emitting Materials Products List is a good place to start. See www.chps.net.

Indoor pollutants include volatile organic compounds (VOCs), microbial volatile organic compounds (MVOCs), particulates, inorganic compounds (such as CO_2, CO, and ozone), and semi-volatile organic compounds (SVOCs) such as pesticides and fire retardants. Pollutant sources include the outside air, construction materials, furnishings, the building envelope, equipment, maintenance, and the occupants themselves. VOCs are of special concern because they can damage the natural environment during building material production and disposal, create hazards for installers and manufacturers, as well as cause health problems for building occupants.

VOCs are some of the most commonly discussed chemical emissions that affect IAQ. VOCs can occur in the air at normal environmental conditions and are emitted from interior materials such as paints, adhesives, sealants, sealers, carpets, resilient flooring, furniture, and ceiling panels. Materials and

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[7] California Air Resources Board. 2005. "Report to the California Legislature. Indoor Air Pollution in California." www.arb.ca.gov/research/indoor/ab1173/finalreport.htm

products emit ("off-gas") VOCs during and after installation, which can cause health problems for construction workers and building occupants.

Concentrations of a number of VOCs and formaldehyde are currently found in indoor air. In the indoor environment, formaldehyde can cause several health problems for occupants, including skin and eye irritation, upper respiratory system irritation, and symptoms of sick building syndrome. Formaldehyde is a known carcinogen so human exposure should be minimized, and indoor air concentrations should be kept as low as is reasonable to achieve.

In many cases, the best products, with the lowest VOC emissions, are made from water-based constituents. This said, it is also important to select materials that are easy to clean and maintain without the use of odorous, irritating, or toxic cleaning supplies.

Designers should also be aware that a product can be labeled as "low-VOC" or even zero-VOC and still emit VOCs that are odorous, toxic, or otherwise undesirable. Even small quantities of some chemicals can create problems indoors. The EPA VOC labeling requirements do not provide a straightforward way to compare VOC content since labels are required to only list chemicals classified as reactive, with the potential to create smog. Unreported non-reactive VOCs may react with oxidants to form odorous, irritating, or toxic chemicals in the indoor environment. While some VOC emissions may not cause an *air quality* problem for occupants, they may still be hazardous to installers and manufacturers.

VOC emissions are generally highest immediately after a new product is installed or a finish is applied, but emissions may continue for days, weeks, or months, and actual emission rates will be impacted by the ventilation conditions, indoor temperature, and humidity conditions. Even with low-VOC emitting materials, it is important to provide temporary ventilation during and after installation. However, the length of the required venting period depends on the amount of surface covered, as well as the volatility and toxicity of the finish. In addition, it is recommended that, prior to substantial completion, each school be flushed out with 100% outside air for a period long enough to eliminate the effects of construction and initial material emissions. The CHPS Criteria recommends a minimum of 14,000 ft^3 of outside air ventilation for each ft^2 of space. If the fans deliver, say, 1.5 cfm/ft^2, the time required for outside air ventilation would be 14,000/1.5 or 9,333 minutes which is equal to about 155 hours. If the fans were operated continuously, the flushing period could be completed in about a week.

Fleecy and absorbent surfaces such as carpets, wall coverings, window coverings, and ceiling tiles should be protected from exposure to the air during periods of high VOC emissions. Even better, construction work should be sequenced so that soft and/or porous materials are installed after VOC-emitting materials, finishes, or sealants have had a chance to "off-gas." Otherwise, emitted chemicals will be absorbed by porous surfaces, increasing the time required to clear the chemicals from the building.

Understanding chemical emissions adds to the complexity of reviewing contractor-initiated material and product substitution requests. Construction specifications should require that product ingredients and VOC emissions be reported, as well as information about any adhesives or solvents that are required during installation or maintenance. However, substitutions should be welcomed when contractors and subcontractors can provide information about new and improved product alternatives.

CHPS Low Emitting Products List

> ***CHPS Section 01350***
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> *CHPS provides a model Special Environmental Requirements Specification (Section 01350), which includes testing procedures for chemical emissions from materials. The chemical testing procedures have been superseded by the California Department of Health Services Standard Practice. The CHPS 01350 should still be used, however, as a model for specifying other environmental properties.*

To make specifying low-emitting materials easier, CHPS has developed a Web-based Compliant Materials Table (www.chps.net). Initiated by the Los Angeles Unified School District (LAUSD), this table lists products which have been tested using Section 01350/DHS Standard Practice and have been determined to have chemical emissions under the specified limits for a typical classroom. Other products may also have chemical concentrations under the specified limits but should be tested by an independent lab for compliance with Section 01350/DHS Standard Practice. The DHS Standard Practice is based on chamber testing of materials and analysis of concentrations of chemical compounds that have been identified as being harmful to humans and for which a reference exposure level (REL) has been determined.

Carpeting that has been approved under the Carpet and Rug Institute's (CRI) 'Green Label Plus' program is considered equivalent to meeting the DHS Standard Practice emission criteria and is equivalent to being listed in the CHPS Low Emitting Products List.

CHPS recommends that all interior materials that potentially emit VOCs (including adhesives, sealants, sealers, coatings, carpets, resilient flooring, ceiling materials, wall materials and coverings, insulation, architectural wood products, composite wood products, and furniture) meet the emissions criteria.

However, chemical testing alone cannot fully evaluate the potential for *odor* from VOC emissions. Relying on experience, and even ad hoc experiments such as carefully controlled clean glass jar "sniff" tests to determine the odor acceptability of a product, may also be necessary if there is a concern regarding the VOC emissions.

Managing IAQ During Construction

In addition to product selection, the designer should also look for other ways to mitigate potential IAQ problems during construction. Dust and mold are two common construction by-products that can compromise IAQ. Construction activities such as wood sanding and drywall finishing generate large amounts of dust and debris, which can become an IAQ problem. Thoughtful work practices and thorough cleaning before occupancy will mitigate this potential problem. (See Guideline GC3: Indoor Air Quality During Construction for more information.)

Microbial Growth

Mold growth requires moisture, warmth, and a material (food) on which to grow. Excess humidity, caused by moisture intrusion or condensation, will promote the growth of mold and other biological contaminants within building materials that impact human health. Mold growth is commonly found on ceiling tiles, gypsum board, carpet, and other finishes. Special care should be taken during the delivery, storage, and handling of these materials to prevent moisture contamination on the construction site. If any moisture damage occurs, the materials must be removed and replaced as soon as reasonably possible. (See the Overview in the Building Enclosure and Insulation chapter of this manual for more information.)

Summary

In summary, objectives and strategies used to protect IAQ include selecting interior surfaces that are:

- Made with water-based coatings and adhesives.
- Nontoxic and non-polluting during installation and use (low-VOC emitting).
- Resistant to moisture or inhibit the growth of biological contaminants.
- Easy to clean with non-polluting maintenance products.
- Comply with the California Section 01350 Specification/DHS Standard Practice as low emitting.

CHPS Section 01350 Specification

To assist owners, designers, and contractors, CHPS has made available a model specification at www.chps.net (To download, click on "Publications and Resources"). This specification section, Special Environmental Requirements (Section 01350) has been used on several California state projects and is intended to be included in Division 1 of the Construction Document Specifications to lay out special environmental requirements related to IAQ, durability, recycled content and recyclability, wood from sustainably harvested sources, and product packaging. The intent of providing this sample specification is to give designers a base environmental specification from which to work. It is expected that each designer will customize this specification section for their specific project and coordinate with the other specification sections and the other parts of their project manual. Specification Section 01350 is intended to be placed into Division 1 of the project manual, so that it will govern all the other divisions (as is the case with submittal requirements and substitution requests, etc.).

Specification Section 01350 sets out environmental goals (specifically needed by the contractor if they are considering substitution requests), product emission testing methods, test protocols, sample procedures and reporting requirements. The indoor air quality parts of the CHPS Section 01350 references the DHS "Standard Practice for the Testing of Volatile Organic Emissions from Various Sources Using Small-Scale Environmental Chambers." This standard is maintained by DHS on behalf of the "Green Action Team." It establishes Chronic Reference Exposure Levels (CRELs)[8] for hazardous

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[8] According to California's Office of Environmental Health Hazard Assessment website, "Chronic RELs are designed to protect the individuals who live or work in the vicinity of emissions of these substances. A chronic REL is an airborne level that would pose no

airborne substances, based on the California Environmental Protection Agency Office of Environmental Health Hazard Assessment (OEHHA).

The Vinyl Debate

Few building materials have generated more debate over material efficiency and the environment than those containing polyvinyl chloride (PVC). PVC is a highly versatile, stable compound used in numerous building products, including pipes, siding, wire and cable coatings, resilient flooring, carpets, wall coverings, and furniture. In fact, construction materials account for the largest percentage of PVC use.

Commonly referred to as "vinyl," PVC products are highly durable and require low maintenance, which have made them a popular choice in schools. For instance, vinyl composition tile (VCT) is the most commonly used flooring material for non-carpeted areas in schools due to its long life, low maintenance requirement, and moisture-resistant properties. First cost for PVC products is low.

Much of the debate focuses on environmental concerns with the production of PVC. PVC is derived from petroleum, which is a non-renewable resource and can be highly polluting during extraction, refinement, and manufacturing.[9] It should also be noted, however, that because many PVC products are manufactured in the U.S., they can have lower embodied energy than other materials that are manufactured overseas.[10]

Vinyl chloride (VC), a colorless, flammable gas that serves as the building blocks for PVC, is a known human carcinogen. Studies of PVC factory workers have shown that long-term exposure (365 days or more) to high levels of VC can cause liver cancer, nerve damage, and immune system problems.[11] In response to these findings, the Occupational Safety and Health Administration in 1974 reduced the occupational exposure standard for VC gas in the air from 500 parts per million (ppm) to 1 ppm.[12] These tighter restrictions, in combination with a closed-loop polymerization process adopted by the industry in the U.S., have reduced the high-risk exposure for workers.[13] While most of the studies on VC exposure have focused on long-term exposure in factory workers, breathing high levels of VC gas for short periods

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significant health risk to individuals indefinitely exposed to that level. RELs are based solely on health considerations, and are developed from the best available data in the scientific literature." http://www.oehha.org/air/chronic_rels/Jan2001ChREL.html.

9 U.S. Environmental Protection Agency, Environmentally Preferable Purchasing Program. "Leading by Example: Two Case Studies Documenting how the Environmental Protection Agency Incorporated Environmental Features into New Buildings." December 1997. http://www.epa.gov/opptintr/epp/pubs/grnbldg.pdf.

10 Ibid.

11 U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. "Vinyl Chloride Fact Sheet." September 1997, CAS #75-01-04. http://www.atsdr.cdc.gov/tfacts20.html.

12 Centers for Disease Control, Morbidity and Mortality Weekly Report. "Epidemiologic Notes and Reports: Angiosarcoma of the Liver Among Polyvinyl Chloride Workers—Kentucky." 1974, update 1997. http://www.cdc.gov/epo/mmwr/preview/mmwrhtml/00046136.htm.

13 Ibid.

of time can cause dizziness and unconsciousness, while breathing extremely high levels in a short period of time can cause death.[14]

Concerns also exist surrounding the disposal of PVC products. PVC products are not biodegradable, and since recycling options for PVC are currently limited, most products are not recycled. PVC can also cause air quality problems due to dioxins emitted during combustion in improper waste incineration[15] and building fires.

While some environmental organizations have serious concerns about its environmental impact, PVC also has some beneficial properties that have made it a widely used material in schools traditionally. CHPS has chosen to remain neutral on the use of vinyl products in schools. The guidelines in this chapter discuss the pros and cons of using PVC products for various building surfaces, but neither recommends nor discourages their use.

Other Considerations in Material Selection

Embodied energy is the energy consumed during the entire life cycle of a product, including resource extraction, manufacturing, packaging, transportation, installation, use, maintenance, and when appropriate, even disposal. Energy is but one of the resources used to manufacture products, but is one that is more easily measured and accounted for. Products with low embodied energy are environmentally preferable. Consideration of transportation energy gives preference to products that are manufactured locally.

Products produced in a way that protects the eco-system are also environmentally preferable. One example is certified wood products, which are produced from trees grown and harvested from Forest Stewardship Council (FSC)-certified, sustainably managed forests. FSC is the accrediting agency for organizations such as Smart Wood and Scientific Certification Systems (SCS), which in turn oversee forestry practices and certify their sustainability.

Acoustical benefits can also factor into a product selection. For instance, consider carpet and other acoustical materials for areas when noise control is a concern. Also, be aware of how the acoustical properties of certain products can be impacted by other interior materials. For example, most ceiling tiles will lose their acoustical benefits if painted.

A product's color can also influence the decision-making process. While color is always a factor for visual appeal, it can also have a functional impact. Consider light-colored finishes, including paints and coatings to enhance daylighting.

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[14] U.S Department of Health and Human Services. "Vinyl Chloride Fact Sheet."

[15] U.S. Environmental Protection Agency, Environmentally Preferable Purchasing Program. "Leading by Example: Two Case Studies Documenting how the Environmental Protection Agency Incorporated Environmental Features into New Buildings." December 1997.

Because of their high visibility, interior surfaces and furnishings provide an excellent opportunity to highlight the high performance approach. Environmentally preferable choices teach the importance of caring for the health of occupants, as well as the health of the natural environment.

In summary, when selecting materials, including interior building materials, for a high performance school, designers should look for cost-effective, durable, and material-efficient products that protect indoor air quality and provide the desired acoustical performance and aesthetic qualities. In addition, high performance school designers should attempt to minimize the impact on the natural environment, or are ecosystem protective, by selecting locally produced materials, as well as those produced in an environmentally benign manner, preferably using suppliers and manufacturers that practice “sustainable” or environmentally conscious management principles. Look for manufacturers that have a corporate policy incorporating sustainability. The selection process should consider installation and maintenance requirements as well as how the material or furnishing performs during its service life. Table 7 summarizes the goals and objectives described above and shows the relationship between them and the guidelines that follow later in this chapter.

Table 7—Interior Surfaces Goals and Relationship to Guidelines

Goals		IS1: Carpeting	IS2: Resilient Flooring	IS3: Ceramic Tile/Terrazzo	IS4: Concrete Flooring	IS5: Wood Flooring	IS6: Bamboo Flooring	IS7: Gypsum Board	IS8: Acoustical Wall Panels and Ceilings	IS9: Paints and Coatings	IS10: Casework and Trim	IS11: Interior Doors	IS12: Toilet Partitions	IS13: Acoustics–Reverberation Time
Protect Indoor Environmental Quality	Use low-VOC emitting coatings and adhesives.	●	●	●	●	●	●	●	●	●	●	●	●	
	Use low-VOC emitting materials.	●	●	●	●	●	●	●	●	●	●	●	●	●
	Use moisture-resistant materials.			●	●									
	Use low-VOC emitting maintenance products	●	●	●	●	●	●				●		●	
	Use sound-absorbing materials	●							●					●
Material Efficiency	Made from sustainable resources		●			●	●				●	●		●
	Made with recycled content	●	●	●	●			●	●	●			●	●
	Recyclable	●	●	●	●	●		●	●		●			●
	Movable, refinishable, and reusable					●					●	●	●	●
Other Environmental Considerations	Locally available	●	●		●	●		●	●	●	●	●		●
	Durable	●	●	●	●	●	●	●						●
	Low in embodied energy					●								
	Eco-system protective		●			●					●	●		

Selection Guidelines

This section of the Overview provides some guidelines for the selection of products for major finishes and surfaces within a school.

Flooring

Flooring should be durable to withstand heavy use without requiring frequent replacement, be easy to maintain, contain recycled content, be recyclable, contribute to a comfortable indoor environment, and not adversely affect human health. Based on life-cycle costs, highly durable materials are justified, especially for high-use areas.

Floor choices include resilient flooring, concrete, tile, wood, and carpet. When selecting these surfaces, review the cleaning products that might be used throughout the life of the flooring.

Carpet systems require maintenance, as do other flooring materials, and their need for more frequent replacement makes them materials- and energy-intensive over their lifetime. If selecting a carpet, select those carpets with a longer warranty to increase the service life and reduce the need for replacement. Consider using carpet tiles where worn or damaged sections can be replaced without the need to replace the entire carpeted area. However, carpeting offers acoustical and comfort benefits that are generally not available with other flooring choices. Smaller children especially will spend more time sitting or laying on the floor. For these reasons, carpeting is often used in classrooms and administrative areas.

Hard surfaces are often selected for use in high traffic areas not requiring the acoustical benefits of carpet. Hard surfaces are also used in specialty areas such as art rooms or labs.

Walk-off mats are recommended for all major school entrances to help minimize cross-contamination by pollutants brought into the building on occupants' shoes. Using walk-off mats to trap dirt, dust, grit, and moisture can also reduce maintenance costs, improve safety, and protect the life and appearance of the flooring. To be effective, walk-off mats should allow room for at least six footsteps. This can be from 12 to 20 feet depending on the age and size of the students, with most adults in the 18 to 20 foot range. Many California classrooms have direct access to the outdoors making the use of walk-off mats impractical. Table 8 summarizes advantages and disadvantages of the flooring choices addressed in these guidelines.

Table 8—Environmental Criteria for Floors

Type	Advantages	Disadvantages
Carpet Guideline IS1	Material efficient options available: minimum recycled content guideline of 50%, with at least 10% post-consumer recycled content. (In the CHPS Criteria, Materials Credit 4: Recycled Content gives priority to products with high post-consumer recycled content.) Thermal comfort. Physical comfort (cushion). Provides safety for small children. Noise control. Some recycling options are available. Carpet tiles make partial replacement easier.	May emit some VOCs during and after installation (low VOC options are available). Can harbor dust and other allergy-causing particles. Requires regular maintenance. Requires frequent vacuuming, which stirs up dust. Can absorb VOCs and re-emit (desorb) later. Adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available). Potentially need to allow time to air out carpet (precondition off site) before occupancy. Less durable and stains easier than other flooring options. Significant debris generated when it must be replaced. Can be a source of mold/mildew if placed in contact with moisture.
Resilient Flooring Guideline IS2	First cost can vary from low to high, depending on product, but due to its high durability, this flooring type tends to cost less per year of use than carpet. Easy to clean. High reflectivity can enhance daylighting.	Flooring adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available). Most are not recyclable or biodegradable. Hard surface does not have the acoustic benefits of softer surfaces.
Ceramic Tile / Terrazzo Guideline IS3	Recycled content options available: minimum recycled content guideline of 55-77%.(Scrap glass and feldspar waste from mining are sometimes used.) Easy to clean and stain-resistant (some tile may need to be sealed first). Highly durable. High reflectivity can augment daylighting.	High initial cost but life cycle cost can be low for some applications. High embodied energy. Made from nonrenewable resources. Some ceramic tile is recycled as clean construction waste. When contaminated by bonding and setting agents, recycling is not feasible. Tile installation materials (mortar and grout) are sources of VOCs and toxic materials. (Portland cement-based mortar and grout appear to have less significant environmental impact than latex or solvent-based systems.) Terrazzo poses installation risks, depending upon type. (Cementitious type appears to have less significant environmental impacts than epoxy systems.) Hard finished surface can compromise physical comfort. Adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available).
Concrete Flooring Guideline IS4	Material efficient if manufactured with high fly ash content. Highly durable. Low maintenance and low cost. Resource efficient when structural slab is finished floor.	Sealers and wax products can add to indoor pollution load (but low-toxic/low-VOC options are available).
Wood Flooring Guideline IS5	Renewable resource, if properly managed (FSC-certified). Low embodied energy. Wood flooring is recyclable and the market for recycled wood flooring is expanding. Biodegradable. Factory prefinished products offer air quality benefits (no sanding or finishing performed on site) Easy to clean. "Warm," comfortable surface. Durable and can be refinished to prolong its life. Good aesthetics.	High cost. Adhesives, sealants, and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available). Requires special moisture-prevention care in handling and installation to prevent later IAQ problems. On-site sanding requires special measures.
Bamboo Flooring Guideline IS6	Material efficient. Durable and hard. Easy to clean. "Warm," comfortable surface.	High cost. Adhesives, sealants, and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available).

Walls and Ceilings

Walls and ceilings should be durable, be easy to clean, contain recycled content, and be recyclable, as well as contribute to a healthy and comfortable indoor environment. Classrooms and other rooms require plenty of tackable wall space for teaching aids and displaying student projects. The type and color of surfaces on teaching walls should also be visually comfortable and not detract from teacher presentations. Light colored finishes should be used to enhance daylighting and electric lighting by reflecting the light and providing for better light distribution.

Drywall is potentially recyclable and can be composted. Recycled content gypsum board core is available, but it is important to explicitly specify recycled content to ensure its use. Although they may not advertise it as recycled, many manufacturers already use post-industrial recycled content in their drywall product, and virtually all make the facing paper component from post-consumer recycled content paper. To protect indoor air quality, it is recommended that all drywall products meet the emissions requirements outlined in Specification Section 01350 and DHS' Standard Practice. See the discussion on Special Environmental Requirements (Section 01350) and the DHS' Standard Practice above. It is important that drywall remain free from moisture contamination during construction to prevent mold growth. Damaged materials should be removed and replaced as soon as is reasonably possible.

When using wall coverings, use biodegradable papers that contain recycled paper or fiber content. Vinyl wall coverings are widely used but have raised concerns since they contain polyvinyl chloride (PVC). (For further discussion of vinyl, see the Vinyl Debate section above.) Installation of wall coverings using traditional wallpaper paste is preferable to using self-stick wall coverings, due to the levels of VOC content in the adhesive. Wall coverings should also meet the emissions requirements outlined in Specification Section 01350 and DHS' Standard Practice.

Avoid using ceiling tile and sprayed-on ceiling finishes containing asbestos, formaldehyde, or crystalline silica, as these items are possible cancer and respiratory tract hazards. Table 9 summarizes advantages and disadvantages of the wall and ceiling choices addressed in these guidelines.

Table 9—Environmental Criteria for Walls and Ceilings

Type	Advantages	Disadvantages
Gypsum Board Guideline IS7	Gypsum is highly recyclable if not contaminated (with paint, tape, compound, adhesives or other coatings). Recycled content gypsum is readily available at no cost premium, and the paper facing is typically made with recycled paper. Durable, high impact drywall contains up to 15% post-consumer recycled content. Recycled gypsum is more durable than conventional wallboard. Easy to repair. Low cost.	Dust generated during sanding (can specify “wet sanding” process). Gypsum surfaces are potent “sinks” for odors, which they can later re-release. Requires periodic painting. Paints and primers can add to indoor pollution load (but low-toxic/low-VOC options are available). Low durability compared to concrete block.
Ceramic Tile Guideline IS3	See Table 8, Ceramic Tile/Terrazzo Flooring.	See Table 8, Ceramic Tile/Terrazzo Flooring.
Acoustical Wall Panels and Ceilings Guideline IS8	Recycled content materials readily available: minimum recycled content guidelines for ceiling tile is 79-85%, for suspension system is 25%. Formaldehyde-free products available. Reclamation programs available (though limited). Easy installation. Acoustical ceiling tiles often cost less than wallboard ceilings and are easier and less expensive to repair. Do not require painting or other finish materials to complete the installation. Easy to reuse. Provides for easy relocation of fixtures, if required. Reduce reverberation time within the classroom.	Tile collects dust and adsorbs odors. Tile and plenum requires periodic maintenance. Due to the grid organization, acoustical tile ceilings may not be as adaptable to renovations as a gypsum board ceiling. If the T-bar ceiling space has a return air plenum, as is common, this type of air handling design is difficult to clean. Many materials are used in the space above the T-bar ceiling. Material off-gassing, odors and microorganisms in the plenum area can spread and be distributed to other areas. (Avoid this by installing return air systems using dedicated metal ductwork with access hatches for inspection and cleaning.)

Coatings

Paints and other coatings affect indoor air quality and may produce hazardous waste. Most conventional products off-gas VOCs, formaldehyde and other chemicals that are added to enhance product performance and shelf life. These chemicals, especially in combination, may pose health concerns. Fortunately, high quality, low-toxicity and low-VOC substitutions are now available for all these products. It is recommended that only paints that meet Section 01350/DHS Standard Practice emission criteria be used in classrooms and other high occupancy areas.

Adhesives and Sealants

Many conventional construction adhesives, sealants, caulking, grouts, and mortars used to bond structural components are solvent-based, toxic and may off-gas large amounts of toxic VOCs (including solvents and aromatic hydrocarbons). Avoid using products, which include butyls and urethanes, indoors. Low VOC, low-toxic, water-based formulations are now available for many more applications.

Specify the least toxic/lowest VOC product suitable for the application and require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer’s performance specifications for that product.

Non-solvent adhesives have 99% less hazardous emissions than solvent adhesives, although their emissions may last much longer. When used to adhere dense floor coverings, emissions will be low, but prolonged. Yellow and white glues are recommended. When specifying sealants, consider using only silicone sealants in interior areas. However, some silicone sealants do contain acetic acid, which has an unpleasant odor that may be irritating. Other environmentally preferable alternatives include acrylics and siliconized acrylics. They are typically the safest to handle and have the lowest solvent content. All other sealant types, especially butyl sealants, emit VOCs and other toxic compounds, and emission test data should be requested and reviewed prior to including the product in a specification.

Adhesives and sealants are also covered by should also be low emitting and be in compliance with Section 01350/DHS Standard Practice emissions testing. Many products are tested as an assembly which includes any applicable adhesives. Be sure to check the test results or web listing to see if a specified adhesive has been tested with the flooring or other material.

Applicable Codes

Applicable state and local school district design and materials standards.

California State Ventilation and Indoor Air Quality Code.

State of California, South Coast Air Quality Management District Rule #1168 for adhesives and sealants.

State of California, South Coast Air Quality Management District Rule #1113 for coatings.

American Concrete Institute ACI 530, Building Code Requirements for Masonry Structures. The 1999 Building Code Requirements for Masonry Structures, Specifications for Masonry Structures and Related Commentaries. Will be referenced by the International Building Code (IBC 2000) for the design and construction of masonry structures. This publication is a joint effort of the American Concrete Institute, the American Society of Civil Engineers, and The Masonry Society.

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Bernheim, Anthony, "Saving Resources," Urban Land Institute, pp. 76-81, 94-95, June 2001.

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Building Ecology Research Group/Hal Levin & Associates. 1999. *Indoor Air Bulletin*. Contact: PO Box 8446, Santa Cruz, CA, 95061-8446. Tel: (831) 426-6624. A newsletter for architects and building professionals on indoor air quality.

California Integrated Waste Management Board (CIWMB) Database of Recycled Content Products. www.ciwmb.ca.gov/rcp.

Center of Excellence for Sustainable Development, U.S. Department of Energy, Energy Efficiency and Renewable Energy Network (EREN). Provides web pages on green building and green development. www.sustainable.doe.gov.

Los Angeles, City of. Sustainable Building Reference Manual. Contact: Nady Maechling. (213) 473-8226. Contains detailed local information and many resources.

Maryland State Department of Education. Building Ecology & School Design; Technical Bul*letin: Carpet and Indoor Air Quality in Schools;* and *Interior Painting and Indoor Air Quality in Schools.* To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager, (410) 767-0097.

National Clearinghouse for Educational Facilities (NCEF). *Managing Indoor Air Quality in Schools.* Available on-line at www.edfacilities.org.Spiegel, Ross and Dru Meadows. *Green Building Materials, A Guide to Product Selection and Specification.* John Wiley & Sons, Inc. 1999. ISBN 0-471-29133-1.

Acknowledgments

The following resources were particularly useful for developing this chapter:

Sustainable Building Task Force. The Sustainable Building Task Force was formed by a number of state agencies to institutionalize sustainable building practices into state construction projects. The task force meets on a monthly basis to discuss strategies for implementing sustainable building practices in all future and current state buildings, including those leased by the State. Visit www.ciwmb.ca.gov/GreenBuilding/TaskForce/ for more information and links to member agencies.

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BUILT GREEN™ Handbook. 1999. BUILT GREEN™ is a program of the Master Builders Association of King and Snohomish Counties (MBA) in partnership with King County and Snohomish County, Washington. www.builtgreen.net/.

Maryland State Department of Education. Building Ecology & School Design; Technical Bulletin: Carpet and Indoor Air Quality in Schools; and Interior Painting and Indoor Air Quality in Schools. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201, (410) 767-0097.

GUIDELINE IS1: CARPETING

Recommendation

Select a carpet, carpet tile, cushion, pad, and adhesives that:

- Cause minimal pollution (low-volatile organic compound emissions).
- Are durable. Compare warranties.
- Are made with recycled-content.
- Can be easily cleaned and maintained.
- Are constructed so as to prevent liquids from penetrating the backing layer where moisture under the carpet can result in mold growth.
- Can be easily removed without the use of toxic chemicals.
- Can be easily replaced.
- Absorb sound.

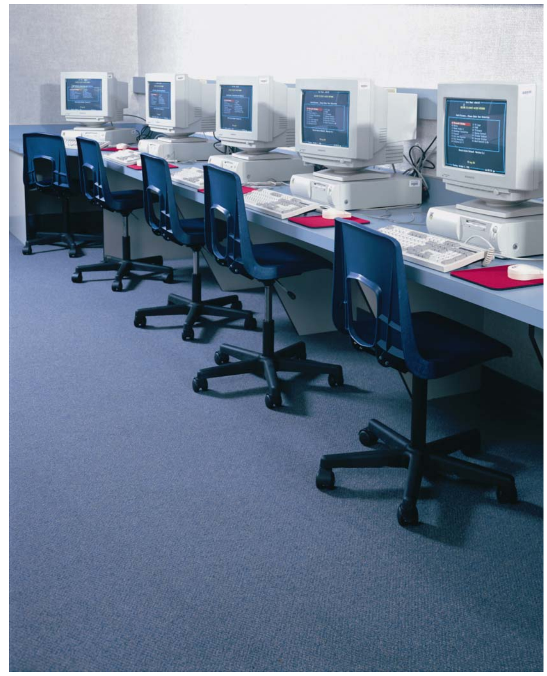


Figure 27—Recycled/Reused Carpet Tiles

This environmentally sound, no-VOC carpet line is leased and maintained by the mafnufacturer who reduces waste by recycling and reusing the carpet tiles. The up-front and maintenance costs are lower and the environmental and health benefits are substantial. Photo courtesy National Renewable Energy Laboratory (PIX # 03041).

Classrooms	■
Library	■
Multi-Purpose / Cafeteria	□
Gym	□
Corridors	□
Administration	■
Toilets	□
Other	□

Climates	
South Coast	■
North Coast	■
Central Valley	■
Mountains	■
Desert	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	■

To reduce waste during construction and installation consider the use of carpet tile instead of broadloom carpet, if applicable. Carpet tile also allows for the replacement of worn or damaged sections without replacing the entire carpeted area. This helps to keep maintenance and replacement costs lower and can extend the life of the carpet.

Where practicable, select a carpet and pad that is recyclable at the end of its life. Even when made from recycled materials and/or with potential for recycling at the end of their useful lives, carpet service life is relatively short compared to other flooring alternatives. Energy and other resources are consumed in the recycling process. Also, some carpet recycling does not re-use the material as carpet but rather in a lower form of carpet materials. Due to these factors, carpet should be used only when its performance characteristics outweigh its environmental costs. Most carpet produced in the United States is manufactured in the state of Georgia; therefore energy is consumed in the transportation of the product to California.

Follow recommendations from the Carpet & Rug Institute (CRI) for installation and maintenance.

Description

Because carpet systems off-gas when new, carpet is a potential source of indoor air pollution. Typically, most volatile organic compounds (VOCs) are emitted from the backing, adhesive, and seam sealer rather than from the wear layer. The specifications listed under the Design Details section below provide guidelines for procurement of low-emissions carpeting and adhesives.

Particles and debris accumulate on carpets, exposing occupants who regularly use the room. Easy and effective cleaning of carpets is critical to reduce long-term exposure to pollutants. Cleaning requirements include both vacuum use and wet-extraction processes. Most of the dirt, dust, grit and moisture tracked in on shoes is trapped within the first 12 to 15 feet of the carpet. Providing walk-off mats in this area can reduce the amount of cleaning required and reduce maintenance costs.

Moisture trapped below a carpet can result in mold growth and the release of mold spores and mold metabolic products (microbial VOCs) into the air. Concrete must be sufficiently cured, dried, and/or sealed before carpet is installed over it.

CRI's Green Label Plus program makes it easy to choose a carpet or rug that meets standards in Section 01350 and DHS' Standard Practice. The CRI Green Label Plus logo displayed on carpet and adhesive samples informs customers that the product type has been tested and certified by an independent laboratory and has met stringent criteria for low emissions.

Applicability

Most suitable for classrooms, libraries, and administrative areas.

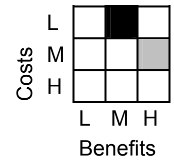
Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than most resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Recycle clean construction/installation waste carpet, if possible (require subcontractor to take back for recycling). Research carpet reclamation programs if the project involves disposing of an existing carpet. Flooring type also affects acoustics, noise control, safety, and maintenance. Complete all painting and other adhesive use prior to the installation of carpets to prevent VOC "sinks."

Cost Effectiveness



A typical nylon carpet installation costs between $\$2.20/\text{ft}^2$ and $\$3/\text{ft}^2$. Recycled content padding and carpeting are priced competitively, with a life expectancy between 10 and 15 years.

Benefits

Although not as material efficient as durable flooring, recycled content and recyclable flooring are material efficient. Carpeting provides acoustic benefits not available with other flooring types. Carpeting provides a more comfortable surface than hard flooring. This is an especially important consideration for classrooms with small children who spend more time sitting or laying on the floor. Section 01350/DHS Standard Practice or the equivalent Green label Plus certification programs provide easy access to databases of low emitting carpet products. Low-toxic adhesives minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See the Overview at the beginning of this chapter.

Design Details

If regular, effective maintenance and cleaning cannot be assured (due to budget constraints, inadequately trained staff, or other reasons), then carpeting should not be used. (See the Operations and Maintenance discussion below).

Emissions Criteria

The adhesives used to attach face fibers to backing materials and the adhesives used to install carpets usually contain VOCs. These compounds may not be listed on the container or on manufacturer’s literature if they are considered exempt under the definition of VOCs in the Clean Air Act regulating reactive chemicals known to be precursors of photochemical smog. However, many of the exempt VOCs are of concern for indoor air quality. Depending on the strength, type, and duration of emissions from these chemicals, carpet can be a significant source of indoor air contamination.

The CRI has developed a program known as the CRI Indoor Air Quality Carpet Testing Program. This includes the Green Label and Green Label Plus testing procedures. While the Green label program should be a bare minimum requirement for carpet selection, it is not a sufficient indicator of carpet emissions into indoor air. Green Label Plus has been developed in cooperation with California’s Department of Health Services (DHS) and the Sustainable Building Task Force and is deemed equivalent to Section 01350/DHS Standard Practice emissions testing.

It is recommended that all carpet products (virgin and recycled-content) and adhesives meet the emissions criteria outlined in Specification Section 01350, and the subsequent DHS Standard Practice, or the equivalent Green label Plus to ensure improved IAQ benefits required for a high performance school. Additionally, the specific criterion for 4-PC emissions applies to carpets.

- Under a test over a 96-hour time period after 10 days of conditioning (as described in Specification Section 01350 and DHS Standard Practice), the carpet should emit less than 10 $\mu g/m^2$-hr of 4-PC.
- The proposed specifications should require that the contractor submit a compliance table, which documents the required performance criteria (as provided in the specifications) and actual test results as well as a letter from the laboratory stating the product has been approved for use in the specific application for which it is intended.

School designers should also require manufacturers to submit the following information for each product making up the carpet system:

- The ingredients, including identification and quantified amounts of substances that are listed on either: (a) the International Agency for Research on Cancer List of Chemical Carcinogens; (b) the Carcinogen List of the National Toxicology Program; or (c) the Reproductive Toxin List of the Catalog of Teratogenic Agents.
- Emission factors for VOCs contained in the product, in mg/m^2-hr.
- Product TVOC emission factor (after 10 days of conditioning in clean air at 1 air change per hour then tested at 24, 48, and 96 hours (mg/m^2-hr).
- Emissions test protocol used.
- Organization evaluating the product.

Type of Carpet

When selecting carpet, space classification, desired design life, and desired aesthetics are the traditional considerations.

Look for low pile, dense loop, and needle-punch carpet types, which trap the least soil and show the least wear. One good choice for schools is a low-nap, all-nylon carpet, which is less attractive to dust mites and mold.

Natural carpets are made from grasses, cotton, and wool with minimal treatment. However, natural carpet materials can harbor insects and support mold growth, as well as being more difficult to maintain. For these reasons, natural carpet is not recommended for schools.

Recycled Content

Select a carpet with a minimum of 50% total (yarn and backing) recycled content (minimum 25% post-consumer recycled content). The manufacturer's warranty period should be reserved for such carpets, and those with a shorter life span should be used in low-traffic areas. Type One Commercial Carpet is available, either a tile or a broadloom, with backing made with post-consumer plastic (typically nylon, polypropylene or a mix of these two plastics). Some manufacturers offer product lines that contain 50% or more recycled content plastic by weight and above. Generally commercial carpet made from nylon 6 or 6,6 is the most durable type of carpet. At this writing, at least two manufacturers supply products made with 100% recycled nylon. Many manufacturers will offer a surface wear warranty of 15 years or more (e.g., 10% surface wear by weight). Some carpet manufacturers also offer reclamation programs to facilitate carpet recycling at the end of its useful life.

The life expectancy of recycled content carpet is between 10 and 15 years.

Carpet Tiles

Carpet tile systems save money and resources. They generate less waste during installation. They are also easily removed and replaced during renovation, and individual tiles can be easily replaced as needed, considerably extending the average service life of the carpet. A few disadvantages to carpet tiles are that they may be more subject to vandalism by students who discover the system is modular. Also, flooding or spills may cause moisture to infiltrate the joints, creating potential IAQ hazards.

Refurbished Carpet

At least one manufacturer refurbishes commercial carpet for reapplication as modular carpet tiles. The manufacturer super-cleans, re-textures and overprints new colors and patterns to previously used carpet. The end product has a warranty and costs about half of new. Refurbished carpet is considered a 100% post-consumer recycled content product. However, in some instances, manufacturers will add new backing to the refurbished product, which would reduce the amount of post-consumer recycled content.

Pad

Specify carpet pad with the highest percentage of recycled content (and is compatible with selected carpet product). Fibrous pad is also available in commercial grades made from recycled synthetic and natural fiber from textile mill waste.

Recyclability

Carpet recycling is a priority because of the large volumes being disposed and its resistance to decomposition. A national agreement for carpet stewardship called the Memorandum of Understanding for Carpet Stewardship (MOU) was signed on January 8, 2002. The MOU states that, “the amount of carpet that is reaching the end of its useful life and entering the waste stream is ever-increasing: estimated total discards for 2002 are 4.7 billion pounds.” Fully recyclable carpets are just newly available. Many manufacturers now take the carpet and carpet tile at the end of its useful life and will recycle it back into new carpet backing (i.e., closed loop system).

Installation

Where new carpet odor is a concern, require suppliers to unroll and air out carpets in a warehouse before bringing them into the building. Tests indicate that carpet emissions will decrease significantly within 48 to 72 hours with proper ventilation. Ideally carpets should be installed at least two weeks before the school is occupied.

When installing carpet over concrete floors, ensure that the concrete is sufficiently dry prior to installation. If water vapor emissions from the concrete floor are greater than 5 lb/1,000 ft^2, a vapor emission control treatment should be applied to the floor until emissions meet the maximum levels allowed by the carpet manufacturer.

Specify the least toxic carpet adhesive system compatible with selected carpet products. Section 01350/DHS Standard Practice and Green Label Plus list carpeting and adhesives that have been tested as an assembly and should be specified as such. Require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer’s performance specifications for that product. Alternately, specify tack-down carpet to eliminate gluing, while taking precautions to prevent potential mold and mildew growth under the carpet.

If covering a large surface area, carpet and other fabrics can act as "sinks" for the adsorption of VOCs from other sources (during application of paint and other finish coatings, for example) and re-emit them later. To minimize this “sink” effect and subsequent extended re-emitting of VOCs, install soft surfaces as late as possible and/or remove or cover all soft surfaces and use direct ventilation until the offensive coating dries.

Air out space(s) where carpet has been installed for a minimum of 72 hours. With a central HVAC system, the ventilation supply should be on, the return grille(s) sealed, and windows open.

In renovations, carpet installation should occur only when the school building is not in use. An exception would be for small installations in which the space can be exhausted directly to the outdoors, causing the room to be under negative pressure relative to adjacent spaces in the building. Extra ventilation should continue for a minimum of 72 hours after installation.

To reduce the risk of mold growth on carpet, do not install carpet near water fountains, sinks, showers, pools, or other locations where it may get wet.

Operation and Maintenance Issues

Carpeting acts as a highly-effective reservoir for allergens such as dirt, pollen, mold spores, pesticides and other toxins, which are present outdoors and often introduced into the indoor environment in dirt from occupants’ shoes. Old carpeting may pose more health risks to its occupants than new. Microbial contamination resulting from water infiltration or inadequate cleaning procedures is a potential problem. The presence of fungi and dust mites can exacerbate allergies. To help ensure longer life, maintain appearance, and help protect indoor air quality, carpet requires regular vacuuming with a well-functioning vacuum cleaner equipped with strong suction and a high-performance filtration bag. Walk-off mats should also be provided at all major entrances.

Spills must be cleaned up immediately and thoroughly. If carpet becomes saturated and water is not quickly removed (less than 24 hours), experience suggests that carpeting will have to be discarded.

See CHPS Best Practices Manual Volume IV: Maintenance and Operations for a more detailed discussion on this topic.

Commissioning

Airing out the space during and after carpet installation is essential and is recommended by the CRI, the U.S. Environmental Protection Agency, and the U.S. Consumer Product Safety Commission. The typical recommendation is to continuously operate the building ventilation system at normal temperature and maximum outdoor air during installation and for 72 hours after installation is completed. A longer flush out of the entire building should also be considered. CHPS recommends flushing out the building for 30 days after all VOC emitting materials have been installed. The CRI *Standard for Installation of Commercial Carpet* (CRI 104) includes Guidelines for Maintaining Indoor Air Quality During Carpet Installation and other installation procedures.

References/Additional Information

California Integrated Waste Management Board (CIWMB) Database of Recycled Content Products: www.ciwmb.ca.gov/rcp.

Carpet and Indoor Air Quality in Schools. Published by the School Facility Branch of the Maryland State Department of Education. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201, phone for Capital Projects Assistant Manager, (410) 767-0097.

Carpet & Rug Institute (CRI) website, www.carpet-rug.com. Provides information on selection, installation, and maintenance.

Comprehensive Procurement Guidelines. The recommended recovered material content for polyester face carpet fiber is listed as 25% to 100% PET resin (recycled plastic soda bottles). Envirotech (Image) and Envirolon (Talisman) lines meet this standard. The Environmental Protection Agency is expanding its definition of environmentally preferred carpet by including nylon fiber with recycled content backing (i.e., Collins and Aikman, Shaw, Interface). These new standards will soon be reflected in the CPGs. For more information on carpet manufacturers and suppliers and a GSA link, visit EPA's Web site: www.epa.gov/epaoswer/non-hw/procure/products/carpet.htm.

Environmentally Responsible Carpet Choices, Sustainable Practices and Opportunities Plan. A project of the Department of Interior, National Park Services. www.nps.gov/sustain/spop/carpet.htm.

Standard for Installation of Commercial Carpet, CRI 104. An industry minimum commercial installation standard published by the CRI. Contains detailed outlines of technique, procedure, and terminology used in specification writing, planning, layout, and installation. Includes accepted tools and materials, floor preparation, installation in special areas, diagrams and charts. (800) 882-8846.

GUIDELINE IS2: RESILIENT FLOORING

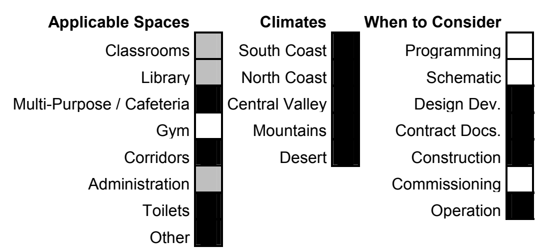
Recommendation

Select resilient flooring and adhesives that:

- Cause minimal pollution (low-volatile organic compound emissions).
- Are durable. Compare warranties.
- Are made with recycled-content.
- Can be easily cleaned and maintained.
- Are material efficient.

Figure 28—Natural Linoleum

Natural linoleum was one of the renewable resources used in the construction of the Chesapeake Bay Foundation Philip Merrill Environmental Center. Photo Courtesy National Renewable Energy Laboratory (PIX # 10885).



Description

Vinyl composition tile (VCT) has been the finish of choice for uncarpeted areas in schools, due to its durability and low maintenance. However, VCT is made of non-renewable resources and there is concern about environmental degradation associated with its production (see the Vinyl Debate section in this chapter's Overview).

Linoleum, often the choice of environmentally conscious designers, is durable as well and is produced from minimally processed, rapidly renewable materials. However, it also poses some risks, including offensive odor during its early months and, sometimes, much longer.

Chlorine-free resilient flooring and recycled content rubber (tire-derived) tile/sheet flooring are also becoming available. The compositions of these products differ from VCT in that they do not contain vinyl.

With respect to materials efficiency and air quality, there are important distinctions between material types, installation methods, and maintenance requirements. Final selection will depend upon the application and cost constraints.

Applicability

Most suitable for high traffic areas not requiring the acoustic benefits of carpet, such as hallways, kitchens, cafeterias, art rooms, toilets or anywhere that liquid spills are likely. Resilient flooring is also suitable for classrooms in cases where school districts have a no carpet policy.

Applicable Codes

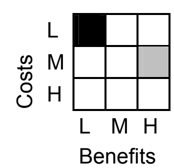
See Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting reduces heat loss slightly more than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Resilient flooring does not generally provide the acoustic benefits of carpeting. Teacher preferences should also be considered, if feasible. Resilient flooring is more easily cleaned than carpeting and may last considerably longer. Some resilient flooring requires application of sealants and waxes, which result in periodic increases in occupant exposure to the chemicals emitted from these products. Recycle waste flooring, if possible (require subcontractor to take back for recycling).

While often considered environmentally preferable, linoleum contains linseed oil, which does off-gas. The oxidation products when the emissions occur are odorous compounds that may affect the acceptability of linoleum as a floor covering. It is recommended that resilient flooring products be tested under Section 01350/DHS Standard Practice emission testing procedures to ensure good indoor air quality will be maintained. The CHPS Compliant Materials Table (www.chps.net) list products which have been tested and approved for use in a typical classroom.

Cost Effectiveness



Costs will vary with type of product chosen. Cork and vinyl-free resilient flooring products have recently entered the marketplace and may be more expensive than VCT products. The designer should obtain cost data.

Benefits

- Resilient flooring is highly durable.
- Recycled content flooring and recyclable flooring are material efficient.
- True linoleum is made with renewable materials (linseed oil, cork, wood dust and jute). Its known ingredients are minimally processed, commonly available, and biodegradable. Linoleum is durable.

- Low-toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See the Overview at the beginning of this chapter.

Design Details

Most resilient flooring products produce some air pollutant emissions; so do their setting and maintenance products. It is recommended that all resilient flooring products meet the emissions criteria outlined in Specification Section 01350 and DHS' Standard Practice.

Natural linoleum is another chlorine-free product, made out of all nearly natural ingredients. Linoleum is highly durable, does not show scuffs or scratches and is flexible and resilient. Linoleum is naturally biodegradable, therefore reducing waste problems, does not burn easily and is waterproof. Linoleum emits far lower levels of contaminants than other products, however it is recommended that all products be tested to be sure they meet the emissions criteria outlined in Section 01350 and DHS Standard Practice. Linoleum emits a fairly strong smell when the flooring is newly installed. The smell comes from linseed oil's oxidation products, which are primarily fatty acids—compounds that react with oxidants to produce new chemicals that have a strong smell even at very low concentrations. Emissions of odors have been measured and observed on aged linoleum as well.

Resilient textile flooring is a newly formulated product that comes in 1-m^2 (39 in. x 39 in.) tiles, comprising a sandwich of very different materials that is designed to come apart for recycling. Developed as part of the specific manufacturer's corporate sustainability policy and initiative, resilient textile flooring is recyclable, durable, and manufactured using renewable energy. Acoustically it performs like carpet, according to the company. The manufacturer has targeted schools and hospitals as its primary markets, because both those settings benefit from the comfort and acoustic qualities of carpet but struggle with the maintenance and cleanliness issues.

Cork is a natural material and harvested from trees in a sustainable manner; the bark is peeled off the tree in nine year cycles without harming the tree. Cork flooring is durable, fairly easy to clean, thermally insulating, and naturally moisture-, mold-, rot-resistant and has good acoustical properties. Drawbacks are its high cost and high-embodied energy (because it is imported and is energy intensive to ship to North America). Also, some flooring manufacturers use hazardous materials as binders and in installation. It is recommended that binders, adhesives, and coatings meet Specification Section 01350 and DHS Standard Practice specifications. If Specification Section 01350/DHS Standard Practice has not been used to test particular products, request and carefully review the MSDS and ASTM emissions test data for these materials. Emissions tests of cork flooring have shown that some of the binder elements are emitted. Some chemicals emitted from cork flooring are toxic at elevated concentrations.

Recycled rubber tile and sheet goods made with waste tires are also available. These are material efficient choices for heavy traffic and utility areas, but may be strong volatile organic compound (VOC) emitters and odor sources.

Specifications should require the installer to use the smallest amount of adhesive necessary to fulfill the manufacturer's performance specifications for that product. (In some applications, interlocked rubber tiles and heavy linoleum can be laid without adhesive.)

When installing resilient flooring over concrete floors, ensure that the concrete is sufficiently dry prior to installation. If water vapor emissions from the concrete floor are greater than 3 lb/1,000 ft^2, a vapor emission control treatment should be applied to the floor until emissions meet the maximum levels allowed by the flooring manufacturer.

Specify adequate ventilation during installation and flush out the building for a minimum of 72 hours after installation.

Operation and Maintenance Issues

Maintenance products are also significant pollution sources. Flooring with sealed "low maintenance" surfaces should be preferred, both for reducing maintenance costs and the use of cleaners and waxes. It may be possible to require manufacturers to provide cleaning and maintenance product specifications and application procedures. In these cases, the chemicals in these products should be evaluated along with the emissions from the flooring itself.

Low-VOC cleaners and sealers are available. Be sure to consult with the manufacturer when specifying sealers and other maintenance products. Use of the wrong products can cause problems, especially with natural linoleum. To help ensure longer life, maintain appearance, and help protect indoor air quality, resilient flooring requires proper cleaning/vacuuming. Walk-off mats should also be provided at all entrances to prevent dirt from being tracked onto the flooring surface.

See CHPS Best Practices Manual Volume IV: Maintenance and Operations for a more detailed discussion on this topic.

Commissioning

None.

References/Additional Information

See resources listed in this chapter's Overview.

Also see the following articles from Environmental Building News:

"A New Chlorine-free Competitor to Vinyl Flooring," Volume 7, No. 10, November 1998. (About Amtico Stratica flooring.)

"Solenium—The First Resilient Textile Flooring," Volume 8, Number 5, May 1999.

"Cork Flooring," Volume 5, No. 1, January/February 1996.

GUIDELINE IS3: CERAMIC TILE / TERRAZZO

Recommendation

Select locally available, recycled content ceramic or clay tile. If installing terrazzo, avoid the epoxy type; substitute cementitious terrazzo where appropriate. Specify low-toxic adhesives, grouts, caulks, sealants, and setting materials.

Figure 29—Ceramic Tile With Recycled Content

TerraTraffic from Terra Green Ceramics is made in the USA from over 55% recycled glass and select ceramic materials. Photo reprinted with permission from Terra Green Ceramics. www.terragreenceramics.com/.

Applicable Spaces	
Classrooms	□
Library	□
Multi-Purpose / Cafeteria	□
Gym	□
Corridors	□
Administration	□
Toilets	■
Other	■

Climates	
South Coast	■
North Coast	■
Central Valley	■
Mountains	■
Desert	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	■

Description

Recycled content ceramics, clay tiles, and terrazzo (made with cement and crushed stone) are durable and low-emission interior finishes. Maintenance of these flooring types may require toxic or VOC emitting products however.

Terrazzo is a family of flooring materials that incorporates natural marble chips and other aggregates in a cementitious or epoxy mixture, which is usually applied wet and allowed to cure in place.

Applicability

Tile is most suitable for traffic areas requiring high durability and low maintenance, but not requiring the acoustic benefits of carpet, such as entryways and toilets.

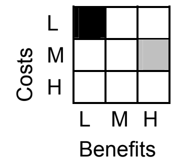
Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Tile/terrazzo flooring does not provide the physical comfort or acoustic benefits (tile flooring does not absorb sound and does not reduce impact noise transmission to spaces below) of carpeting, so this, along with teacher preferences, should be considered. As part of the C&D plan, recommend that the subcontractor take back waste tile for recycling.

Cost Effectiveness



Terrazzo costs between $\$5/\text{ft}^2$ and $\$10/\text{ft}^2$ to install, and will last the life of the building. Ceramic tile costs between $\$6/\text{ft}^2$ and $\$12/\text{ft}^2$ installed, and will last 40 to 80 years. Recycled-content tile can be higher priced than average tile products. Low-toxic adhesives used with tile and terrazzo are generally available locally and at competitive prices.

Though costly to purchase and install, the ceramic tile/terrazzo *life-cycle* cost is among the lowest of all finishes for some applications, due to its long life and minimal maintenance. Ceramic tile with recycled content may cost 1.5 to 2 times more than conventional.

Benefits

Use of local or regionally manufactured ceramics reduces the high transportation consumption/cost associated importing with this heavy building material. Ceramics and terrazzo (made with cement and crushed stone) are durable and low emitting. Some tile is available with recycled content (up to 70%), such as scrap glass and feldspar waste from mining, which is material efficient, durable, and low- to non-emitting. Some manufacturers also have added heat recovery, water recovery, and clay mine restoration measures to their operations that exceed industry norms, which is ecosystem-protective.

Low toxic adhesives and coatings minimize the indoor pollution load and health risks to both installers and occupants. It is recommended that adhesives meet the emissions criteria outlined in Specification Section 01350 and DHS' Standard Practice.

Design Tools

See the Overview at the beginning of this chapter.

Design Details

Tile is a packaging-intensive product. Specify recyclable packaging. Check with the manufacturer to see if there is a collection program in place at no cost to owner or contractor. Packaging and construction waste should be included in the C&D plan.

Terrazzo

The two types of binders used in terrazzo flooring raise different environmental issues during installation. Cementitious terrazzo is composed of inert ingredients mixed with water. The primary installation hazard is dust during mixing and grinding. The installation of epoxy terrazzo, however, requires the use of

OSHA-approved respirators, protective gloves, and safety glasses, as well as ventilation with 100% fresh air. The epoxy matrix contains a number of toxic materials. For these reasons, use of the epoxy type terrazzo should be avoided.

A variety of techniques are available to add designs—for example, cultural, school, community symbols—for use as teaching tools or school identity. Such artistic/educational amenities, however, will increase the cost.

Tile

Avoid the use of imported tile. The glazing used on imported tiles can contain lead, which is toxic and a potential health threat. Another disadvantage is that imported tiles have high-embodied energy.

Mortar, Adhesives, Caulking, and Sealants

Cement mortars, usually modified with acrylic additives, are the safest to handle for tile setting and offer the best performance for most applications. All plastic adhesives contain some solvents and will contribute to indoor air pollution. Where adhesives and caulking must be used, such as for cove bases and flexible joints, choose a low-solvent content product such as an acrylic. Cement-based, cellulose-based and acrylic-modified grouts are safe and have low emissions. Glazed tile and high-fired tile usually do not require sealers. If a porous tile is chosen, the safest sealers are the low-volatile organic compound, acrylic, or water-based silicone types. Check with the tile manufacturer to select the lowest VOC, low-toxic mortars, sealers, caulks, and adhesives that will provide the desired performance. Review MSDS and emission test data for sealers, caulks, and other adhesives to understand their impact on indoor air quality.

Installation

- Specify adequate ventilation during installation.
- Tile is a non-porous surface and should be installed prior to porous, fleecy, and absorbent materials, which can act as “sinks”, absorbing VOCs from other materials and later re-emitting them.
- Require the installer to use the smallest amount of adhesive and sealant necessary to fulfill the manufacturer’s performance specifications for that product.
- Perform building flush out after floor installation.

Operation and Maintenance Issues

Terrazzo flooring should be sealed to prevent absorption of dirt and stains. Water-based sealers are available. Maintenance for ceramic tile varies with the type of surface and grout. Most unglazed tile is sealed after installation. Once floors are sealed, they may require re-sealing throughout their lives, in which the process may impact indoor air quality. Walk-off mats should also be provided at all entrances to help ensure longer life, maintain appearance, and help protect indoor air quality. Three types of binders are used in terrazzo flooring with each type having its own maintenance requirement. It is important that the custodial staff knows which type of floor it is maintaining and the proper procedures and products for that type of flooring.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE IS4: CONCRETE FLOORING

Recommendation

Select concrete flooring, made with fly ash. Use low-toxic adhesives, sealers, and wax.

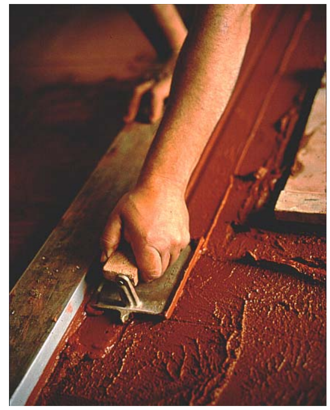
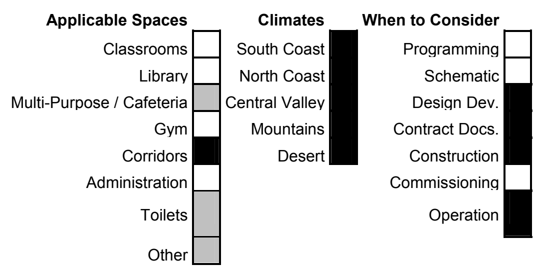


Figure 30—Installation of Finished Concrete Flooring

Photo reprinted with permission from Davis Colors, Inc. www.daviscolors.com/.



Description

Finished concrete flooring is an integral system of slab and finish, produced by adding colorants and a sealer to the topping concrete (colorized cement) either before or after it cures. This is a resource efficient system as a finished flooring system is not needed. The concrete is often stamped with tile patterns and grid lines that also control cracking.

Applying a colorized stain to a cured concrete surface produces stained concrete flooring.

Both types of concrete flooring provide a durable and low maintenance finish. Saw-cut and other designs and colors can add interest and educational value.

Fly ash is a byproduct of burning coal for electricity production. Fly ash is captured from the boiler exhaust and was originally treated as waste and disposed of in landfills. Over the past decade the use of coal combustion products that are recovered and used for productive uses has increased by 50%. Fly ash acts as a lubricating agent in concrete causing it to flow and pump better while using 10% less water. Fly ash is cost effective as the amount of concrete needed is reduced. (Refer to: www.flyash.com/ and www.geocities.com/CapeCanaveral/Launchpad/2095/.)

Applicability

Especially suitable for high traffic areas, such as hallways, cafeterias, and gathering areas. Staining existing concrete flooring is generally appropriate for renovation. Finished concrete flooring with integral colorants is generally applicable to new installations. Concrete may be used for other building surfaces.

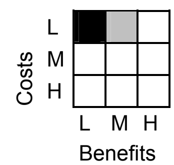
Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Concrete flooring adds thermal mass which has an effect on the thermal properties and energy requirements of the space in which it is used. Concrete floors do not absorb sound or reduce impact noise transmission to spaces below.

Cost Effectiveness



Medium ($\$3/ft^2$) to high first cost, depending upon complexity of the installation/design.

Benefits

Concrete flooring is highly durable and low maintenance, which conserves materials and reduces potential indoor air quality (IAQ) problems due to maintenance products. Concrete with fly ash is material efficient. Low-toxic coatings minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See Design Tools listed in this chapter's Overview.

Design Details

Selection

Finished systems with integral color added to the entire topping layer are more resistant to damage, and less likely to require re-coloring than systems that are dyed after placing the concrete.

Ask supplier to recommend least toxic, volatile organic compound (VOC)-compliant sealers and wax that will fulfill performance requirements. It is recommended that sealers meet the emissions criteria outlined in Specification Section 01350 and DHS' Standard Practice.

Concrete staining is a technique often used in renovation of existing buildings with existing concrete sub-floors.

A variety of techniques are available to add designs—for example, cultural, school, community symbols—for use as teaching tools or school identity. Such artistic/educational amenities, however, will increase the cost.

Installation

Specify adequate ventilation during installation and flush out the building in accordance with project specifications.

Require installer to use the smallest amount of sealers and wax necessary to fulfill the manufacturer's performance specifications for that product.

Operation and Maintenance Issues

Proper sealing and re-waxing of stained concrete floors will ensure a long service life. Stained concrete flooring requires periodic re-waxing. Maintenance materials should be reviewed for low-VOC emissions.

Walk-off mats should also be provided at all entrances to help ensure longer life, maintain floor appearance, and help protect IAQ.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter:

Lick Wilmerding High School, San Francisco, CA—stained concrete flooring in the corridors of a new library.

Ross Middle School, Ross, CA (Marin County)—Installed stained concrete floors, eliminating all carpet, resilient flooring, and related adhesives. Used low-VOC sealers.

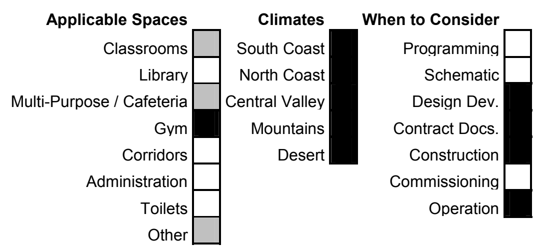
GUIDELINE IS5: WOOD FLOORING

Recommendation

Select environmentally preferable products for wood flooring. Specify low-toxic adhesives, sealers, and finishes.

Figure 31—FSC Logo

Trademark reproduced with permission. FSC Trademark © 1998 Forest Stewardship Council A.C.



Description

Environmentally preferable wood flooring types include Forest Stewardship Council (FSC)-certified hardwood, salvaged wood, and laminated or veneered wood products. When permitted by the school district, other environmentally preferable choices include salvaged or reclaimed wood, sources of which are locally available in California. Salvaged flooring is material efficient and considered a 100% post-consumer recycled content product. Points are earned under the CHPS Criteria for FSC certified wood, recycled wood or salvaged wood.

If using hardwood, specify products certified by the FSC. FSC is the accrediting agency for organizations that certify forests as well managed. Other environmentally preferable alternatives to conventional hardwood flooring include a wide range of veneered and laminated products that have a hardwood surface with plywood, MDF, or other materials in the core.

Applicability

Wood flooring is typically now specified for schools only where its performance characteristics make it uniquely desirable: gymnasiums, stages, and dance studios. However, some studies suggest that wood flooring from sustainable forests may be an appropriate flooring material for more functions, including classrooms, especially in regions where desirable species are native.

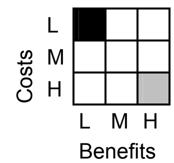
Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with higher reflectivity enhance daylighting). Wood floors do not absorb sound or reduce impact noise transmission to spaces below.

Cost Effectiveness



Wood flooring costs between $6/ft^2 and $10/ft^2. The life expectancy averages 38 years. The cost premium for certified wood ranges from modest to significant, depending upon quantity, type, and current availability.

Benefits

FSC-certified wood is eco-system protective. Low-toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants. The factory pre-finished products have substantial air quality benefits because no sealer is applied, no sanding is performed, and no finishing is done on site.

Design Tools

See the Design Tools listed in this chapter's Overview, and:

Certified Forest Products Database, Certified Forest Products Council. Web site: www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Tel: (503) 590-6600. Industry information on suppliers and standards.

Design Details

Selection

Several FSC-certified hardwood-flooring products are available. Look for woods grown in regional forests, which reduce the energy consumption involved in transportation. Woods common to the western area include pine, aspen, spruce, fir, and hemlock. Other forest certification systems exist and each must be evaluated to ensure their goals coincide with the environmental issues discussed in this chapter. The key concepts to understand in comparing forest certification systems include openness and transparency of standards development and governance, objectives of it's standards and the rigor of it's operating procedures.

Veneered and laminated products that have plywood, composite wood products, or MDF cores are material efficient, but are less easily repaired than solid wood. These are usually pre-finished at the factory with a very durable, low-maintenance finish.

Low-toxic, clear sealers are also available to use as finishes for woodwork. Water-based varnishes, polyurethane, and other finishes for hardwood floors are very durable and much safer to handle than traditional products. Low-toxic solvents, water-based strippers, and all-natural thinners are also locally available.

A word of caution: not all water-based products are low emitters and, in fact, some emissions continue far longer than those from traditional, oil-based sealers. For example, acid cured lacquers can be strong emitters of formaldehyde while they are curing, and for considerable time afterwards. Formaldehyde-free alternatives should be specified for schools. It is recommended that all veneered and laminated products should meet the emissions requirements outlined in Specification Section 01350 and DHS' Standard Practice.

Handling

Specify that woodwork be protected from water damage during transit, delivery, storage, and handling In addition to saving materials, this helps prevent future moisture/indoor air quality (IAQ) problems.

Installation

A steel track system using wedges to hold the flooring in place, or a "floating system," using edge gluing where necessary, makes wood floors easy to remove. A nail down system is also salvageable, but with some loss of material. Avoid parquet systems, which require a glue-down system and are therefore the least salvageable. Eliminating the use of adhesives reduces the impact on IAQ.

If sanding is done on the premises, the area must be carefully isolated, including sealing off the doors and HVAC system, and using temporary fans. Specify final cleanup with a HEPA filter-equipped vacuum.

Require installer to use the smallest amount of adhesive/coating necessary to fulfill the manufacturer's performance specifications for that product.

For finishing on site, use low-VOC emitting finishes. Hardening oils, varnishes, and acid cured varnishes have prolonged emissions. If edge gluing is required, specify a low toxicity product such as white carpenters or woodworkers glue. If glue-down methods are required, such as for parquet, specify a low-VOC emitting flooring adhesive.

Specify adequate ventilation during installation and for 72 hours afterwards.

Woods naturally emit formaldehyde.

Operation and Maintenance Issues

After being finished with a synthetic topcoat, maintenance requirements for wood floors are similar to VCT and terrazzo. A typical hardwood floor might need re-sanding (which generates airborne dust) every eight to 10 years and can be re-sanded up to five times. Annual screening and re-coating maintains the protective wear layers. Wood flooring is easier to repair than most other materials.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter:

For general information on certified lumber, contact: Certified Forest Stewardship Council, Jeff Wartelle. Tel: (503) 590-6600. Refer also to: www.fscus.org/. Industry group provides information on distribution and other assistance.

Certified Forest Products Database, Certified Forest Products Council, www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Phone: (503) 590-6600. Industry information on suppliers and standards.

Two private companies in the U.S. are authorized to issue the FSC stamp of approval: Scientific Certification Systems (SCS) in Oakland, CA (www.scscertified.com/forestry/), and SmartWood Certified Forestry, based in Richmond, VT, with an affiliate in Oregon (www.isf-sw.org).

GUIDELINE IS6: BAMBOO FLOORING

Recommendation

Specify domestically produced flooring made from rapidly renewable bamboo (it matures in less than five years). Install and finish with a low toxic, water-based sealer and wax.

Description

Bamboo is a natural material, technically a grass that can reach timber height of 100 ft. It is a renewable resource, requiring no pesticides, fertilizers or irrigation, so it is not labor intensive to farm. Some manufacturers source their bamboo from managed forests using a harvesting method done by hand. This reduces the impact on the local environment in terms of erosion and habitat destruction. Most bamboo used in flooring production is grown in, and imported from, China. Boric acid is sometimes added during the manufacturing process. Bamboo flooring is harder than most common wood flooring, very durable, fast-growing, and dimensionally stable.

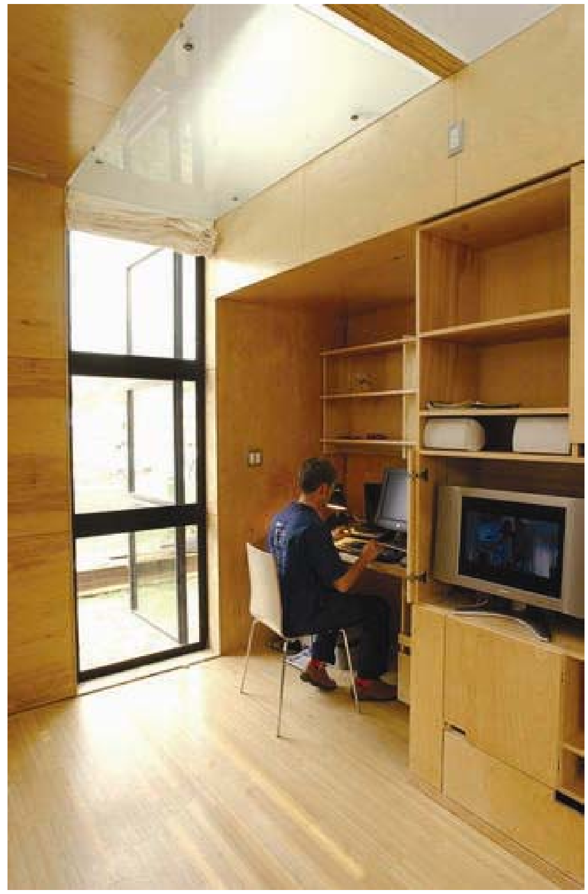
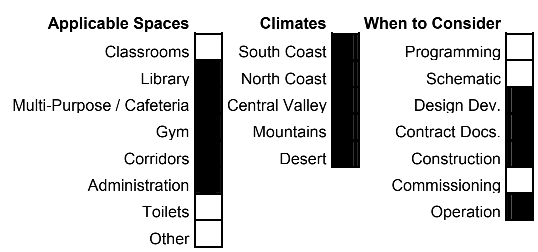


Figure 32—Bamboo Flooring Photo Courtesy: SoundSuckers (permission not requested)

Bamboo flooring in student housing at the University of Virginia. Photo courtesy National Renewable Energy Laboratories (PIX # 12173).



Applicability

Suitable wherever wood flooring would be used. Bamboo may also be used as plywood, paneling, and veneer.

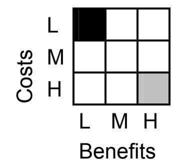
Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than other flooring does, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Bamboo floors do not absorb sound or reduce impact noise transmission to spaces below.

Cost Effectiveness



Costs range from $4/ft^2 to $8/ft^2, which is slightly more than domestic hardwoods. However, bamboo is more durable than wood (25% harder than oak, 12% harder than maple, and 2.5 times more dimensionally stable than maple, according to one manufacturer).

Benefits

Bamboo flooring is aesthetically pleasing, low emitting, durable, and produced from a renewable, harvested resource which matures in 3 years. Low-toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See the Design Tools listed in this chapter's Overview.

Design Details

Specify use of adequate ventilation during installation. Flooring is best applied by nailing, stapling, or gluing to a wood sub-floor, but can be glued to concrete at or above grade. If installing over concrete, moisture testing is recommended prior to installation.

Operation and Maintenance Issues

Place mats at entrances and exits to trap dirt from incoming traffic. Bamboo floors must be vacuumed or swept regularly with a nylon broom. Use non-alkaline cleaning solutions. Do not mop with water, since excess water can damage the floor.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter, and:

The American Bamboo Society. Web site: www.americanbamboo.org/.

West Coast suppliers include:

Terafren, LLC, 9790 NE Murden Cove Drive, Bainbridge Island, (206) 842-9477 or (800) 929-6333. Email info@teragren.com or Web site: www.teragren.com .

Bamboo Hardwoods, 3834 4th Ave. South, Seattle, (206) 264-2414. Web site: www.bamboohardwoods.com/.

Smith & Fong Company, San Francisco, CA., Web site: www.plyboo.com/.

Bamboo Hardwoods Mfg. Co, Seattle, WA. Web site: www.bamboohardwoods.com/.

Bamboo Flooring International Corp., Walnut, CA. Web site: www.bamboo-flooring.com/.

GUIDELINE IS7: GYPSUM BOARD

Recommendation

Specify gypsum wallboard with a minimum 100% recycled content paper facing. Post-consumer recycled content gypsum board core is also available.

Gypsum used for recycling should be clean construction waste, uncontaminated by paint, tape, compounds, adhesives, or other coatings.

Figure 33—Gypsum Board

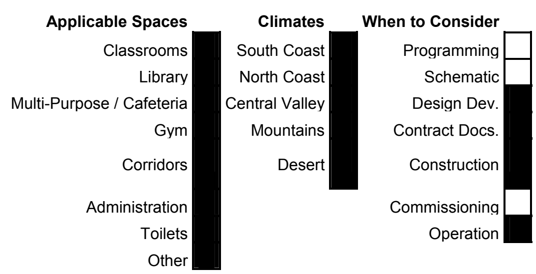
Photo courtesy of O'Brien & Company, Inc.

Description

Gypsum products are the most common interior panels used due to their fire retardant characteristics and low cost.

Applicability

Suitable for all spaces. High impact gypsum is appropriate for spaces requiring higher than normal durability.



Applicable Codes

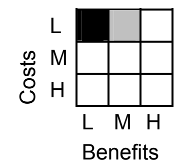
See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Wallboard installation should be coordinated with the job-site waste reduction plan. Recycle clean construction waste drywall (require subcontractor to take back to the manufacturer for recycling). Several manufacturing facilities in California will accept clean gypsum board construction waste by the ton. Contributing this material back into the manufacturing process increases the amount of post-consumer recycled content in the core of gypsum board products available in the marketplace.

When recycling gypsum board from a demolition site, check to see if the joint or topping compounds contained asbestos fibers. Sanding such material will result in the release of fibers into the air. State and federal laws regulate disposal of asbestos-containing materials.

Cost Effectiveness



Gypsum board is the lowest cost option for walls. However, for ceilings, it is competitively priced with drop-in ceilings.

Benefits

Gypsum is highly recyclable if not contaminated (with paint or adhesives) and the paper facing is generally made with recycled paper. Use of recycled-content gypsum is material efficient. High impact gypsum is more durable than conventional wallboard and has higher recycled content.

Design Tools

See the Design Tools listed in this chapter's Overview, and:

Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction. Revised July 2000. A publication of the California Integrated Waste Management Board. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix F sample specifications for: Section 09250 Gypsum Board. Designing with Vision can be downloaded in four parts from www.ciwmb.ca.gov/GreenBuilding/. Chapter 8 is in Part D.

Design Details

Selection

Specify a minimum 10% recycled content gypsum board core with 100% recycled content facing paper. (Recycled content board must be specified, since recycled content is not automatically provided).

Consider gypsum produced by a recent innovation, the fibergypsum process. This board, now available in the U.S., has no paper facing but contains recycled wood, paper fiber, and perlite. It is very strong and scratch-resistant, and appropriate for high-wear areas such as schools. Fiberbond from Louisiana Pacific Corporation is an example of this type of gypsum.

Another environmentally preferable option is the use of gypsum board made with synthetic gypsum. Synthetic gypsum is produced with flue-gas desulfurization (FGD) gypsum, fluorogypsum, citrogypsum, and titanogypsum. This technology is not widely available in plants on the west coast, so embodied energy loads should be considered when selecting synthetic gypsum. Also, synthetic gypsum can have a negative environmental impact on agricultural land if it is ever applied as a soil amendment, due to its heavy metal content.

It is recommended that all gypsum board products (virgin, recycled content, synthetic) meet the emissions standards outlined in Specification Section 01350 and DHS' Standard Practice.

Installation

Special care should be taken during the delivery, storage, and handling of gypsum board to prevent to accumulation of moisture on the material or within its packaging. Exposure to moisture can cause mold growth in the gypsum paper facing. To prevent possible interior mold problems, any stored or installed gypsum board showing evidence of moisture damage, including moisture stains, mildew, and mold, should be immediately removed from the site and disposed of properly. Replace contaminated gypsum board with new, undamaged materials.

Specify wet sanding processes during finishing. An exception is that dry sanding may be allowed subject to full isolation of the affected space(s), installation of protective plastic sheeting to provide air sealing during the sanding; closure of all air system devices and ductwork, sequencing of construction to prevent contaminating other spaces with gypsum dust, use of proper worker protection, and owner approval of these measures. Using vacuums during dry sanding to reduce dust can also help protect the health of installers.

Unpainted gypsum surfaces are potent "sinks"—they absorb volatile organic compounds (VOCs) and then re-emit them. Require adequate ventilation during installation of adhesives and other materials that emit indoor pollutants. Where feasible, sequence work to avoid applying VOC-containing materials in spaces with exposed, unpainted gypsum surfaces.

"The Nailer" is a wallboard installation hardware product made by The Millenium Group, Inc. of Estes Park, CO ((800) 280-2304) that replaces wood backing used in traditional gypsum board installation. Besides saving wood, the product is material efficient (contains 25% post-consumer plastic and 75% post-industrial waste) and laborsaving.

Operation and Maintenance Issues

Requires periodic painting for aesthetic purposes. Type of paint determines cleanability. Wallboard is easy to repair.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter, and:

Information on synthetic gypsum may be obtained from manufacturers' Web sites and the following gypsum trade sites: www.gypsum.org/environmental.html and www.gypsum.org/topical.html#synthetic.

Ross Middle School, Ross, CA (Marin County)—Used recycled content gypsum board.

GUIDELINE IS8: ACOUSTICAL WALL PANELS AND CEILINGS

Recommendation

Select formaldehyde-free acoustical ceiling and wall systems with recycled content and high light reflectance.

Figure 34—Acoustical Ceiling Tile/T-Bar Installation

Acoustical ceiling tile/T-bar ceiling installation at the Central Market, a recycled content products demonstration project, Poulsbo, Washington. Photo reprinted with permission from O'Brien & Company, Inc.

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	■	Mountains	■	Contract Docs.	■
Corridors	■	Desert	■	Construction	■
Administration	■			Commissioning	□
Toilets	■			Operation	■
Other	■				

Description

Acoustical wall and ceiling systems are widely used in school for sound absorption. A variety of products are available including modular wall panels (textile and metal-covered), suspended ceiling tiles (t-bar ceilings), and surface mounted ceiling and wall panels.

Ceiling tile (usually in a T-bar ceiling) is the most common ceiling finish in schools. Because of the large ceiling surface area, the likelihood of its being disturbed during modifications/renovations, and its contact with HVAC systems, it is an important product to consider for air quality and materials efficiency.

Types currently available include recycled content ceiling tiles made of recycled newspaper, mineral wool, perlite, glass fiber, and clay. Look for a minimum recycled content of 79%. (A recent informal survey conducted by the California Integrated Waste Management Board indicates that the recycled content of acoustical ceiling tiles varies between 18% and 82%). New products on the market can attain 85% recycled content, but with some diminished noise reduction value. Natural fiber acoustic ceiling panels are also available, for both walls and ceilings.

Applicability

Use anywhere sound absorption and easy ceiling plenum access is desired.

Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

The T-bar ceiling system integrates with HVAC system ducting layout and operation. Do not use the space above the T-bar ceiling as a return air plenum because it is difficult to clean, and, if there is any off-gassing, odors, or microorganisms from any material in this area, contaminants can spread throughout the air space and be distributed to other areas. Instead, install return air systems using dedicated metal ductwork with access hatches for inspection and cleaning. Recycle construction waste (require subcontractor to take back for recycling).

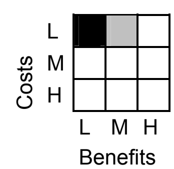
Make sure insulation is not installed directly over drop-in ceilings. Lighting fixtures, diffusers, and other equipment interrupt the insulating barrier, leading to poor insulating performance. (Often the space above the ceiling is considered an attic space, requiring outside air ventilation.)

Make sure no fiberglass is exposed in the plenum.

High light reflectance levels (light colored) ceiling tiles work in conjunction with electric lighting and daylighting strategies to provide better quality and energy efficient classroom lighting.

Cost Effectiveness

Costs are low.



Benefits

Formaldehyde-free acoustical panels with recycled content are available. These panels are considered a material efficient, low-volatile organic compound (VOC) product that promotes healthy indoor environmental air quality. At least one manufacturer offers a reclamation program (see References below for more information).

Acoustical products from wood fiber and other sustainable raw materials are highly durable.

Ceiling tile waste, either from construction or demolition, is non-toxic (as long as lead paint and asbestos were not used on older ceiling installations). One company claims that its panels can be ground up successfully and composted to produce a soil amendment.

Design Tools

See the Design Tools listed in this chapter's Overview.

Design Details

General

It is recommended that ceiling tiles meet the emissions standards outlined in Specification Section 01350 and DHS' Standard Practice. Emission test data and MSDSs for ceiling tile materials should also be obtained and reviewed.

Acoustical materials, including acoustical ceiling tiles, can act as "sinks" for the absorption of odorous or irritating VOCs from other sources (during application of paint and other finish coatings, for example, or from occupant activities) and re-emit them later. Where feasible, sequence work to avoid exposing acoustical ceiling and wall systems while applying VOC-containing materials in spaces with exposed acoustical surfaces. Require adequate ventilation during installation of finish materials that emit pollutants.

Consult with the manufacturer before painting/coating any acoustical material. For example, with most ceiling tiles, the material loses its acoustical properties once it has been painted. Exceptions include several product lines from Tectum, which they certify for up to 10 applications of a non-bridging paint.

Sound absorbing materials such as acoustical wall panels and ceiling tiles should have their sound absorbing properties measured in a laboratory environment. Sound absorption is typically rated in terms of NRC (Noise Reduction Coefficient). The NRC scale ranges from 0.00 (totally reflective) to 1.00 (totally absorptive). Materials with "good" sound absorbing capabilities should have a minimum rating of NRC 0.65. Another acoustical parameter to be considered is the Ceiling Attenuation Class (CAC). Ceiling tiles typically range from CAC 25 to 40. Ceiling tiles with higher CAC ratings allow less sound to pass through and tend to absorb less sound than those with lower CAC ratings. In areas that have noise-producing elements (i.e., Variable Air Volume (VAV) or Fan Powered Boxes (FPB)) in the ceiling space and also have a need for low background noise levels, a high CAC ceiling tile may want to be considered to help reduce background noise from terminal air devices or other noise sources. The important acoustical concept for use within a classroom or other occupied space is reverberation time which is a measure of the echo from sound generated within the space. Acoustical wall panels and ceiling tiles with high NRC ratings absorb noise in the mid frequency range, thus reducing the echo within the space.

Acoustical Wall Panels

Low-density fiberboard is made from paper and wood fiber, and is available made from 100% recycled newsprint. Most processes use no glue. They are suitable for use as acoustic panels. Fiber-free foam panels are also available from some manufacturers.

Ceilings

Coordinate placement of lighting fixtures and other equipment in ceilings to provide clear access for inspection and servicing of HVAC system air filters and other components.

Where daylighting has been incorporated as a design strategy and/or suspended indirect or direct/indirect luminaries used, consider using ceiling tiles with high light reflectance as specified in ASTM Standard E1477 (0.83lr).

Special care should be taken during the delivery, storage, and handling of ceiling tiles to prevent the accumulation of moisture on the material or within its packaging. To prevent possible interior mold problems, any stored or installed ceiling tiles showing evidence of moisture damage, including moisture stains, mildew, and mold, should be immediately removed from the site and disposed of properly. Replace contaminated tiles with new, undamaged materials.

Suspended light fixtures allow more of the ceiling to be covered by the acoustical ceiling tiles. This helps to reduce reverberation time and noise infiltration from the plenum.

Operation and Maintenance Issues

Ceiling tiles and other acoustical materials collect dust as well as absorb and re-emit VOCs. Tile with mineral fiber content may also begin to shed hazardous fiber if disturbed or as it deteriorates. Both problems are a particular concern where the ceiling is used for a return plenum to carry air back to the HVAC air handlers. If this type of return system is used, the tile should be checked for damage and the plenum space occasionally cleaned with a high performance vacuum. If possible, in new and renovation design, HVAC returns should be ducted instead of risking contamination by debris in suspended ceilings (See the Integrated Design Implications discussion above.)

Commissioning

None.

References/Additional Information

See the Overview section of this chapter, and:

Armstrong World Industries has a program for recycling old ceiling tiles, which it collects from building owners and uses as raw materials in the manufacture of new acoustical ceilings. For more information: Phone: (888) CEILINGS. Armstrong ceilings Web site: www.armstrong.com/armstrong_ceilings, (From Newsbriefs, Environmental Building News, Oct 00, p. 6). Armstrong also provides software for analyzing and comparing the acoustical performance of acoustical products.

"Natural-fiber Acoustic Ceiling Panels," Environmental Building News, Volume 7, No. 4 (April 1998).

Ross Middle School, Ross, CA (Marin County)—Acoustic ceiling tile has 75% recycled content.

Tectum Web site, www.tectum.com/. According to a Tectum rep, their biggest users are schools. For certain applications (e.g., gymnasiums), their product is lowest cost option. In its 1-in. form, it costs about $2/ft^2 to the installing contractor.

GUIDELINE IS9: PAINTS AND COATINGS

Recommendation

Specify the least toxic, low-formaldehyde, low- or zero-volatile organic compound (VOC) paint that meets durability and other high performance requirements. Light colored surfaces enhance daylighting.

Figure 35—Paint Being Applied

Photo courtesy Eartheasy

Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose / Cafeteria	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

Climates	
South Coast	■
North Coast	■
Central Valley	■
Mountains	■
Desert	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	■

Description

Emissions from paints and coatings are primarily from evaporating solvents, other VOCs and by-products released after oxidation. Water-based acrylic latex paints are lower in VOCs (<250 mg/L) than solvent-based paints. Low-VOC is generally accepted to mean paint with a VOC content less than 100 mg/L.

Low-VOC paints are usually those in the lighter color ranges. Tinting may increase VOC emissions.

Formaldehyde-free paint is not yet available, but several low-formaldehyde options exist. Select paint with the lowest formaldehyde concentrations possible.

While a variety of low-VOC and zero-VOC paints are now available to choose from, they vary in cost, potential toxicity, and performance. Therefore, paint selection should consider VOC content as well as overall composition and required performance characteristics, including cleanability, hideability (i.e., how well a product conceals a surface), and durability.

Recycled content paint is now available and may be considered for interior and exterior use.

Applicability

All interior painted surfaces.

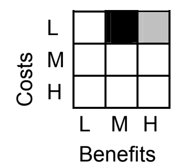
Applicable Codes

See the Applicable Codes section in this chapter's Overview, as well as OSHA and local regulations for lead-containing paint (for renovation work).

Integrated Design Implications

Light colors enhance daylighting. Integrate with ventilation system installation/operation to provide proper ventilation during application, curing, and occupancy. Change out HVAC filters following application and before occupancy.

Cost Effectiveness



Costs vary widely with paint type and application. Low-VOC and zero-VOC paints have tended to cost 10% to 30% more than conventional paint, but prices are becoming more comparable as demand/production increases. Many low-VOC paints are now comparable in price to conventional paint.

Benefits

Zero-VOC or low-VOC paints minimize the indoor air pollution load, odors, and health risks to both workers and occupants. Water-based paints are generally safer to handle and can be cleaned up with water, reducing health risks to workers and minimizing/avoiding hazardous waste. Leftover latex paint may be recyclable, thus reducing waste.

Design Tools

See the Design Tools listed in this chapter's Overview.

Design Details

Where practicable, leave surfaces of exposed structure unpainted.

A paint can be labeled low-VOC yet still contain odorous, irritating, toxic, or otherwise undesirable ingredients such as ammonia, formaldehyde, crystalline silica (a known carcinogen in dust form)[16], acetone, odor-masking agents, glycols, and many other compounds, including fungicides and bactericides. Some of these may not be an *air quality* problem for occupants, but they may be hazardous to painters and those involved in manufacture of the paint. In addition, hazardous ingredients can degrade the natural environment during production and after disposal. Look for water-based paints

[16] Some low-VOC paints contain crystalline silica, a known carcinogen. One manufacturer's representative stressed that this ingredient is not a hazard in the wet paint — it is an issue only when dried paint is sanded, and dust is generated.

that are low-formaldehyde, zero- or low-VOC, *and* low toxic. While information supplied on manufacturers' data sheets may make certain claims about VOC content or toxicity, speak with technical staff at the manufacturers' headquarters or manufacturing facility to obtain detailed information on product performance and environmental hazards. It is recommended that all paints meet the emissions testing standards outlined in Specification Section 01350 and DHS' Standard Practice.

Specification Section 01350/DHS Standard Practice testing standards require a 10-day conditioning period followed by a 96-hour test period. During this 14-day period many of the more volatile compounds dissipate entirely. In the course of renovation projects and routine maintenance paint may be applied within 14 days (and sometimes within 24 hours) of the classroom being occupied. In this case the paints should be labeled low VOC as well as meeting Section 01350/DHS Standard Practice criteria. The ingredient list should be checked to verify that harmful VOCs are not present that will off gas during the first 14 days.

Specify products containing no lead, mercury, hexavalent chromium, or cadmium. Though regulations have eliminated many toxic components from consumer paint lines, industrial and commercial paints may still contain them. Check the MSDSs; all hazardous contents present at 1% of total weight and listed by OSHA as hazardous must be disclosed. Besides using Specification Section 01350/DHS Standard Practice and the MSDS review, more detailed information can be obtained from the manufacturer and by reviewing emissions test results to determine the type of biocides used as well as the presence of other potentially hazardous ingredients.

High-traffic areas or areas vulnerable to graffiti may call for a more durable and smoother (enamel) finish. These paints typically have a higher VOC content. While there is little test data comparing "high durability" and low-VOC paints, anecdotal information suggests that "high durability" (usually alkyd paint) products would be expected to show roughly twice the performance of low-VOC paints.

If possible, the selection process should include a side-by-side paint comparison of the various products being considered, and should include comparison of abrasion resistance (durability), hideability, volume solids, odor, and overall appearance. Final paint selection should consider the following elements:

- What is the allowable drying cycle for initial painting and subsequent maintenance cycles? Is the paint locally available? (An important consideration for future maintenance.)
- What is the expected durability or life expectancy required? Requirements will likely vary with the space. For example, one manufacturer had specific and different recommendations for gymnasiums, cafeterias, restrooms, general classrooms, and hallways.
- What is the method of application? Choices, such as in-house versus contractor and spray versus roller, have a bearing on paint choice.
- What are the budget constraints, including first-time and maintenance? Budget analysis should consider not just cost per gallon, but also evaluate area coverage per gallon and projected time between re-painting, which can vary greatly with conditions of use.

Installation

Paint should be installed prior to soft surfaces such as carpeting to prevent absorption of VOCs. Specify isolation requirements (isolation of construction zones from completed zones to prevent cross-contamination; removal, coverage, or isolation of porous materials to avoid their absorption and subsequent re-emission of solvents; maintaining negative pressure by exhaust ventilation in construction areas). Low-VOC paints may require a longer airing out time than other paints, so be certain to specify appropriate ventilation. When sanding dried paint, a dust mask should be worn.

Operation and Maintenance Issues

Review recommended duration between paint application and occupancy and review for compatibility with maintenance schedules/requirements. Ideally, work should be scheduled during unoccupied periods or periods of least occupancy. Large projects should be scheduled during the summer vacation months or other breaks. The maintenance schedule should also factor in manufacturer recommended air temperatures for application.

> ***Caution***
>
> *In jobs that require removal of old paint and may require chemical strippers, closely observe manufacturers recommendations for use, including ventilation and personal protective equipment.*
>
> *If performing renovation at a school constructed prior to 1980, do not begin work until testing paint samples for possible lead contamination. If lead-containing paint is present, observe appropriate abatement controls.*

Where possible, perform painting and stripping off-site or select materials with factory-applied finishes. For on-site interior painting, cover surfaces, such as fabric-covered furnishings, to which VOCs may adsorb. Consider constructing barriers (for example, walls or curtains of plastic sheeting) to help isolate portions of larger areas and minimize the distribution of dust and other pollutants.

Wipe down all surfaces with a wet cloth as soon as practical after completing all dust-generating work typically associated with surface preparation.

Carefully observe manufacturers recommendation for cleanup, storage, and disposal, for paints, primers, and thinners. Some products are classified as “flammable liquids” under federal regulations and must be stored in a specifically constructed safety cabinet. Keep paint containers covered as much as possible during and following use to protect against VOC release. For excess paint, consider recycle/reuse options.

All paint containers with residual liquid must be disposed of as hazardous waste per U.S. Environmental Protection Agency regulations. Only dry containers can be placed in municipal landfills. The contractor should leave only enough excess paint for touch up work after completion of the project and properly dispose of the remaining paint.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter, and:

Bainbridge Island High School (Bainbridge Island, Washington)—As part of a major renovation at the existing high school, Capital Works personnel, with assistance from an environmental consultant, conducted an investigation of locally available, low-VOC paint options.

Interior Painting and Indoor Air Quality in Schools. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager: (410) 767-0097.

Ross Middle School, Ross, CA (Marin County)—Interior wall & ceiling paint is “zero” VOC formulation.

GUIDELINE IS10: CASEWORK AND TRIM

Recommendation

Specify casework and trim constructed from formaldehyde-free binders and other environmentally preferable materials. Design for easy future disassembly and reuse. Specify assembly off-site where major off-gassing can occur before products are brought into the building. Install with least hazardous, low-volatile organic compound (VOC) content adhesives and coatings.

Figure 36—Wheatboard

This construction particleboard is made from wheat straw instead of wood fibers. Utilizing strawboard eliminates formaldehyde and other emissions, reduces forest exploitation and supports the use of an agricultural by product. Cabinetmakers found that the product is less coarse than wood fiber particleboard, although the edges required several costs of paint for proper sealing. For woodworkers, the product was lighter than wood fiber particleboard, and was more pleasant to work with because of its odor. Photo courtesy National Renewable Energy Laboratory (PIX # 09811).

Applicable Spaces
Classrooms
Library
Multi-Purpose / Cafeteria
Gym
Corridors
Administration
Toilets
Other

Climates
South Coast
North Coast
Central Valley
Mountains
Desert

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Description

Conventional particleboard is made with bonding agents including urea-formaldehyde, which can off-gas for years after application. (Please refer to the discussion of formaldehyde-related indoor air quality problems in the Overview.) Authorities recommend fully covering all six sides of each surface with plastic laminate, or coating the particle board with a sealer to prevent off-gassing of formaldehyde and other volatiles (see Caution callout, below). However, unless a product's particleboard is fully-covered, CHPS recommends using only products that use formaldehyde-free binders for interior use in high performance schools.

Environmentally preferable product alternatives for interior casework and/or trim include exterior grade plywood with phenolic formaldehyde resin, formaldehyde-free medium density fiberboard (MDF), oriented strand board (OSB), certified wood, salvaged lumber, bamboo, recycled plastic, metal, biocomposites (only for areas not subject to frequent wetting), and engineered wood. Certified MDF and plywoods also exist. Pre-assembled cabinets made with low-toxic materials and finishes, solid wood, engineered wood, and enameled metal are also available.

OSB, MDF, and other composite wood products can be strong sources of VOCs. Some of the emitted VOCs are terpenes which, when oxidized, form formaldehyde, higher molecular weight aldehydes, and acidic aerosols. Some of these oxidation products are more irritating or toxic than the chemicals emitted from the wood products. For instance, composite wood is the leading contributor to indoor formaldehyde levels, so reducing the amount of composite wood used is crucial to protecting indoor air quality. Some composite wood products manufactured with urban waste wood can contain wood preservatives, lead-containing paint, and other toxic compounds.

Acid-cured lacquers applied as finishes to wood products can be long-lasting sources of formaldehyde emissions.

Applicability

All interior casework and trim.

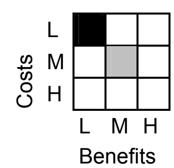
Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

None.

Cost Effectiveness



There is a cost premium for certified wood, ranging from modest to significant, depending upon quantity, type, and current availability. Engineered wood often costs less than virgin lumber. MDF made with formaldehyde-free binders may also cost more.

Benefits

Formaldehyde-free products and low toxic glues/adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants. Certified wood is produced in a way that is ecosystem-protective. Products made from certified hardwoods are durable and reusable.

Engineered lumber makes use of wood waste that would otherwise be discarded. Products made with engineered wood have low moisture content and are warp-resistant and shrink-resistant, adding to their durability. The products are strong, and their predictable qualities lead to less rework.

Bio-composite materials are made from natural, renewable resources including straw, recycled paper products, and a soy-based resin systems. These products have reduced emissions and are material efficient.

When plastic laminates are selected, look for options made from recycled laminating manufacturing wastes, which are material efficient and recyclable.

Design Tools

See the Design Tools listed in this chapter's Overview, and:

Certified Forest Products Database, Certified Forest Products Council, www.certifiedwood.org. 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. (503) 590-6600. Industry information on suppliers and standards.

Design Details

Caution

Many of the engineered lumber products contain formaldehyde or other chemicals that are detrimental to the environment and to indoor air quality. Some types of particleboard are now being manufactured with resin binders that do not contain formaldehyde. If formaldehyde-free particleboard or plywood products are not available, select exterior grade plywood in lieu of interior grade products. Exterior grade contains phenol formaldehyde, which is less harmful than the urea formaldehyde in interior grade plywood.

Note: Some practitioners recommend coating conventional particleboard with an impermeable sealant to prevent out-gassing of formaldehyde and other volatiles. However, others disagree that this is effective mitigation.

Design interior building components for future disassembly, reuse, and recycling.

Selection

Environmentally preferable alternatives include:

- Using certified hardboards with woods grown in regional forests, which reduces the energy consumption involved in transportation. Woods common to the western area include pine, aspen, spruce, fir, and hemlock.
- For casework, consider urea formaldehyde-free MDF, or equal, exterior grade plywood (made with phenolic formaldehyde, which emits far less formaldehyde than the urea formaldehyde in traditional interior grade products).
- Consider veneered wood panels, such as OSB with hardwood facing, for cabinets and millwork. If installed for easy removal, they are reusable.
- Powder-coated finishes are harder than many paints and can actually rival plating for durability. For woods, factory-applied and -cured coatings such as urethanes have minimal emissions, and the factory can capture the resulting dust and recycle solvent.
- Bamboo can be used for countertops. Also consider biocomposites for countertops in reception or other high profile (but not wet) areas.
- Low-density fiberboard is made from paper and wood fiber, available made from 100% recycled newsprint. Most processes use no glue. They are suitable for uses such as underlayment and tackboards.

- Recycled plastic panels made from consumer product waste are available for functional worktops. If installed for easy removal, they are reusable.
- Vegetable oil-based plastics are available in both flexible and rigid types. They can be colored and filled with minerals, metal shavings, or other plastic waste and wood fiber giving them a large range of texture and color possibilities. If installed for easy removal, these also have good reuse potential.
- Fiber reinforced cement boards made with recycled fiber are a durable, material efficient choice for use as substrates for tile and decorative finishes. If installed for easy removal, these also have good reuse potential.
- It is recommended that all casework assemblies and wood furnishes meet the emissions standards outlined in Specification Section 01350/DHS Standard Practice. It may also be beneficial to obtain and review MSDS and emission test data. Wood naturally emits formaldehyde, so test data should be carefully reviewed.

Installation

Dust from cutting and emissions from glues used for installation are indoor air quality issues during and after installation. Specify work to be performed in a shop off the premises where practicable. Require installer to use the smallest amount of adhesive/sealant necessary to fulfill the manufacturer's performance specifications for that product. Specify use of adequate ventilation and VOC-safe worker masks. Where appropriate, specify installation to permit easy removal and reuse, for example, screwed assembly instead of glued.

Operation and Maintenance Issues

Issues will vary with type of material selected, but are similar to requirements for traditional materials.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter, and:

For general information on certified lumber, contact: Certified Forest Stewardship Council, Jeff Wartelle. Phone: (503) 590-6600. Industry group provides information on distribution and other assistance.

Certified Forest Products Database, Certified Forest Products Council. Web site: www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Phone: (503) 590-6600. Industry information on suppliers and standards.

Two private companies in the U.S. are authorized to issue the FSC stamp of approval: Scientific Certification Systems (SCS) in Oakland, CA (www.scscertified.com/forestry/), and SmartWood Certified Forestry, based in Richmond, VT, with an affiliate in Oregon (www.isf-sw.org/cert.htm).

The American Bamboo Society. Web site: www.bamboo.org/abs.

APA -The Engineered Wood Association. Phone: (206) 565-6600. Web site: www.apawood.org. Email: product.support@apawood.org

American Institute of Timber Construction. Phone: (303) 792-9559. Fax: (303) 792-0669. Web site: www.aitc-glulam.org. Email: webmaster@aitc-glulam.org.

American Wood Council. Phone: (202) 463-2700. Web site: www.awc.org/. Email: AWCINFO@afandpa.ccmail.compuserve.com.

National Particleboard Association. Phone: (301) 670-0604. Web site: www.pbmdf.com. Email: info@pbmdf.com.

Western Wood Products Association. Phone: (503) 224-3930. Web site: www.wwpa.org. Email: info@wwpa.org.

Phenix Biocomposites, LLC. Makes a variety of engineered panel products using agricultural byproducts and other renewable, sustainable and recycled resources. Phone: (800) 324-8187. Web site: www.phenixbiocomposites.com.

GUIDELINE IS11: INTERIOR DOORS

Recommendation

Select formaldehyde-free interior doors constructed with recycled content or from certified wood. Avoid particleboard core board doors, which contain urea-formaldehyde and luan doors, which are made from wood harvested from rain forests. Select pre-finished products, if possible. If finishing on-site, select low-toxic, low-volatile organic compound coatings.

Figure 37—Interior Door

Randy Karels, photographer.

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	■	Mountains	■	Contract Docs.	■
Corridors	■	Desert	■	Construction	■
Administration	■			Commissioning	□
Toilets	■			Operation	■
Other	■				

Description

Interior doors are usually wood, molded hardboard, or hollow core. Luan plywood is harvested from rain forests, so it should be avoided unless it has a Forest Stewardship Council (FSC) or other certification. Molded hardboard is often made with recycled material and pressed into shape, but some is made with urea-formaldehyde and should be avoided.

If using solid wood doors, select products with FSC or other certification (clear stock is becoming rare and if uncertified, often comes from old-growth forests).

Applicability

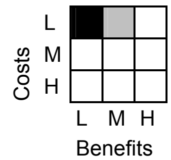
All spaces.

Applicable Codes

See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

In areas where a high degree of speech privacy and/or sound isolation is required, doors should be solid core wood or hollow metal with acoustic fill. Full perimeter gaskets should also be included to reduce sound leaks around the edge of the door. Standard weather stripping with a door bottom sweep will minimize sound leaks, but wears down with use. Doors in areas that require a high degree of sound isolation should have heavy-duty adjustable sponge neoprene gaskets at the head and jamb. Automatic door bottoms with a neoprene element should also be used.



Cost Effectiveness

Costs are low.

Benefits

Avoiding luan and solid wood doors help protect limited forest resources. Formaldehyde-free materials protect indoor air quality and contribute to a more healthful environment. Low-toxic finish coatings minimize indoor air pollution load and health risks to both installers and occupants.

Design Tools

See the Design Tools listed in this chapter's Overview.

Design Details

Review emissions data and MSDS prior to specification of a recycled content molded hardboard product to ensure that it is urea-formaldehyde-free. It is recommended that all hardboard products meet the emissions specifications outlined in Specification Section 01350 and DHS's Standard Practice.

Operation and Maintenance Issues

May require periodic re-coating for aesthetic purposes. Type of paint determines the ability to clean the surface.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE IS12: TOILET PARTITIONS

Recommendation

Select high durability, solid plastic toilet and shower partitions with recycled content.

Description

Several styles of toilet partitions are available, including baked enamel over metal, plastic laminate over particleboard, and solid plastic panel. Solid plastic toilet/shower partitions are the most durable type overall. Recycled content products are made with a post-consumer, high-density polyethylene (HDPE) content between 20% and 35%, depending on the manufacturer. In addition, some brands contain postindustrial plastic material. Look for purified HDPE, as it contains a predominant amount of post-consumer waste.

Figure 38—High-Density Polyethylene Partitions

High-density polyethylene (HDPE) restroom partitions are maintenance-friendly and durable. Photo reprinted with permission from Santana Solid Plastic Products. www.santanaproducts.com

Applicable Spaces		Climates		When to Consider	
Classrooms	☐	South Coast	■	Programming	☐
Library	☐	North Coast	■	Schematic	☐
Multi-Purpose / Cafeteria	☐	Central Valley	■	Design Dev.	■
Gym	☐	Mountains	■	Contract Docs.	■
Corridors	☐	Desert	■	Construction	■
Administration	☐			Commissioning	☐
Toilets	■			Operation	■
Other	■				

Applicability

All toilet/shower partitions.

Applicable Codes

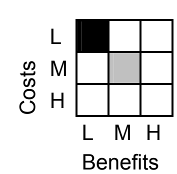
See the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

None.

Cost Effectiveness

Recycled content units cost 20% more than conventional units, but are more durable, require less maintenance, and can be reused. In addition, recycled content toilet partitions generally have a 15-year warranty verses the standard five-year warranty of other partition products.



Benefits

Recycled content partitions are material efficient, low maintenance, rot resistant, and graffiti/vandal resistant.

Design Tools

See the Design Tools listed in this chapter's Overview.

See also Santana Solid Plastics Products, www.santanaproducts.com/products-partitions.asp, for sample specifications for solid plastic, recycled content toilet partitions, floor-mounted, ceiling mounted, and floor-to-ceiling models.

Design Details

None.

Operation and Maintenance Issues

None.

Commissioning

None.

References/Additional Information

See the Overview section of this chapter, and:

Cold Spring Elementary School, Santa Barbara, CA. Used recycled content toilet partitions.

Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction. Revised July 2000. A publication of the California Integrated Waste Management Board. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix E sample specifications for: Section 10160; Solid Plastic Partitions. Designing with Vision can be downloaded in four parts from www.ciwmb.ca.gov/GreenBuilding/. Chapter 8 is in Part D.

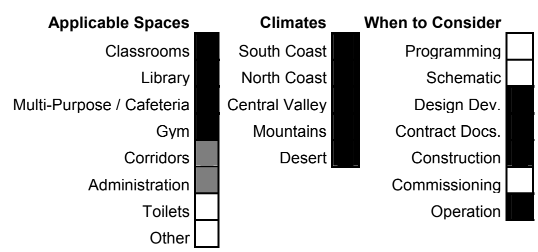
GUIDELINE IS13: ACOUSTICS—REVERBERATION TIME

Recommendation

Specify soft interior surfaces which have an appropriate Noise Reduction Coefficient (NRC) and result in a reverberation time of less than 0.6 seconds in typical classrooms.

Figure 39—Acoustical Ceiling Tiles

Photo Courtesy: SoundSuckers (permission not requested)



Description

Reverberation time is an important acoustical measure that is used to determine the amount of time it takes for a sound to decay within a room. Simply put, it is the echo within the room. Softer surfaces with a higher NRC absorb more sound therefore reflecting less back into the room. Ceiling tiles, carpeting and acoustic wall panels are the primary sound absorbing materials that are specified in schools.

Applicability

Reverberation time is critical in classrooms and other teaching spaces. Auditoriums, cafeterias, gymnasiums, multipurpose rooms and administrative areas also have acoustical considerations.

Applicable Codes

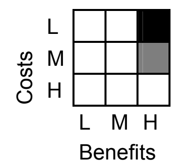
ANSI Standard S12.60-2002.

See also the Applicable Codes section in this chapter's Overview.

Integrated Design Implications

Classroom acoustics is also affected by external noise transmitted into the classroom and noise form the HVAC system. See the Building Envelope chapter for a discussion on Sound Transmission Classification (STC) ratings and the HVAC chapter for Noise Criteria (NC) considerations in the design and selection of HVAC systems. Finish surface materials also have an effect on other issues. Carpeting, for instance, absorbs sound and makes for a more comfortable surface for sitting, while hard floors reflect sound but may be easier to maintain. The NRC of a ceiling tile is independent of it's ability to reflect light for use with daylighting strategies.

Cost Effectiveness



The cost of a mediocre acoustical ceiling (NRC 0.55) and a good acoustical ceiling (NRC 0.75) is about $ 0.40 /ft². (The reverberation time for the mediocre classroom is 0.75 seconds and the good classroom is 0.55 seconds, a noticeable improvement to within the classroom standard). The cost of poor acoustics includes teacher absenteeism (data shows that teachers miss 2 days a year on average due to vocal fatigue[17]) and reduced student learning.

Benefits

Proper classroom acoustics will ensure an environment conducive to learning. Teachers should be able to use a natural teaching voice free from stress and students should be able to clearly hear teachers and other students. Studies have shown (ASA 2000) that in many classrooms only 75% of spoken words can intelligibly be heard by the students.

Design Tools

See the Design Tools listed in this chapter's Overview.

Reverberation time can be estimated by the following formula:

$$RT(60) = \frac{0.05 \cdot V}{\sum S \cdot \alpha}$$

Where V is the volume in ft^3, S is the surface area of a room surface in ft^2 and α is its sound absorption coefficient at a given frequency. Absorption coefficients of common interior surface materials are provided in the ASA guideline on classroom acoustics (ASA 2000) and from manufacturer's data. The Noise Reduction Coefficient (NRC) is the average of absorption coefficients at different frequencies that occur in human speech.

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[17] See Classroom Acoustics II, p 8. See the bibliography for a complete citation.

Design Details

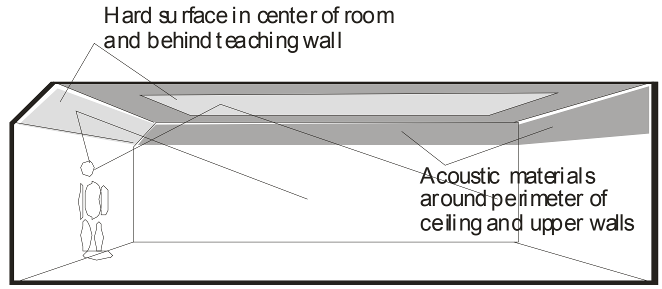

Figure 40—Classroom Acoustics

Using both hard and soft (NRC) materials can be used to achieve good classroom acoustics.

A RT of 0.4 to 0.6 seconds is the standard for classrooms, depending on volume. A longer RT results in echoes, reducing speech intelligibility. On the other hand, too much sound absorption can reduce the benefits of early sound reflections causing the speakers voice to fall off rapidly with distance. This is especially true in larger spaces such as lecture halls. Diffusing elements placed on the walls of a classroom are another method to reduce reverberation time. This technique scatters the sound into many directions thereby reducing the sound reflected in any one direction.

Reverberation Time (RT) depends on the physical volume and the surface materials of a room. Since the size of the classroom and the ceiling height are determined by program requirements and needs for lighting and daylighting. The only reasonable way to design for acceptable reverberation is through the use of materials with an appropriate noise reduction coefficient.

Reverberation time is a common problem in large spaces such as gymnasiums. Recommended maximums for reverberation time is 0.8 seconds for auditoriums, and 1.2 for gymnasiums. If the roof construction is an exposed metal deck, perforations on the deck and fiberglass above the deck can absorb sound. Adding fiberglass or wood panels to the interior walls will also help.

Acoustic wall panels can help reduce reverberation where ceiling panels alone do not achieve the recommended reverberation time of ANSI Standard S12.60. A 1" thick panel provides a noise reduction coefficient of 90% or higher. A new panel made of recycled cotton fibers, bonded acoustical pad, meets flammability and durability standards and is relatively inexpensive. Their application in classrooms is limited to the small amount of wall space not covered by white boards, casework and student posting. They are a good high performance option for school gymnasiums and a good retrofit option for classrooms with excessive noise levels.

Operation and Maintenance Issues

It is important that surfaces be maintained in their original form to retain their acoustical integrity. Painting over acoustic ceiling tiles, for example, raises the NRC, effectively negating their acoustical benefits.

Commissioning

None.

References/Additional Information

Acoustical Performance Criteria, Design Requriements, and Guidelines for Schools, American National Standards Institute (ANSI) Standard S12.60-2002.

Classroom Acoustics, A resource for creating learning environments with desirable listening conditions. Acoustical Society of America, 2000.

Classroom Acoustics II, Acoustical barriers to Learning. Acoustical Society of America, Acoustical Society of America, 2002.

Lighting and Daylighting

OVERVIEW

This Overview introduces lighting and daylighting in schools and reviews important design criteria. This is followed by a primer on daylighting and a primer on electric lighting. The primers review principles and concepts that may not be familiar to all readers. The guidelines listed below then follow this material. The guidelines include both daylighting guidelines and electric lighting guidelines, presented in that order.

- Guideline LG1: View Windows
- Guideline LG2: High Sidelighting—Clerestory
- Guideline LG3: High Sidelighting—Clerestory with Light Shelf or Louvers
- Guideline LG4: Classroom Daylighting—Wall Wash Toplighting
- Guideline LG5: Central Toplighting
- Guideline LG6: Patterned Toplighting
- Guideline LG7: Linear Toplighting
- Guideline LG8: Tubular Skylights
- Guideline LG9: Classroom Lighting—Conventional Teaching
- Guideline LG10: Multi-Scene Classroom Lighting
- Guideline LG11: Teaching Board Lighting
- Guideline LG12: Lighting Controls for Classrooms

- Guideline LG13: Gym Lighting
- Guideline LG14: Corridor Lighting
- Guideline LG15: Lighting for a Multi-Purpose Room
- Guideline LG16: Lighting for a Library or Media Center
- Guideline LG17: Lighting for Offices and Teacher Support Rooms
- Guideline LG18: Lighting for Locker and Toilet Rooms
- Guideline LG19: Outdoor Lighting

Some of the material that would otherwise be repetitious in the guidelines is included in the Overview, such as information on codes and standards and references.

Daylighting is the cornerstone of energy efficient, sustainable, and high-performance school design. Windows and skylights, if properly designed, can provide high quality interior illumination without excessive solar heat gain, and they can also be used to provide natural ventilation. Electric lighting systems can then be extinguished or dimmed for most school hours, saving significant electric lighting and cooling energy and extending the useful life of the electric lighting components. In addition to energy benefits, daylit schools have been shown to improve learning (see the Daylighting Primer below).

Classroom with Balanced Illumination

Central toplighting from a saw tooth monitor with sun baffles is combined with view windows to provide balanced illumination in a classroom. Source: Barbara Erwine

Daylight is provided via windows and glazed doors, and skylights. These glazed openings are referred to as "fenestration." See the Building Envelope chapter for information on fenestration performance criteria. The placement, design, and selection of fenestration are extremely important and can tip the balance between a high- and low-performance school. Fenestration has an impact on building energy efficiency by affecting cooling loads, heating loads, and lighting loads. Visual comfort is strongly affected by the window location, shading, and glazing materials. Well-designed windows can be a visual delight. But poorly designed windows can create a major source of glare. Thermal comfort can also be compromised by poor fenestration design. Poorly insulated windows add to a winter chill or summer sweat, while windows with low U-values keep glass surface temperatures closer to the interior air temperature, improving thermal comfort. In addition, east-west windows and unshaded south windows can cause excessive cooling loads. And although windows and skylights provide opportunities for natural ventilation, they must be designed to ensure a safe, secure, and easily maintained facility.

Moreover, daylighting provides opportunities for architectural creativity, such as the creation of structures and shapes that produce filtered or indirect daylighting while serving as visually stimulating elements of the design.

Daylighting design today is very similar to electric lighting design. Rather than selecting fenestration simply for view or aesthetics, architects must now carefully consider the amount and distribution of daylight. Some daylighting techniques have limted applications and often it is best to combine two or more daylighting techniques to achieve a good design. Selection criteria for some common daylighting strategies are summarized in Table 10. A guideline is provided later in this chapter for each of the referenced daylighting patterns.

Table 10—Selection Criteria for Daylighting Strategies

	Daylighting Patterns							
Design Criteria	**View Windows**	**High Sidelight**	**High Sidelight w/ Light Shelf or Louvers**	**Wall Wash Toplight**	**Central & Patterned Toplight**	**Linear Toplight**	**Atria & Light Well**	**Tubular Skylights**
Uniform Light Distribution	○○	**○**	●	●	●●	**○**	**○**	**○**
Low Glare	○	●	●●	●●	●	●	●	●/○
View	●●	○	○○	○○	○	●/○	●●	○○
Reduced Energy Costs	○	●	●	●	●●	●	●	●
Low First Cost	●	●	○	●	●●	●	○○	●●
Cost Effectiveness	●	●	●	●	●	●	●	●●
Safety/Security Concerns	○	●	●/○	●	●	●	●/○	●●
Low Maintenance	○	●	●	●	●	●	○	●

●● Extremely good application ● Good application ○ Poor application ○○ Extremely poor application **○** Depends on space layout and number and distribution of daylight apertures ●/○ Mixed benefits

While many of California's climate zones provide ample daylight for most school activities, there will always be a significant need for good quality electric illumination. Schools are operated early in the morning and late in the afternoon in winter months, and during inclement weather. Also, many schools are used at night in support of adult education, community activities, and other events. While daylighting serves to save energy when daylight is abundant, the electric lighting system remains necessary and it should be of good quality overall.

In a high performance school, electric lighting systems should:

- Use T-8 and T-5 fluorescent lighting systems in most spaces, using the latest electronic or electronic dimming ballasts and efficient luminaires.
- Use ceramic metal halide, compact fluorescent, or other efficacious sources when fluorescent systems can't be used.
- Be carefully designed to meet modern lighting design criteria while operating at lower lighting power density than allowed by Title 24.
- Achieve an aesthetic appearance that is in balance with architecture and interiors elements.

- Address multiple function spaces with additional layers of lighting designed to achieve the right mood for each use.
- Employ automatic daylight controls to “harvest” daylight whenever it is available.
- Employ motion sensing controls to appropriately turn off electric lights in response to occupancy.
- Employ time of day controls for public spaces that ensure lights are off when not needed.
- Provide manual switching and dimming controls that permit teachers and staff to configure lighting for the needs of the room.
- Employ carefully designed exterior lighting that prevents artificial sky glow, glare and obtrusive light.

In order to achieve the substantial energy savings possible in high performance schools, all members of the design and construction teams must collaborate more than ever. For instance, in the programming and schematic design of the school, architects will need to seek the input of electrical and mechanical engineers and other consultants who traditionally become involved later in the project. In particular, daylighting analysis is mostly performed in early schematics as the architect evaluates possible basic massing and site plan options. Proper decisions made early in the design can minimize more difficult choices later as the whole building energy modeling process is undertaken.

While the design of electric lighting can be undertaken later in the process, keep in mind that the principal objective of integration is to turn off as many electric lights as possible. The lighting designer must understand the performance of the daylighting on a daily and annual basis. Then, design lighting with the knowledge that specific luminaires are intended to be off or dimmed during daylight hours.

Lighting Design Criteria

The primary purpose of lighting, whether electric light or daylight, is to provide a visual environment that enhances teaching and learning, provides an appropriate mood and atmosphere and allows students and teachers to perform their visual tasks quickly and comfortably. In setting lighting design criteria, it is important to consider all of the possible issues involving lighting. In its *Ninth Edition Lighting Handbook (2000*), the Illuminating Engineering Society of North America (IESNA) has devoted an entire chapter to the complex criteria that are involved in modern lighting design. The IESNA recommends consideration of all of the following criteria, varying the importance of each on a project:

- Appearance of space and luminaires.
- Color appearance.
- Daylighting integration and control.
- Direct Glare.
- Flicker and Strobe.
- Light distribution on tasks and surfaces (illumination).

- Light distribution on task place (uniformity).
- Luminance of Room Surfaces.
- Modeling of faces or objects.
- Points of interest.
- Reflected glare.
- Shadows.
- Source/task/eye geometry.
- Sparkle/Desirable reflected highlights.
- Surface characteristics.
- System control and flexibility.

In a classroom, illumination, distribution, luminaire and daylighting integration will be among the most important considerations, while sparkle and highlights, which are often more important in entertainment and retail lighting, are significantly less important in the classroom. A chapter in the IESNA Lighting Handbook is devoted to lighting in schools, and for more information, the IESNA publishes "Lighting for Educational Facilities," RP-3-00. Readers should note that the California energy efficiency standards and CHPS are significantly more concerned about energy efficiency and daylighting than the IESNA, so keep this in mind when consulting IESNA and other national and international publications.

Light Quantity (Illumination and Uniformity)

Visual tasks are the things we do inside our buildings that require light, such as reading, walking down a corridor, watching a presentation, etc and light quantity is the most important criterion in school lighting. In order to determine whether there is enough light, the common measure of the quantity of light is footcandles at the task level or position. The IESNA publishes illumination level recommendations (see above) for a variety of spaces types or visual tasks. In the *IESNA Lighting Handbook (2000)*, the IESNA provides as part of its recommended lighting design procedure the most recent recommendations for horizontal illuminance. Table 11 shows some of the common recommendations for general visual tasks.

Table 11—IESNA Recommended Illumination Levels for General Visual Tasks

Category	Description	Recommended Illuminance (fc)
Orientation and Simple Visits	Public spaces (Corridors at night, entrance canopy)	3 fc
	Simple orientation for short visits (Waiting rooms, elevators)	5 fc
	Working spaces where simple visual tasks are performed (Lobbies, corridors, locker rooms)	10 fc
Common Visual Tasks	Performance of visual tasks of high contrast and large size (Meeting rooms, storage areas, copy rooms)	30 fc
	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size (Filing, open offices, private offices)	50 fc
	Performance of visual tasks of low contrast and small size (Feature displays & inspection areas)	100 fc
	Performance of visual tasks near threshold (Surgery & sewing)	300–1,000 fc

Source: IESNA Lighting Handbook*, 9th ed. (2000), p. 10–13*

The lighting levels listed above are AVERAGE levels, and that a variation of about ⅓ this value is acceptable. For visual tasks of high contrast and large size (an average of 30 footcandles is recommended above), 30 footcandles plus or minus 10 footcandles is considered acceptable.

The process of selecting light levels requires the lighting designer to consider, among other things, the age of the viewer, the importance of speed and accuracy, the number and type of different tasks and the size of the visual tasks. For instance, examination of Table 11 suggests that classrooms will most likely have a combination of high contrast, large size tasks and high contrast, small size tasks. Given a wide range of ages that use a classroom (considering both normal and adult education) and moderate needs for speed and accuracy, most of the space should have a minimum of 30 footcandles, with an average of about 40–45 footcandles. In this way, most of the classroom will meet more demanding criterion (50 footcandles ± ⅓) and yet use a minimum amount of energy.

The IESNA recommendations are based on electric illumination. In a well designed daylit classroom, light levels can easily range between 30 and 250 footcandles throughout of the day (badly designed daylighting levels can be much higher). More lighting is generally better and visual performance increases, up to a point. However, as projected media is more widely used in the classroom teaching environment (see Teaching Technology Issues, below) this adage is not necessarily true. In the fully modern classroom, it may be necessary to set several criteria for light levels, e.g. one for general instruction and one that works better with LCD projectors or other teaching technology.

Table 12—Illumination Criteria for Daylit Classrooms

Activity (Scene)	Task Light Level (average at desks in classroom)	Acceptable Variation of Task Light Level	Other Considerations
Reading, artwork, social time, etc.	45 footcandles (minimum of 30 footcandles)	30–250 footcandles	Daylight glare control required
Normal Lecture Chalkboard or whiteboard	45 footcandles (minimum of 30 footcandles	30–250 footcandles; dimming to lower levels may be useful	Additional vertical surface lighting for board should be considered
Screen Lecture	15 footcandles	Dim to lower levels is permissible; higher levels should probably not be used.	Maximum of 5 vertical footcandles at any point on screen; room use shades required

Also note that special purpose classrooms, such as arts or shop, may have higher light level requirements. It is critically important to identify these spaces and tasks. Note, however, that unlike classrooms, in which seats are generally evenly distributed throughout and can move around, special work areas such as industrial arts equipment are fixed and the high light levels are only needed at the machine itself. It is normal to set different task light levels in the same space and to then design accordingly.

Lighting Quality

IESNA's lighting design procedure consists of a six-step process that emphasizes the relative importance of numerous design issues for specific applications. IESNA is clear that adequate illumination consists of much more than just horizontal illuminance. Other issues and design criteria include: color appearance, daylighting integration and control, illumination of room surfaces, vertical illumination, glare control, uniformity, and color rendering.

Vertical Illumination. Vertical illumination is one of the more critical design issues in many building types. The perception of what comprises lighting quality is strongly influenced by vertical (not horizontal) illumination. For example, wall illumination is a critical factor in the sense of brightness and cheerfulness of a room. In nighttime environments, vertical illumination enables facial recognition and is important to create a sense of safety and security. Appealing vertical illumination also promotes social communication. In the case of classrooms, vertical surface illumination may be critical with respect to chalkboards, whiteboards and other teaching surfaces.

Glare Control. Light sources that are too bright create uncomfortable glare, particularly in rooms with dark colored surfaces. In extreme cases, direct or reflected glare can also impair visual performance by reducing task visibility. In such a case, fatigue results from the eye having to work much harder to adjust to the luminance (brightness) extremes. All sources of light, including daylight, must be carefully controlled to avoid causing discomfort or disabling glare. Common glare problems include uncomfortable overhead glare from direct distribution luminaires, reflected luminaire imaging on video display terminals and whiteboards, and direct glare from uncontrolled windows or skylights. Very bright electric sources, such as bare fluorescent lamps, should be shielded or mounted sufficiently far away so as not to create an unacceptable level of glare. Luminaires using at least some indirect lighting systems tend to produce less glare.

Uniformity. Most task-oriented building spaces should be illuminated as uniformly as possible, avoiding shadows or sharp patterns of light and dark. In most instances, luminance contrast ratios between the visual task and its immediate surrounding should not exceed 3:1, and contrast between the brightest surfaces in the visual field and the visual task should not exceed 10:1 (see also the Glare Control paragraph above). Higher ratios contribute to fatigue, because the eye is constantly adapting to differing light levels. Avoid recessed or surface-mounted parabolic fixtures in spaces where it is important to have bright upper walls and ceilings. Exceptions might include lighting systems for theaters and social spaces, where downlighting systems might be used to create a dramatic atmosphere. Daylight should be balanced across a space or should be supplemented with electric lighting that balances its distribution in the space.

Maximize overall lighting uniformity by following guidelines for maximum spacing of luminaires, which is provided by the lighting fixture manufacturer in the form of spacing criteria. Spacing Criterion (formerly spacing-to-mounting-height ratio) is a number that indicates the ratio of the maximum spacing between luminaires to the mounting height above the work plane to achieve uniform illuminance. This value can be expressed in length and width for non-symmetrical illuminance patterns, i.e., 24 in. x 48 in. fluorescent troffer. The best method of maximizing uniformity is to make a concerted effort to light the ceiling and vertical surfaces using indirect or indirect/direct luminaires and light-colored, diffuse surface materials.

Color Rendering. Light sources that render color well enhance the visual environment. Light sources should have a minimum color-rendering index (CRI) of 80 for most interior spaces. Daylight through modern glazing systems has slightly distorted color, but in most cases it maintains CRI >80. Ceramic metal halide lamps, the latest high-performance T-8 lamps, T-5 lamps, and most compact fluorescent lamps have a CRI in the range of 82–86. (In critical color rendering environments, such as fine arts, it is possible to use fluorescent T-8 lamps with CRI>90, although due to their expense, lower lumen output, and uncommon nature, restrict these choices to spaces where they are really needed.)

Color Temperature. Modern lighting systems are typically available at 3000K (warm), 3500K (neutral) and 4100K(cool). In general, spaces designed at 3000K are more agreeable in colder climates, and 4100K appears better in warmer climates. It is very common to choose 3500K to split the difference. All fluorescent lamps allow the choice of lamps at these color temperatures, and in most lamp types, at 5000K as well. Halogen lamps, which should probably be restricted to art display, for theater house lighting and for “mood” lighting in select spaces, are around 3000K and look good with 3000K and 3500K fluorescent lamps. Ceramic metal halide lamps are available at both 3000K and 4000K, and the 3000K goes well with both 3000K and 3500K fluorescent lamps. Avoid extremely low color temperature lamps like 2700K.

There is a growing debate over visibility benefits and photobiological affects attributed to 5000K (and higher) lamps. In California, extensive experiments using this theory have been pursued by PG&E and are part of a US Department of Energy investigation, but so far the IESNA has not yet determined that the results warrant changes in theory or practice. CHPS presently advises careful consideration of the use of this theory, noting that many of the benefits attributed to these lamps are achieved far better by daylighting. If students are mostly in daylit classrooms and activity areas like libraries, the benefits of these lamps are almost totally moot as the spectral qualities that cause the so-called scotopic effects are abundant in daylight.

Lighting Control Flexibility

Lighting controls should be designed to accommodate the varying nature of most spaces. In addition to saving energy, bi-level or multiple-level switching enables different light levels to respond to changing requirements. Separate circuiting of luminaires in daylit zones also enhances space flexibility and energy savings. Control flexibility improves lighting energy performance by encouraging the use of lights that are only needed for the activity at hand and increases occupant satisfaction through user control.

Lighting control systems must also be easy to understand and operate. Non-intuitive control interfaces are likely to be ignored at best, and disabled in more extreme cases.

The Need for Light Modulation and Control

The visual needs of a classroom have evolved as the tools and technologies used for instruction have changed. In the 1960s and 70s, when many school lighting standards were developed, teachers were instructing with chalk on blackboards and running super-8 film clips, handing out lessons on fuzzy mimeo sheets. In the 1980s and 90s, white marker boards and overhead projectors increasingly replaced chalk boards, TV screens and computers replaced old film projectors, and high contrast copies replaced mimeo sheets. Now, in the new century, we have the prospect of rapidly evolving technology that is likely to permeate the classroom and once again change the visual needs of the classroom. Any classroom designed and built now, should be be flexible enough to accommodate both current technology and any future innovations.

Thus, any increase the ability of the teacher to control and modify the lighting conditions in the classroom is likely to both support current teaching needs, and the ability to adopt future innovations. California's Title 24 energy efficiency codes require a minimum of two levels of illumination in classrooms and other spaces. In a high performance school, multiple levels of illumination control are recommended so that all current and future visual needs can be met.

Contrast and the Screen

The ability to obtain information from any visual task is largely due to the contrast between data, such as letters or numbers, and the background, such as paper or a whiteboard. In the simplest of terms, contrast is the ratio of white levels to black levels (in the real world, black levels are not really zero, but very low levels of luminance). For example, the contrast of black marker letters on a whiteboard may be 20:1 or higher.

It is recommended that illumination on the screen from daylight or electric lights be limited to a maximum of 5 vertical footcandles, which will generally result in 10:1 contrast which is minimally acceptable for most video presentations. When possible, higher contrast should be able to be achieved by further dimming, turning lights off or through use of black-out shading. Rear screen projection systems and large screen plasma and direct CRT systems are less susceptible to room light but are significantly more expensive and/or physically more intrusive.

Finally, computer screens, especially laptop screens, are expected to become a significant part of the classroom. Most computer screens are adequately bright in rooms lighted to 30 footcandles or more. However, careful juxtaposition to windows and skylights is important.

Lighting and Daylighting Implications

Restricting vertical surface illumination to 5 footcandles is difficult when daylighting is provided by windows. Windows can easily create 100 vertical footcandles or more, suggesting the need for window shades that allow only 1%–3% of the light to pass. Electric lighting systems can also provide too much light on the screen. Most general lighting systems including troffers as well as suspended lighting systems produce 15-25 vertical footcandles when generating 40–50 horizontal footcandles for typical classroom work. So in addition to reducing or eliminating daylight, it is necessary to reduce electric lighting levels as well, either through dimming or through switching.

Table 13—Teaching Technologies and Impacts

Medium	Requires external illumination	Sensitivity to ambient light	Recommended provisions
Chalkboard (black or green)	Yes, at least 30–40 vertical footcandles are recommended	Not at all	None
Markerboard (white or gray)	Yes, at least 10–15 vertical footcandles are recommended	Specular finish can cause bright flashes	Should not be opposite windows; not suitable for use as a projection surface
Television (CRT)	No	Specular (glass) screen is subject to bright flashes from windows and lights; room may need to be darkened for best visibility.	Should not be opposite windows; curved screens can be affected by skylights, windows and lights from many angles
Video display (flat panel)	No	Room may need to be darkened for best visibility	Should not be opposite windows or directly washed by skylights.
Rear projection (self contained)	No	Room may need to be darkened for best visibility	Should not be opposite windows or directly washed by skylights
Smart Screen with self contained rear projection	No	Room will need to be darkened	Room will require darkening shades
Front Screen Video Projection	No	Room will need to be darkened	Room will require darkening shades
Conventional overhead projection	No	Almost none	None
Conventional film and slide	No	Room will need to be darkened	Room will require darkening shades

Mercury and Lamp Recycling

Mercury in fluorescent lamps is a serious issue that has been documented and is being addressed by the lighting industry. Mercury is a toxic element and there are significant concerns about mercury being emitted into the atmosphere or released into groundwater when fluorescent lamps are discarded.

Fluorescent lamps use electricity to excite mercury gas so that it emits ultraviolet light, which in turn causes the phosphor coating to fluoresce and emit light. On average, fluorescent lamps traditionally contained approximately 40 mg of mercury per 4-ft lamp (about 1980). Recent developments in lamp technologies have resulted in low mercury lamps that contain about 10 milligrams or less per lamp. However, without special lamp components to preserve useable mercury, less mercury can decrease lamp life.

Most HID lamps also contain mercury, and low mercury versions exist for some types, especially high-pressure sodium. A few mercury-free HPS lamps are available for special situations. The low mercury HPS lamps, also called unsaturated, offer similar or better performance compared to standard lamps, and do not cycle at the end of lamp life.

The U.S. Environmental Protection Agency (EPA) has declared that most lamps containing mercury are hazardous materials requiring special handling. This mandate applies to most fluorescent lamps and in some cases may also be defined to include HID lamps. Spent lamps may be properly disposed of in well-designed landfills; however, it is much more ecologically responsible to recycle them. Some states require all mercury containing lamps to be recycled, and it is expected that more states will require adopt similar regulations. Most lamps can be completely recycled by a number of different recycling companies. Current costs for recycling lamps average about $0.01/linear ft. When preparing a maintenance plan for a lighting system, include a lamp recycling procedure. Refer to National Electrical Manufactures Association (NEMA) (www.nema.org/lamprecycle) and the Association of Lighting and Mercury Recyclers (www.almr.org) for additional details, including links to state regulatory agencies and their codes.

Building owners should be good environmental stewards and engage in recycling programs for fluorescent lamps. For demolition and renovation projects, recycling of lamps should be required where local recycling options are available. See the *Advanced Lighting Guidelines*, chapter three, for additional discussion of lamp and ballast recycling topics.

Maintenance

Maintaining lighting systems is critical to the continued performance, lighting quality, and energy efficiency of lighting systems. Establishing proper maintenance procedures is as much a responsibility of the designer as it is of the custodian who changes lamps. A good lighting maintenance plan should be included within the building specifications.

The Electrical Systems and Lighting chapter of the CHPS *Maintenance and Operation Manual* covers issues and guidelines relative to maintaining lighting systems in schools. Topics covered in the chapter include:

- Lighting Maintenance Plan (Guideline ES1). Develop a maintenance plan for lighting, making it available to all maintenance and administrative staff to promote good procedures and enhance planning and budgeting.
- Lighting Supply Procurement (Guideline ES2). Purchase in bulk efficient lamps, ballasts and controls that meet district standards.
- Fluorescent Troffers, Pendant and Surface Luminaire Maintenance (Guideline ES3). Clean, repair, and re-lamp troffers according to a regular schedule that does not interfere with school operation.
- Maintenance for Luminaires with Screw-Based Sockets (Guideline ES4). Use compact fluorescent lamps exclusively and purchase in bulk (see above).
- HID Luminaire Maintenance (Guideline ES5). Standardize lamps whenever possible.

- Control Maintenance: Occupant and Motion Sensors (Guideline ES6). Test controls on a regular basis. Respond to complaints promptly to prevent tampering. Explain operation to users. Keep calibration instructions under the cover for use by maintenance personnel.
- Daylighting Controls Maintenance (Guideline ES7). Test controls on a regular basis. Explain operation to users. Keep calibration instructions under the cover for use by maintenance personnel.
- Timers and Timeclock Maintenance (Guideline ES8). Explain operation to users. Keep calibration instructions under the cover for use by maintenance personnel.
- Exit and Emergency Lighting Maintenance (Guideline ES9). Retrofit incandescent signs with LEDs as soon as possible.

Commissioning

All automatic lighting control systems must be tuned after installation to ensure optimal performance and energy efficiency. Malfunctioning automatic control systems waste energy and will disturb the occupants. Building specifications should include a commissioning plan that identifies the commissioning authority and details the required procedures. See *CHPS Best Practices Manual, Volume V, Commissioning of Schools* for more information. Specific commissioning recommendations for specific design strategies and technologies are also contained with each of the guidelines.

For lighting, the commissioning plan should include the following specific items:

- *Dimmed Fluorescent Lamps.* Manufacturers recommend that fluorescent lamps be fully seasoned prior to being dimmed. Dimming the lamps without this "burn-in" period can result in unstable light output and/or shorter lamp life. Recommendations vary from 10 to 100 hours, depending on the manufacturer. Eventually this requirement may become unnecessary by the use of "smart" ballasts that can sense a lamp's status. Until such ballasts are available, both new and replacement lamps should be seasoned before dimming.
- *Occupancy Sensor Sensitivity/Time Delay.* Motion sensors must be adjusted to ensure that they only sense motion in the controlled space. Motion in adjoining spaces can cause false triggering or cause the lights to remain on needlessly, thereby wasting energy. Similarly, sensors must not turn lights off when spaces are occupied. An additional adjustment to the sensors can control the time delay period between last detection and lights off. In most cases, this period can be set to 10 minutes for good results. For some motion sensor applications the frequent lamp on-off cycles will decrease lamp life. Program Start ballasts will provide full lamp life in this situation. Specify them if frequent on-off cycles are anticipated.
- *Photosensors.* Photosensors for both open-loop (sensing only the daylight) and closed-loop (sensing both the daylight and electric light they control) control systems must be calibrated to regulate the electric lighting appropriately to maintain the desired light levels. Photosensors designed for use in open-loop daylighting control systems must be mounted so that they cannot detect the lights they control. This may require some tweaking or relocation of the unit after

installation. Ensure photosensors are not obstructed by building components or furniture, and consult the manufacturer's recommendations for proper commissioning procedures for photosensor devices.

Example of Scale Model Used for Daylighting Analysis

- *Dimming Controllers:* Dimming controllers for lighting systems should be tuned so that illuminance at the high dimming range will not exceed design parameters. Only a simple adjustment is required on most dimming boards. Similarly, the commissioning agent can also set the minimum light level.
- *Stepped or Relay Controllers.* If a stepped lighting control system is employed for daylight harvesting, it is important to adjust the deadband between the on and off switching thresholds so that the system does not cycle on cloudy days. Continuous on-off cycling is annoying to building occupants and reduces lamp life.

Design and Analysis Tools

There are three general categories of tools for evaluating lighting, daylighting and fenestration: physical models, lighting computer simulation programs, and whole-building energy simulation programs.

Physical Models

For daylighting, physical scale models are probably the easiest and most intuitive way to understand daylighting design options. Scale models can be easily built that quickly and accurately illustrate the daylighting conditions created by any given design. They also help non-professionals to see lighting quality issues directly, and understand why one design is better than another. Photographs of the interior of scale models are an easy way to record the impacts of various design options. Many daylighting textbooks include a chapter on the construction and testing of daylight models. The Lighting Design Lab in Seattle has two excellent resources on constructing and testing daylight models: a training video and PDF file (See the References section below for more information.)

Daylighting models can also be used for numerical analysis. The models may be tested either outside under real sky conditions or in artificially constructed overcast sky and direct sun simulators. Small light measuring devices (photocells) can be used to record light levels within the model. Sun simulators (heliodons) can be set to represent the correct sun angle for the site latitude and hour of day, and are used to visualize the movement of light during a typical day. Measurements in a simulated sun or sky are more reproducible than in the real sky, which is constantly changing. Many universities and electric utilities have sun and overcast sky simulators, associated video equipment, and photocell arrays.

Lighting and Daylighting Computer Simulations

Electric lighting and daylighting simulations programs are available which give information about the distribution of both electric lighting and daylighting in spaces. The simplest of these programs provide rudimentary zonal cavity calculations to predict average horizontal footcandles, while the most sophisticated tools can handle extensive calculations and produce photo-realistic renderings. Most of these programs can calculate horizontal and vertical illuminance for a number of points within the space. Some can produce rudimentary renderings as well. Most can import/export data from CAD software.

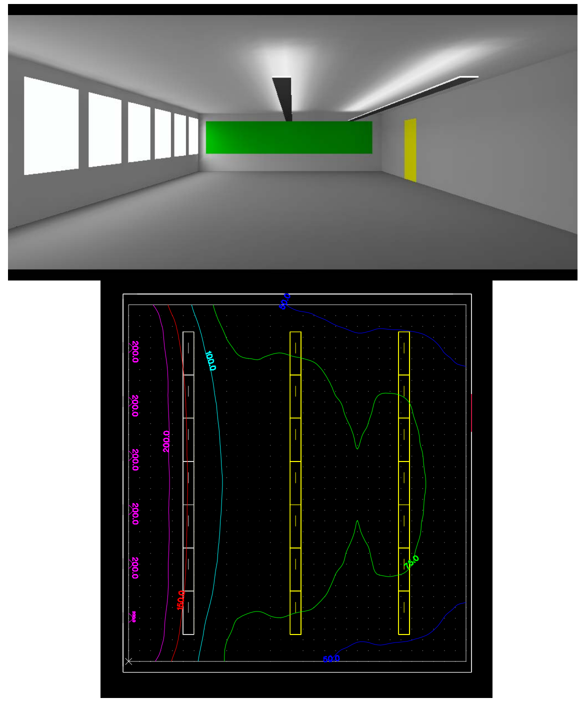

Figure 41—Results from Lighting/Daylighting Analysis Software

This is example output from a lighting/daylighting analysis program. The results are for a classroom with west facing windows at noon in June and under cloudy sky condition. The image on the left is a gray scale rendering while the image on the right shows iso-lux contours.

These tools are effective in integrating the contributions from windows and skylights as well as electric lighting systems. These programs produce results for a single instant in time, and multiple calculations are needed to study varying sky and solar conditions. These computer-based tools give light level values and gradients for both daylight and electric light across the space. Some of these tools also produce realistic renderings of lighting within the space, which may be linked to generate an automated "walkthrough" of the space for a particular day and time or to simulate the daylight variations through the hours of the day. The programs that are easiest to use may be constrained by the complexity of shapes they can simulate. The more complex programs can simulate almost any room shape or material, but require significantly more expertise and modeling time.

Companies that specialize in lighting software offer the most sophisticated lighting software packages. These products are typically much more robust than the manufacturer-provided packages, and can handle more complex problems, such as surface luminances, daylight effects, irregularly shaped rooms, and high resolution rendering.

Sample manufacturers and products:

- SPOT
- Skycalc

- Lighting Analysts, Inc. (AGI32)
- LCA (LitePro)
- Lightolier (Genesys)
- Autodesk (Lightscape)
- Lithonia (Visual)
- Lighting Technologies (Lumen Designer).

Whole Building Energy Simulations

Whole building energy simulation tools, such as DOE-2, EnergyPlus, Equest, and BLAST, consider all aspects of the lighting and daylighting system's impact on building energy use, including solar gains, impact on mechanical equipment sizes, and reduction of electric lighting energy. Many of the energy simulation programs have user-friendly interfaces to make it easier to construct models and evaluate results. Most of these tools have simplified daylighting simulation algorithms that may not accurately represent daylight levels from complex designs (like light shelves). For these designs, daylight predictions from one of the computer simulations mentioned above may need to be input to the energy program to accurately predict daylight's potential to save energy by turning off or dimming electric lights.

Quantifying Daylight

There are several methods of quantifying daylighting. The standard in use presently is Daylight Factor (DF), which is a measure of indoor daylighting to the available outdoor light level. For example if the measured outdoor level is 2000 footcandles and the measured level at a specific point inside the classroom is 40 footcandles the DF is 2%. The DF usually varies across the space so that the measurements are taken at a series of grid points. Daylight Factor was developed for the overcast climates of northern Europe and does not perform well in sunny or partly sunny climates.

A better measure for daylighting in California and other sunny climates is Daylight Autonomy. Daylight Autonomy (DA) is defined as the percentage of time over a year at which daylight can provide a given illuminance for a given point, based on an annual hour-by-hour calculation method. In the simplest form for example, if the design illuminance is 40 fc and the DA is 60% that means that for 60% of the occupied daylight hours the electric lights would not be necessary to achieve the design illuminance of 40 fc at a specific point. During DA calculations partial credit is given for daylight levels which do not meet the design illuminance threshold. For example, when a point receives 30fc of daylight illuminance and the required illuminance is 40fc, this point is credited 30/40 or 75% daylight for that time step. The Maximum DA (DA_{max}) is a measure of direct sunlight into the space or a portion of the space causing glare. The DA_{max} threshold is 10x the design illuminance, or in the case of a design illuminance of 40 fc the DA_{max} is 400 fc. Levels exceeding this are calculated as the DA_{max} and partial credit is not included for levels below this threshold. CHPS calculates the Daylight Autonomy Factor (DAF) as the DA minus two times the DA_{max}:

$$DAF = DA - 2(DA_{max})$$

To calculate DA and DA_{max} an annual simulation analysis must be performed. Some software tools, such as the Sensor Placement + Optimization Tool (SPOT) can perform DA calculations directly. Energy simulation tools, such DOE-2, can calculate the amount of lighting energy saved with the use of daylighting as compared to the lighting energy without daylighting which is another method of calculating daylight Autonomy.

Applicable Codes

Several codes or standards affect the design and installation of lighting equipment. Some of the relevant considerations are outlined below.

Fenestration Area and Performance

Many states and local governments have adopted energy efficiency codes that limit the amount of glazing that can be installed in buildings and require that the fenestration meet performance standards to minimize heat loss (U-factor) and solar heat gain (SHGC). Many of these codes are based on American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)'s IESNA/ANSI/ASHRAE Standard 90.1-2001, which limits skylights to 5% of the roof area and windows to 50% of the wall area, unless a whole building performance approach is used.

Some state codes such as the 2005 California energy efficiency standard, go the other way and specify that some spaces shall have a minimum skylight area for daylighting. These same codes specify a maximum U-factor, maximum SHGC, and in some cases, a minimum visible light transmission. For additional details about building envelope performance and criteria, see chapter three of this document.

Americans with Disabilities Act

The Americans with Disabilities Act (ADA) affects the selection and installation of lighting equipment. For the most part, ADA only affects the location of lighting controls and wall-mounted luminaires, which cannot protrude more than 4 in. when mounted less than 80 in. above the finished floor.

Egress and Emergency Lighting

Emergency egress and exit lighting requirements are mandated in the Uniform Building Code (UBC), National Electric Code (NEC), and National Fire Prevention Association (NFPA) codes. Lighting design must address the minimum lighting levels for egress, as well as include the necessary exit signage. Most counties and municipalities require at least minimal compliance with NEC, and some may require additional measures.

UL Listing

According to the NEC, all luminaires used in construction must be listed by an approved testing agency, such as Underwriters Laboratory. The designer must be sure that all luminaires specified are properly listed by a testing agency recognized by the local electrical inspector. In addition, there are distinctions that need to be made for special applications, such damp, wet, and hazardous locations.

California Building Code

All school buildings in California must comply with the energy efficiency standards for nonresidential buildings (Title 24). Title 24 documentation is available free from the California Energy Commission at www.energy.ca.gov and includes the Title 24 Energy Efficiency Standards ("the Standard"), the Nonresidential Alternative Calculation Method Manual ("ACM Manual"), the Nonresidential Compliance Forms, and the Nonresidential Manual. Until October 1, 2005 compliance with the 2005 Standard is optional and use of the less stringent 2001 Standard is allowed.

A significant portion of Title 24 is devoted to lighting systems. The standards require several mandatory measures for lighting systems including:

- Manual or automatic lighting controls for all spaces.
- Multi-level switching or dimming for spaces where the lighting power exceeds 0.8 W/ft².
- Separate switching in daylit zones.
- Automatic daylighting controls (switching or dimming) under some conditions.
- Automatic shut-off controls.
- Automatic control for exterior lighting.
- Bi-level control for exterior lighting.
- Certification of controls.
- Acceptance testing for controls.

Title 24 also has prescriptive requirements for lighting power. School buildings may comply using the whole building method, the area category method, the tailored method, or by computer modeling. Most designs are based one of the three prescriptive compliance methods as follows.

Complete Building Method This compliance method is the simplest when a whole school building is being built under a single permit. In 2005, this method allows 1.2 watts per square foot for all interior space.

Area Category Method This compliance method is suited for additions, mixed use and all other school project types. The gross area of each use is multiplied by the category allowance. This is the preferred method for compliance documentation for most projects. For most schools, the average for the entire building will be about 1.2 W/ft² but schools with disproportionately high percentages of special spaces such as libraries or multipurpose rooms might end up slightly higher.

Tailored Method The Tailored Method is a more complex system in which lighting power is determined task-by-task. Its applicability to schools is limited—it can not be used for more than 30% of the space in a particular permit and should be reserved for spaces with unusual tasks demanding very high light levels. The tailored method is only beneficial for unique rooms and spaces with unusual lighting level requirements.

As of 2005, the lighting power limits for applicable school building spaces (Area Category Approach) are as follows:

Table 14—California Lighting Power Limits for Schools, Area Method

This is a summary of whole area lighting power density allowances for typical school spaces taken from Table 146-C of the California energy efficiency standards (Title 24).

Area Type	Allowed Lighting Power (W/ft²)
Classrooms, Lecture Halls, Vocational Rooms	1.2
Offices	1.2
Corridors, Restrooms, Stairs, and Support Areas	0.6
Library Reading Areas	1.2
Library Stacks	1.5
Multi-purpose Centers	1.4*
Auditoriums	1.5*
Gymnasiums	1.0
Locker Rooms	0.8
Kitchens, Food Preparation Areas	1.6
Main entry lobby	1.5*
Reception Lobbies, Waiting Areas	1.1*
Electrical and Mechanical Rooms	0.7**
Storage Rooms, Closets	0.6

** up to 1.0 W/ft² may be added for ornamental lighting such as sconces or chandeliers*
*** up to 0.5 W/ft² may be added for task lighting*

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DAYLIGHTING PRIMER

Properly controlled daylight promotes comfort and productivity. To achieve energy savings, electric lights must be turned off (either manually or automatically) when sufficient daylight is available. Some occupants are quite conscientious in manually turning off the lights when not needed, but automatic systems tend to result in greater energy savings over the long run.

Figure 42—Skylit Library

Cameron Park Library, Peter Wolfe Architect. Colorful banners enliven the space while blocking glare from the skylights and helping to diffuse the daylight. Source: Lisa Heschong.

The first and most important step in integrating electric lighting with daylighting is to make sure that the electric lights are circuited so they can be logically switched off or dimmed in proportion to the presence of daylight in the room. This generally means that the electric lights should be circuited in lines parallel to the daylighting contours in the space. The areas of the room with the most daylight, the space adjacent to windows or skylights for example, should be turned off or dimmed first. A good rule of thumb for daylighting integration: control electric lights with a minimum of three separate switch legs/circuits in daylit spaces.

The electric lighting should be designed to provide balanced and sufficient illumination under nighttime conditions, but it should also be circuited to supplement partial daylight when needed on dark days. The electric lighting designer should understand the patterns of daylight illumination expected during different times of the day and year, so that the electric lighting design can supplement the daylight, filling in darker areas of the room or highlighting a wall.

Benefits of Daylighting

Daylighting has a number of advantages, including improved occupant productivity, improved connection to the outdoors, improved health, energy savings, and quality of light. There is strong evidence that if it is done well, daylighting improves the health, well being, and productivity of occupants. Daylight delivers high quality light with excellent color rendering and may increase interior light levels and illuminance on vertical surfaces. Views from windows provide a connection to the environment.

Productivity

A study funded by Pacific Gas and Electric[18] students in San Juan Capistrano elementary schools were found to be performing an average of 21% better in fully daylit classrooms compared to those with no daylight at all. These included both classrooms with diffusing skylights or large daylight windows. Similarly, in Seattle and Fort Collins elementary schools, students in classrooms with skylights or the largest window areas were found to have 7% to 15% higher overall test scores. In a follow-on study in Fresno, funded by the California Energy Commission[19], horizontal daylight illumination levels per se were not found to be associated with better student performance, but students in classrooms with bigger view windows, better views, and fewer problems with glare and sun penetration were all found to be performing better. A companion study[20] of office workers similarly found that those workers with bigger and better views to the outdoors were working faster and performing better on cognitive tests. These findings are consistent with an expectation that a view of a bright, daylit area may have positive impacts on mood, mental function, memory formation, and subtle physiological affects associated with circadian stimulation.

Connection to the Outdoors

Daylight provides a connection to the outdoors by supplying the occupant with information on time of day, season, and weather conditions. In doing so, it enriches the indoor environment and may also help to make using the building more memorable. The constant variety in the quality and quantity of daylight also helps keep occupants more alert.

Improved Health

Views provided by windows contribute to eye health by providing frequent changes in focal distance, which helps to relax eye muscles. This may be especially important for young children, whose eyes are still developing. Daylight, whether associated with a view or not, may also affect moods and stress. From a physiological perspective, daylight entrains and reinforces our circadian rhythms and is thus associated with maintaining good health (sleep cycles, etc.) and avoiding dysfunction of our internal clock (seasonal affective disorder, etc.). Although most research on physiological effects has focused on the role of exterior daylight, our understandings of these benefits of daylight inside our buildings is increasing. Research in Sweden measured cortisol (a stress hormone) levels in school children and showed that work in classrooms without daylight “may upset the basic hormone pattern, and this in turn may influence the children’s ability to concentrate or co-operate, and also eventually have an impact on annual body growth and sick leave.”[21] In a study sponsored by the California Energy Commisison, office

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[18] Heschong Mahone Group 1999

[19] Heschong Mahone Group, 2003, Windows and Classrooms,

[20] Heschong Mahone Group, 2003, Windows and Offices

[21] Kuller and Lindsten. 1992. *Journal of Environmental Psychology* 12:305-317.

workers who had access to a view reported significantly less fatigue and other minor health complaints like head aches and eye strain[22].

Figure 43—North Versus South Windows

South windows are shaded from direct sun, but receive daylight reflected off of concrete walk and white painted overhangs. North windows are large and unshaded. Source: Lisa Heschong.

Energy Savings

Daylighting can save energy and reduce peak electricity demand if electric lights are turned off or dimmed when daylight is sufficient. For many school uses, electric lights are currently the largest energy consumer and daylighting can significantly reduce this energy use. However, daylighting saves no energy unless the electric lighting system is appropriately controlled. To be effective, daylighting must be thoughtfully designed to provided balanced illumination that avoids glare and overheating, and it must include dimming or switching of the electric lighting system.

Better Quality Light

Daylight is generally of high color temperature, high color rendering and rich in blue radiation. Both good color identification and improved visibility are attributed to these factors. People generally describe daylighting as providing better visual clarity and color differentiation.

Daylighting Principles

The following six principles, described in more detail below, provide fundamental guidance in designing daylit spaces.

- Prevent direct sunlight penetration into the space.
- Provide gentle, uniform light throughout the space.
- Avoid creating sources of glare.
- Allow occupants to control the daylight with operable louvers or blinds.
- Design the electric lighting system to complement the daylighting design, and encourage maximum energy savings through the use of lighting controls.
- Plan the layout of interior spaces to take advantage of daylight conditions.

[22] Heschong Mahone Group, 2003. Windows and Offices.

Prevent Direct Sunlight Penetration

One of the delights of daylight is that it changes in quality throughout the day and with each season. The daily and seasonal path of the sun is the prime determinant of sunlight availability, while the presence of clouds and moisture in the air affect the quality and intensity of light from the sky. It is essential that designers understand the basic principles of solar orientation, climate conditions, and shading systems to design successful daylit buildings.

Direct beam *sunlight* is an extremely strong source of light, providing up to 10,000 footcandles of illumination. It is so bright, and so hot, that it can create great visual and thermal discomfort. *Daylight*, on the other hand, which comes from the blue sky, from clouds, or from diffused or reflected sunlight, is much more gentle and can efficiently provide excellent illumination without the negative impacts of direct sunlight. Good daylighting design typically relies on maximizing the use of gentle, diffuse daylight, and minimizing the penetration of direct beam sunlight. In general, sunlight should only be allowed to enter a space in small quantities, as dappled light, and only in areas where people are not required to do work.

Figure 44—Deeply Coffered Ceiling

Deeply coffered ceiling helps to diffuse light from four skylights. There are no electric lights on in this photo. Source: SunOptics

The best daylighting designs are initiated early in the design process of new buildings. The first step in good daylighting design is the thoughtful orientation of the buildings on the site and orientation and size of the fenestration openings. A carefully oriented building will allow maximum daylight while minimizing unwanted solar gains. It is easiest to provide excellent daylight conditions using north-facing windows, since the sun only strikes a north-facing window in early morning and late evening during midsummer. South-facing windows are the next best option because the high angle of the south sun can be easily shaded with a horizontal overhang. East- and west-facing windows are more problematic because when the sun is low in the sky, overhangs or other fixed shading devices are of limited utility. Any window orientation more than 15° off of true north or south requires careful assessment to avoid unwanted sun penetration. However, in extreme northern latitudes, care must be taken in the design of south facing windows because of the low altitude of the sun during the winter.

Windows that are placed high in the wall will distribute daylight best in the space; windows lower in the wall provide less useable daylight, but allow views to the exterior. Good daylighting design uses a balance of high daylighting windows and lower view windows in an integrated approach. The Advanced Buildings Web site has more information on specific daylighting strategies at www.poweryourdesign.org.

For sidelighting, carefully designed shading devices both inside and outside the building can limit direct sun penetration while allowing diffuse daylight. For toplighting, avoid direct sun by using glazing that diffuses the sunlight, or by reflecting it off baffles, louvers, or light well walls.

Provide Gentle, Uniform Illumination

Daylight is most successful when it provides gentle, even illumination throughout a space. Evenly diffused daylight will provide the most energy savings and the best visual quality. Achieving this balanced diffuse daylight throughout a space is one of the greatest achievements of a good daylight designer.

It is easiest to achieve uniform daylight illumination from toplighting strategies that distribute light evenly across a large area. The high windows distribute useable daylight deeper in the room and should be continuous or spaced evenly across the working area. The lower, view windows don’t need to coincide with the full length of the higher daylighting windows, but may be selectively located to provide good views for all occupants. Combinations of sidelighting with toplighting can also be successful in providing uniform illumination levels. The most challenging condition is a room with windows on only one side. There, daylight illumination levels will be very high right next to the window and drop off quickly. Various strategies to distribute light deeper into the space (e.g., light shelves) are available but require more design skill and construction cost.

Daylight can most easily be used to provide a base level of illumination throughout a space, referred to as the ambient illumination, which is often on the order of 20–80 footcandles. Individual work areas can then be highlighted with electric task lights to bring the illumination levels in specific areas to higher task level requirements, such as 50 or 75 footcandles. Alternatively, if the daylighting fenestration area is increased to provide the higher task illumination for most of the day, the electric lighting energy savings will be maximized while heating and cooling costs may increase. The best daylighting designs balance these energy costs with the desired lighting quality.

The arrangement of diffuse high reflectance surfaces that help to distribute the light are just as important as the arrangement of daylight openings for providing gentle, uniform illumination. Whenever possible, place daylight apertures next to a sloped or perpendicular surface so the daylight washes either a ceiling or a wall plane and is reflected deeper into the space. It is essential to recognize that walls and ceilings are part of the daylighting design. For greatest efficiency and visual comfort, they should have a white or a very light finish. Even pastel-colored paint may have a reflectance of only 50%, correspondingly reducing daylight levels. Saturated colors should be used only in small areas, for accents or special effects.

Advanced daylighting designs take advantage of additional exterior and interior reflecting surfaces to shape the distribution of daylight in the space. Light-colored walkways and overhangs can help reflect daylight. Light shelves can be used to project daylight deeper in the space, or a series of reflective or refractive surfaces built into the glazing itself can redirect sunlight onto the space’s ceiling. These approaches are integral to the architecture of the building and should be designed differently for each cardinal orientation. For example, daylight buildings may have light shelves on the south side of the building, but none on the north. In this way, the design is “fine tuned” to optimize the daylight delivery for each orientation.

Avoid Glare

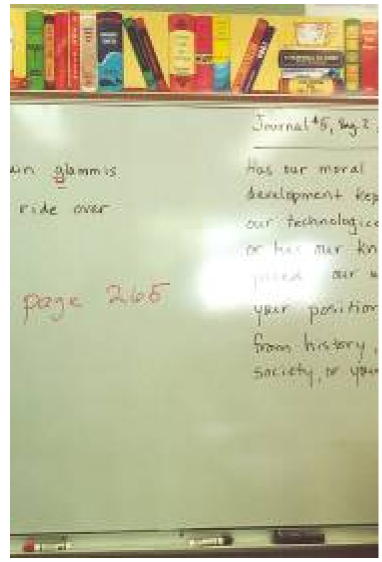

Figure 45—Veiling glare from Windows or Light Fixtures on Whiteboard

Glare from windows or light fixtures reflecting off of shiny surfaces, such as computer screens or whiteboards, can reduce worker performance. Source: Lisa Heschong

Glare is excessively high contrast. Direct glare is the presence of a bright surface relative to the surroundings (for example, a bright diffusing glazing or direct view of the sun) in the field of view that causes discomfort or loss in visual performance. Glare can have negative effects on occupant performance. A recent study in school buildings showed that skylights admitting direct sun (and presumably glare) into classrooms correlated with a *decrease* in student performance on standardized tests[23]. Eliminate glare by obscuring the view of bright sources and surfaces with blinds, louvers, overhangs, reflectors, and similar automatic or manually operated devices.

Placing daylight apertures next to reflective surfaces reduces glare in addition to distributing the daylight more evenly. It brightens interior surfaces to reduce their contrast with the bright glazing surface. If washing a wall with daylight is not possible, some glare reduction can be achieved by splaying window reveals and skylight wells. Blinds or drapes can also reduce contrast by controlling the amount of brightness at the windows, and diffusing the light. Punched windows (simple holes in the middle of a wall) represent the worst scenario for glare and are not recommended for effective daylighting.

Glare can also occur when daylight strikes a reflective surface, like a computer screen or a whiteboard, and produces shiny reflections that make it difficult or impossible to see. These "veiling reflections" can be caused by either daylight or electric lighting. You can predict when these reflections will be a problem by placing an imaginary (or real) mirror on the screen or whiteboard and seeing if any bright light sources or surfaces are visible in the mirror. If they are visible, reorient the screen/whiteboard or redesign the apertures to eliminate their reflection in the surface.

When video display terminals are located in daylit spaces, the designer must take great care to minimize reflections on the screen. This problem is especially acute when the computer screen is oriented so that the screen is facing the daylighting aperture (that is, the user's back is to the window or skylight). Under these conditions, reflected glare may completely wash out the screen, making work impossible without completely closing window blinds or drapes. If the screen is located so that the screen viewing orientation is parallel to or 45° to the windows, reflected glare poses less of a problem and, if present, can usually be reduced by using polarizing filters or meshes attached directly to the screen. Flat screen

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[23] Heschong Mahone Group, "Daylighting in Schools—An Investigation into the Relationship between Daylighting and Human Performance," prepared for Pacific Gas & Electric Company and funded by California utility customers, 1999. Heschong Mahone Group and New Buildings Institute, "Re-Analysis Summary: Daylighting in Schools, Additional Analysis." February 2002.

monitors have fewer glare problems. LCD (liquid crystal display) screens are the best since they are flat and more energy efficient than cathode ray tubes (CRT).

Control the Daylight

Daylight is highly variable throughout the day and the year, requiring careful design to provide adequate illumination for the maximum number of hours while contributing the least amount possible to the cooling load. The ideal daylighting design would have variable apertures or variable transmission glazing that respond to changes in the availability of daylight. The apertures would become smaller or less bright when daylighting is abundant and larger or more bright on cloudy days or at times when daylight is less available.

The principal means of control is through the use of shades or blinds located inside or outside the window. Exterior shading is the most energy efficient, since it intercepts the solar gain before it enters the building. Use horizontal overhangs to shade vertical windows facing within 25^{o} of due south. East- and west-facing windows are more difficult to shade and may need a combination of vertical and horizontal shading elements or landscaping or both. Interior shades or blinds can then eliminate any remaining direct sun or glare.

Figure 47—Horizontal Blinds Allow Control of Brightness from Lower View Windows

High clerestory windows have no blinds so that daylight can reach deep into a room. Most rooms do not need complete black out capability with modern video equipment. Source: Barbara Erwine

Occupants should have easy access to controls for these shades or blinds to adjust light levels as needed throughout the day. These systems should be reliable, as well as easy and economical to clean and repair. Manually operated controls are slightly less convenient but are usually less expensive to purchase and repair. Locating blinds between two panes of glass reduces abuse and dirt collection, extending their life and allowing easy access to cleaning the glass. White, non-shiny, blinds provide the best light distribution and least visual intrusion. Avoid the use of moveable exterior shades; they are exposed to weather conditions that may degrade their performance. Ensure that fixed exterior shading devices are sloped slightly so they drain water.

Figure 46—Veiling Glare from Luminaires on Computer Screen

Careful lighting and daylighting design avoids these problems. Source: Lisa Heschong

If shading devices cannot be provided to eliminate glare from low view windows, then use a lower transmission glazing, adjusted for the window orientation (about 40% transmission for south windows, 30% for east or west facing windows and 60-85% for north windows). In general, visible transmission for view glazing should not be reduced below 30% in clear sky climates or below 50% in heavily overcast climates. If tinted glazing is used, evaluate its effect on distortion of colors (for example, the graying of greens and blues in the landscape) in both overcast & clear skies.

Figure 48—Sidelighting in Library

Library receives daylight from two sidelighting strategies: 1) view windows at perimeter, and 2) high clerestories that bring daylight into the center of the space.

Integrate with Electric Lighting Design

The daylight and the electric light systems must be designed together so they complement each other to create high quality lighting and produce energy savings. This requires an understanding of how both systems deliver light to the space. The Design and Analysis Tools section later in this chapter discusses tools to help visualize the overall light distribution in the space.

Daylight is a “bluer” light source than most electric lighting. Fluorescent lights that are designed to match the color of incandescent light will appear yellow in comparison with daylight. The correlated color temperature (expressed in degrees Kelvin) of a light source is a number that describes its relative blueness (higher Kelvin) or yellowness (lower Kelvin). When designing electric lighting to work with the daylight in a space, most designers choose fluorescent lamps in the bluer range, with a color temperature of 3500 K—4100 K or even higher. Other considerations, including ambience of the space, energy efficiency (lumens per watt) and ability to clearly see the visual tasks, may also affect the choice of color temperature.

Daylighting is also more thermally efficient than electric lighting, which means that for the same amount of light, daylight contributes less heat to the space. . Since electric lighting is a major contributor to the cooling needs in buildings, substituting daylight for electric lighting can reduce cooling costs as well as lighting costs, as long as illumination levels are not significantly increased. However, energy savings will only be achieved if the electric lights are turned off or dimmed in response to the daylight and if direct beam sunlight is controlled.

The electric lighting should be , circuited, and controlled to coincide with the patterns of daylight in the space, so that the lights can be turned off in areas where daylight is abundant and left on where it is deficient. Controls can either be manual or automatic. Automatic controls use a small photosensor that monitors daylight levels and controls the electric lighting accordingly. Manual controls are substantially less expensive, but they need to be convenient and well labeled to ensure their use. Automatic controls assure savings, but they are more expensive and must have overrides so the occupants can darken the room for audio/visual use or when they just don’t want the lights on.

Plan the Layout of Interior Spaces

Successful daylighting designs must include careful consideration of interior space planning. Since daylighting illuminance can vary considerably within the space, especially with sidelighting, it is important to locate work areas where appropriate daylighting exists. Perhaps more importantly, special visual tasks should be located to reduce the probability of discomfort or disabling glare. In general, work areas should be oriented so that daylighting is available from the side or from above. Facing a window may introduce direct glare into the visual field, while facing away from a window may produce shadows or reflected glare from monitors.

ELECTRIC LIGHTING PRIMER

Electric Light Sources

A wide variety of electric light sources are available for use in schools, although the full-length fluorescent tube is the workhorse to be used in the majority of applications. Light source selection critically affects building space appearance, visual performance, and comfort. This section outlines the different types of sources available to the designer. Refer to the *Advanced Lighting Guidelines* for more detailed guidance in selecting lamp types as well as appropriate luminaires (www.newbuildings.org/lighting.htm).

Incandescent and Halogen Lamps

Incandescent lamps represent the oldest of electric lighting technologies. Advantages of incandescent technology include point source control, high color performance, instant starting, and easy and inexpensive dimming. Disadvantages range from low efficacy and short lamp life to high labor maintenance costs.

Incandescent sources should not be used in most new commercial/industrial buildings except for very limited and special accent lighting. Examples might include dimming applications where color performance, beam control, and/or dramatic effect is critical, such as teleconferencing rooms, theaters, and the highlighting of artwork. In most of these cases, halogen sources, which offer longer life, better point source control, and crisper color performance, are superior to standard incandescent lamps. The most efficient halogen technology is infrared reflecting, which should be used whenever possible.

Fluorescent Lamps

Fluorescent lamps should be used for almost all lighting applications where a diffuse light source is acceptable and the size of luminaire is not a critical concern. They offer long life, high efficacy, good color, and low operating and maintenance costs. Dimming requires special ballasts that cost more, but the technology is mature and reliable. Several different types of fluorescent lamps are worth noting, as described in Table 15.

Figure 49—T-12 Fluorescent Lamps Next to Small Diameter T-5 Lamps

Courtesy: CHPS BPM

Table 15—Summary of Fluorescent Lamp Technology

Type of Lamp	Advantages/Disadvantages	Applications
T-12	Antiquated technology. Relatively low efficacy. Supplanted by newer technologies such as T-8 and T-5.	Should not be used in new construction.
Standard T-8 (7xx color)	Smaller diameter standard lamps now in general use throughout the world. Offer 10%–20% higher energy efficiency than T-12 lamps and other performance improvements when used with electronic ballasts. Low-cost lamps and ballasts.	Most general lighting applications in buildings, including classrooms, offices, multipurpose rooms, libraries, and retail.
High Performance T-8	High Performance T-8 lamps offer better color rendition, 20%–30% higher maintained lumens, and a potentially large increase in lamp life over standard T-8s. Energy efficiency can be 10%–30% greater than standard T-8 lamps and standard electronic ballasts depending on brand and type.	Same.
T-5	T-5 luminaires should be well shielded to minimize glare. These lamps are more expensive than the T-8 lamp and ballast system, but offer better optical performance.	Smaller profile luminaires. Especially effective in indirect luminaires, cove lighting systems, and wall washers.
High Performance T-5	Similar to the High Performance T-8. Combines the optical advantages of T-5 with the technology improvements of the High Performance T-8.	Same
T-5 High Output (T-5HO)	Light generation per unit length is the highest. Very good energy efficiency, long lamp life, and high optical efficiency, but less efficient than T-8 and T-5. Currently more expensive than T-8 lamp and ballast system.	Smaller profile suspended luminaires for offices and classrooms. Also, for “high bay” applications such as gyms, manufacturing facilities, or warehouses.

Note: A number of lamp/ballast options are available that perform somewhere between the standard product and the high performance product. These are sometimes referred to a premium lamp.

For most lighting application, the best choices are T-8 premium and high performance lamps, T-5 and high performance T-5, and T-5HO lamps. The added energy efficiency and longer life of the premium and high performance lamps more than pay for the initial cost difference in a very short period of time. Note that T-8 lamps are electrically interchangeable, so substitutions will result in a change in light level but no change in connected power or anticipated energy savings.

“Energy Saving” Lamps

All three major lamp manufacturers offer lower wattage versions of the T-8 lamp. At present one lamp company offers a 25 watt lamp and the other two offer 28 watt lamps; the 30 watt is common to all. These so-called “energy saving” lamps are not more efficacious, but can be used to reduce socket wattage in some existing T-8 applications, at the expense of fewer lumens and lower light levels.

While these products will save a little energy, there are several important drawbacks including:

- Slightly lower system efficacy (less lumens per watt).
- Increased temperature sensitivity and noticeable warm up time.
- Lamps are not dimmable.

For new construction, designers are encouraged to consider one of the many types of standard, 32 watt T-8 lamps, especially the latest high performance lamps, and then use ballast factor, rather than low wattage lamps, to achieve the intended lighting power. This will allow replacement lamps to be more universal, and results in stocking of one lamp when there are both dimming and non dimming applications. Use the low wattage lamps in retrofit situations when spaces are over illuminated.

Fluorescent Ballasts

All fluorescent lamps require a ballast, which is an electric device that starts and regulates power to the lamp. Electronic high frequency ballasts are now standard equipment for most fluorescent sources. In addition to their efficiency advantages, electronic ballasts have minimal flicker and ambient noise, and are available in a variety of *ballast factor* configurations, allowing the designer to “tune” light levels based on the ballast specification.

There are four different fluorescent ballast types:

- *Instant start ballasts*, which have high energy efficiency but may reduce lamp life. A standard T-8 lamp operated for three hours per start on an instant start ballast will last about 15,000 hours, and even longer if the burn cycle is significantly longer. However, if the lamp is operated a short time per start (such as when controlled by a motion sensor), lamp life can drop to less than 5,000 operating hours. Choose instant start ballasts for locations with long light operation cycles. See program start ballasts below for frequent starting applications.
- *Rapid start ballasts*, which are increasingly rare because they are less energy efficient and offer no significant lamp life advantages.
- *Program start ballasts*, which are both energy efficient and significantly reduce the effect of controls and operating cycle. A standard T-8 lamp operated on a program start ballast will last 24,000 hours at 3 hours per start, and premium or “high performance” lamps are rated as long as 30,000 hours at 3 hours per start. Equally important, a “high performance” lamp operated on a motion sensor will still last more than 20,000 hours. Note that most T-5 ballasts are program start, to preserve their 20,000-hour rating.
- *Dimming ballasts* for fluorescent lamps require an additional investment, but increase lighting system performance by optimizing space appearance, occupant satisfaction, system flexibility, and energy efficiency. Dimming fluorescent ballasts should be considered in all cases requiring maximum energy performance and light level flexibility.

The “ballast factor” describes the percentage of rated lamp lumens generated and is related to the power used. By selecting an appropriate ballast factor, it is possible to tune lighting systems to the desired light output, especially with T-8 lighting systems.

- The standard or “normal light output” (NLO) system produces 87% of the rated light output of the lamp. This is the most common ballast system and it is normally furnished unless otherwise requested.

- Use reduced light output (RLO) electronic ballasts produce approximately 75% of rated light output and use 12%–20% less power than standard NLO ballasts. These may be in used where slightly lower lamp lumens will provide adequate light output. Applicable spaces might include corridors, rest rooms, and storage areas. Some RLO ballasts can be matched with high performance T-8 lamps to produce normal light output with very low power draw. In this case, applications include offices, classrooms, and industrial spaces.

Figure 50—Electronic Ballast with Lamps

Source: OSRAM Sylvania

- High light output (HLO) electronic ballasts produces 115%–120% of the lamp's rated light output with a 15%–20% increase in power. Lamp life is unaffected. Designs can sometimes employ two lamps and an HLO ballast rather than three lamps and an NLO or RLO ballast, permitting the use of a smaller luminaire or simply fewer lamps.

Recently, the industry introduced "efficient" electronic ballasts for T-8 lamps. These ballasts provide the same light output with about 10%–12% less power, and should be used in all new designs as the cost difference with respect to ordinary electronic ballasts is trivial. Efficient electronic ballasts are available in both instant start and program start types. When coupled with high performance T-8 lamps, the combination can use 32% less energy than a standard T-8 system while providing the same light output.

Table 16—Fluorescent Lamp/Ballast Power and Light Level

(Based on mean lamp lumens) using generic T-8 lamp and ballast as the reference. For the numbers in parentheses following the lamp name, the first digit represents the CRI and the final two digits indicate the color temperature.

	Ballast			Lamp/Ballast System							
Lamps	Type of Ballast	Relative Light	Relative Power	Ballast Factor	Lumens	LLD	Input Power	MLPW	Relative Light	Relative Power	Relative Efficacy
Standard T-8 (735) **Lowest cost standard lamps**	NLO instant start	100%	100%	0.88	2800	0.9	59	75.2	100%	100%	100%
	RLO instant start	89%	87%	0.78	2800	0.9	54	72.8	89%	92%	97%
	HLO instant start	135%	134%	1.15	2800	0.9	78	74.3	131%	132%	99%
High performance T-8 (835)** **High lumen, special phosphor high CRI lamps with barrier coat for improved lumen maintenance**	Efficient NLO instant start	109%	100%	0.88	3150	0.95	53	99.4	119%	90%	132%
	Efficient RLO instant start	94%	87%	0.78	3150	0.95	48	97.3	105%	81%	129%
	Efficient HLO instant start	150%	134%	1.15	3150	0.95	70	98.3	155%	119%	131%
	Efficient NLO program start	89%	81%	0.88	3150	0.95	55	95.8	119%	93%	127%
	Efficient RLO program start	89%	81%	0.78	3150	0.95	50	93.4	105%	85%	124%
T-5 (835)	Program start	104% (115% @ 35 C)	110%	1.00	2700	0.95	58	88.4	116%	98%	118%
High Performance T-5 (835)	Program start	109% (121% @ 35 C)	110%	1.00	3050	0.95	58	99.9	124%	103%	124%
T-5HO (835)	Program start	179% (199% @ 35 C)	203%	1.00	4600	0.9	114	72.6	187%	193%	97%

** Lamps rated 2,950 initial lumens and high lumen maintenance*

*** Lamps rated 3,100 initial lumens and high lumen maintenance*

This table derived from current manufacturers data, which manufacturers update from time to time.

Compact Fluorescent Lamps

Compact fluorescent lamps (CFLs) can be used in many applications that traditionally have employed incandescent sources. CFLs offer excellent color rendition, rapid starting, and dimmability. A large palette of different lamp configurations enhances design flexibility. Principal advantages of CFLs over incandescent sources include higher efficacy and longer lamp life. They can be dimmed, though dimming CFL ballasts are expensive. In colder outdoor environments, CFLs can be slow to start and to come to full light output.

Use CFL lamps extensively in task and accent lighting applications, including wall washing, supplementary lighting for visual tasks requiring additional task illumination above ambient levels, and portable task lighting in computer environments. They are also valuable for medium-to-low level general illumination in spaces such as lobbies, corridors, restrooms, storage rooms, and closets. In moderate climates they are quite suitable for outdoor corridors, step lighting, and lighting over doorways. High wattage twin-tube CFLs can be used for general space illumination in recessed lay-in troffers (see Luminaires section below), as well as in more decorative direct/indirect luminaires for office lobbies, libraries, and other spaces.

Temperature Considerations for Fluorescent Lamps

All fluorescent lamps exhibit sensitivity to temperature, both for the amount of light they produce and for the starting capability of some lamp-ballast combinations. Many common linear and compact fluorescent lamps have their maximum and rated output at 25°C (77°F), and their output and efficacy can decrease significantly as their ambient temperature changes. For example, the light output may decrease by 10% when the temperature is 10°C too high or too low, and continue to decrease if the temperature deviates even more. Key sources of temperature change are enclosed luminaires that raise temperature and cold operation, such as outdoors or unconditioned buildings in winter, which can lower temperature.

The first consideration for fluorescent lamps in cold temperature is that the ballast will reliably start the lamp at the expected lowest temperature. Check the ballast manufacturer specifications for details, since some lamp-ballast combinations may prove difficult, even indoors.

Some lamp types were designed to compensate for temperature effects. While recessed luminaires can raise the temperature of CFLs so high that light output is disappointing, a few CFLs use a mercury alloy (amalgam) that dramatically decreases both the high and low temperature sensitivity of the lamp. Other lamps, such as F28T-5 and F54T-5HO have their maximum light output at 35°C, allowing them to cope with elevated temperatures inside compact luminaires. T-12HO and T-8HO lamps produce their maximum light output at a lower temperature to permit more light at lower temperatures typical outdoors. But even standard energy efficient fluorescent lamps, like T-8s, can give reasonable performance outdoors in mild climates that have only a few days with temperatures below freezing. Also, good luminaire design can optimize lamp temperature and light output even if the temperature would be too low for a bare lamp.

High Intensity Discharge (HID) Lamps

HID lamps provide the highest light output of any commercially available light source and come in a wide variety of lamp types and sizes. In addition, they offer medium-to-high efficacy and relatively long lamp life. The principal disadvantage to HID sources is that they start slowly and take time to warm up before coming to full brilliance, especially when they are warm from recent operation. It is also difficult to multiple light levels without expensive hi-low switching or dimming systems. As a result, these lamps may not work well in daylit interior spaces or other areas where lights may be turned on and off more than once or twice daily.

Figure 51—High Intensity Discharge Lamps *Courtesy: Energy Star*

There are four principal types of HID lamps, although only the metal halide lamp is recommended in indoor applications:

- Mercury vapor lamps. Low efficacy lamps that produce unflattering greenish-purple light. Obsolete technology not to be considered.

- Metal halide lamps. White light sources of good to very good efficacy and long life. Important improvements will be discussed later as these are the type most recommended for HID lighting in schools.
- High pressure sodium lamps. Golden-pinkish lights with very good efficacy and very long life. The color rendering is so poor, however, that these lamps should be relegated to security lighting and other applications not involving significant human activity.
- Low pressure sodium lamps. Pure yellow lights with high efficacy and long life. Unacceptable monochromatic light sources.

Metal halide lamps offer many choices. The original metal halide lamps, called “probe start,” should be avoided as their performance is relatively poor compared to “pulse start (PS)” lamps and ballasts. There is no cost premium for the “pulse start” technology, and lamps operate longer, with higher light output and better lumen maintenance. The only limiting factor is position sensitivity—in certain luminaires requiring horizontal lamps, not all wattages are available.

The “ceramic metal halide” is a relatively new type of metal halide that is, in many ways, a cross between high pressure sodium and traditional metal halide. Manufacturers are investing to improve the ceramic metal halide lamp, and as a result, they have relatively long life, excellent color rendering, good lumen maintenance, and are available in many compact bulb shapes. Ceramic metal halide lamps should generally be used for all applications that require 150 watts and less, and should be considered for 250 and 400 watt lamps as well.

Electronic ballasts are readily available and recommended for metal halide lamps up to 150 watts due to their superior energy efficiency and improvements in lamp life and lumen maintenance. Above 150 watts, electronic ballasts are just becoming available and their cost may prove to be an impediment. But like the lower wattage lamps, high wattage metal halide lamps still benefit from electronic ballasts and deserve consideration in applications with extended hours of lighting operation, such as in an athletic center with 12 month, 16 hour per day operations.

Light Emitting Diodes (LEDs)

LEDs are semiconductor devices that generate an intensely directional, monochromatic light. Because selection is mainly limited to red, blue, or green products at this time, use of LED as a light source is generally limited to exit and other signs or for dynamic colored effects (i.e., sconces, wall washing, step lights). However, current research is directed toward producing a commercially viable white LED source.

LEDs are highly recommended for use in colored, internally illuminated signs and exit signs. They offer high efficacy and very low maintenance costs when compared with comparable incandescent or fluorescent products. They are available for most of the popular exit sign configurations. The principal advantage of LEDs over other sources is their extremely long life and lowe power (a two-sided LED exit sign can usually be illuminated with less than 5 Watts).

Energy-Efficient Choices

The efficacy of lamp ballast systems is measured in mean lumens of light output divided by Watts of electric power input. The input Watts includes both the lamp and the ballast. In general, it is best to use the system with the highest possible efficacy that is suited for the project. All electric lamps emit less light as they age, called *lumen depreciation*. Significant improvements in certain lamps make lumen depreciation a very important consideration. Lamps are now rated in mean lumens per Watt (MLPW), which better represents the efficacy of the lamp over its life.

Figure 50 and Table 17 gives the MLPW for a variety of lamp/ballast systems and may be used to select light sources. For instance, "high performance" T-8 lamps are the best overall choice for most applications, and you can use 835 (neutral color), 830 (warm color) or 841 lamps (cool color) and get the same efficacy.

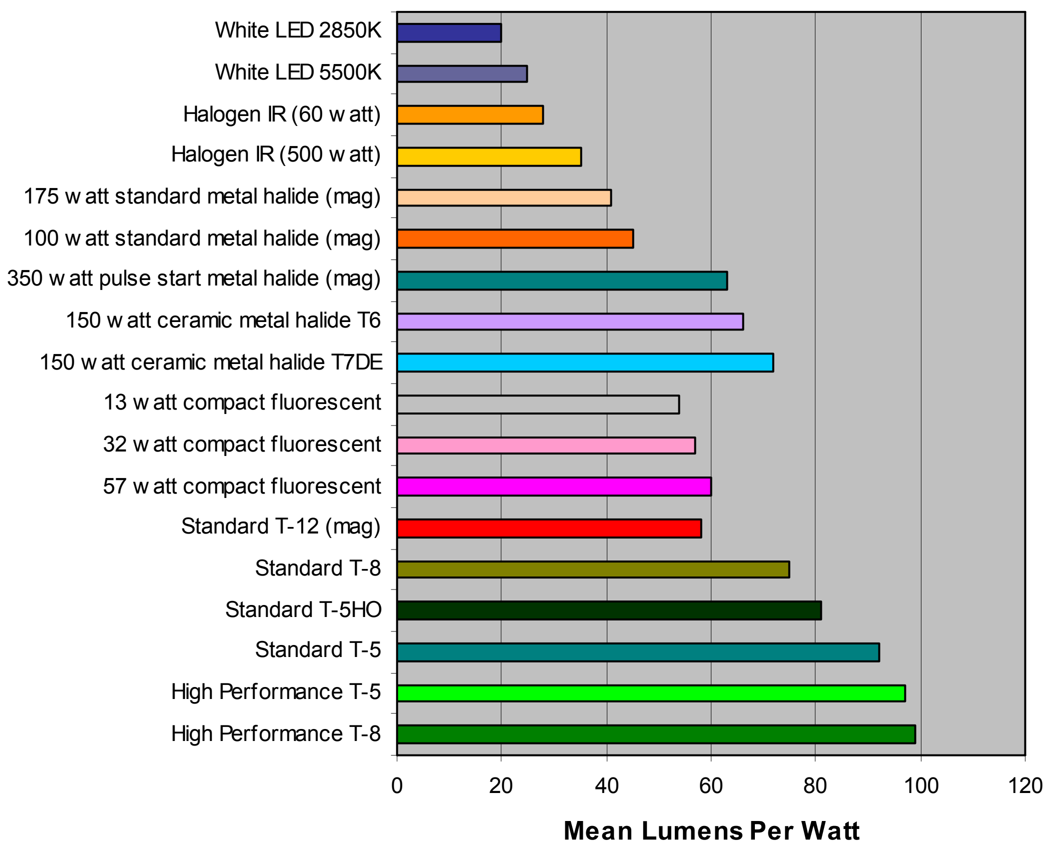


Figure 52—System Efficacy of Common Lamp Ballast Systems

Note: These data are calculated from manufacturers' literature. Values may vary due to different ratings by different companies for similar products.

Table 17—Lamp Application Guidelines

MLPW*	Lamp Type	CRI	Ballast	Good Applications	Limitations
99	T-8 “high performance” lamps (F32T-8/835; 3100+ initial lumens)	86	Electronic instant start (IS)	General lighting. The most energy efficient lighting and longest life system available for most uses.	Use carefully for outside applications.
88	T-8 premium 4 ft lamps (F32T-8/835)	85	Electronic IS	General lighting. Dims with dimming ballast.	Use carefully for outside applications.
93	T-8 premium 8’ lamps (F96T-8/835)	85	Electronic IS	General commercial and institutional lighting. Not dimmable.	8’ long lamps generally best in large spaces; 4 ft lamp systems cost less.
80	Metal halide pulse start lamps, M141 (1000 watt class)	65	Magnetic CWA	Very high bay spaces above 30; sports arenas, stadiums’.	Very long warm up and restrike times prevent rapid switching.
76	Standard T-8 generic lamps (F32T-8/735)	75	Electronic IS	General commercial lighting. Dims with dimming ballast.	Use carefully for outside applications; CRI lower than other T-8 lamps.
72	T-8 premium “U”-bent lamps (F32T-8/U/835)	85	Electronic IS	Recessed commercial lighting. Dims with dimming ballast.	More expensive than straight lamps; consider 2 24" lamps instead. Watch lumen reduction.
63	Metal halide lamps, pulse start, 350 watt	65	Magnetic CWA	General high bay lighting for gyms, stores, and other applications to about 30’; parking lots.	Long warm up and restrike times prevent rapid switching.
97 @ 35°C	T-5 high performance 4 ft lamps	86	Electronic PS	General lighting.	See High Performance T-8 Lamps should be operated at 35° C to achieve best performance
92 @ 35°C	T-5 standard 4 ft lamps (F28T-5/835)	85	Electronic program start (PS)	General and specialty lighting such as valences, undercabinet, coves, and wallwash.	See Premium T-5. Lamps should be operated at 35° C to achieve best performance
76	T-5 twin tube (“biax”) 40-50 watt (FT40T-5/835)	82	Electronic IS	General commercial and institutional lighting; track mounted wallwash and display lighting. Dimming possible.	More expensive than straight lamps; can be too bright in open fixtures; rated life may be short.
70	T-8 2’ lamps (F17T-8/835)	85	Electronic IS	General commercial lighting. Dims with dimming ballast.	Use carefully for outside applications.
80 @ 35°C	T-5HO high output 4 ft lamps (F54T-5/835)	85	Electronic PS	Indirect office lighting; high ceiling industrial lighting and specialty applications such as coves and wallwash. Gyms. Dimmable.	Very bright lamps should not be viewed directly unless mounted very high. Lamps should be operated at 35° C to achieve best performance
54	Metal halide lamps, pulse start, M137 (175 watt)	65	Magnetic CWA	Parking lots, roadway and other outdoor lighting lighting.	Very long warm up and restrike times prevent rapid switching or dimming.
66-72	Metal halide lamps, ceramic pulse start, M142 (150 watt class) ED17 or compact T6 or T7	85	Electronic	Recessed, display, direct and indirect, general indoor and outdoor lighting. Good optically for spotlighting.	More expensive than fluorescent; long warm up and restrike times prevent rapid switching.
60	Metal halide lamps, ceramic pulse start, T-6 (39 watt)	85	Electronic	Recessed, display, direct and indirect, general indoor and outdoor lighting. Good optically for spotlighting.	More expensive than fluorescent; long warm up and restrike times prevent rapid switching.
50-65	Compact fluorescent 13-70 watt	82	Electronic	Downlights, sconces, wallwashers, pendants and other compact lamp locations; can also be used outdoors in most climates.	Efficacy is far better than incandescent for applications needing compact sources.
30	Halogen infrared reflecting lamps in PAR-30, PAR-38, MR16 and T-3 shapes	100	None required	Localized accent lighting and where full range, color consistent dimming is absolutely required such as fine restaurants, hotels, high end retail, etc	Cost effective technology for accent and display lighting; use sparingly.

*Mean lumens per watt vary per specific ballast and lamp manufacturer. Values given are optimum lamp-ballast combinations as of preparation date, and other combinations may be different. Manufacturers update lamp and ballast ratings from time to time.

Efficient Luminaires

Luminaires (light fixtures) consist of lamps, lamp holders or sockets, ballasts or transformers (where applicable), reflectors to direct light into the task area, and/or shielding or diffusing media to reduce glare and distribute the light uniformly. An enormous variety of luminaire configurations exist. This section briefly outlines some of the more important types. See the *Advanced Lighting Guidelines* for more extensive details of luminaire types and considerations.

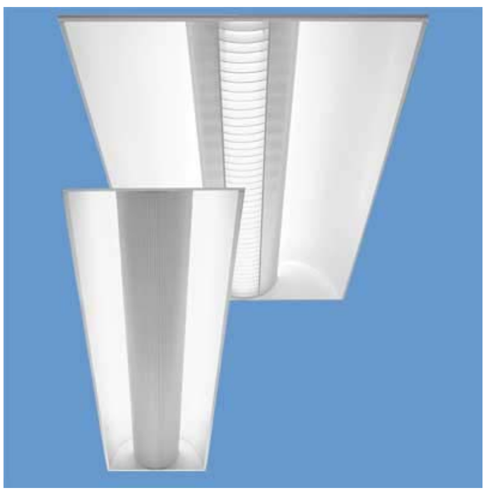
Recessed Troffers

Recessed luminaires represent a large segment of the overall luminaire market. There are two basic variations, lay-in troffers and downlights. The primary use of lay-in troffers is as a direct general light source. Downlights are relatively compact luminaires used for wall washing, accent lighting, supplemental general or task illumination, and for lower levels of ambient illumination. Presently, there are four principal variations of recessed troffers that are commonly considered for modern projects (See Figure 53).

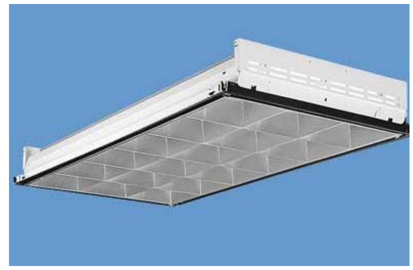
Suspended Luminaires

Suspended semi-indirect or direct/indirect luminaires are the preferred luminaires for lighting typical classrooms, offices, administrative areas, library reading areas, and other spaces. Typically these luminaires use T-8, T-5, or T-5HO lamps, and mount in continuous row configurations. The advantage of suspended luminaires is increased brightness on the ceiling and upper walls. However, as a basic requirement, ceilings should be at least 9 ft. 6 in. Significant advances in suspended lighting provide designers with many choices of varying cost, including those described in Figure 54.

The latest development is the "lay-in coffer," a combination of lens and reflector that uses the T-5 lamp. The lay-in coffer produces general illumination of surprising visual comfort considering that the luminaire has a broad distribution with almost no shielding. This luminaire has extremely high efficiency and can be used in very low ceiling applications. It produces good vertical surface illumination but it may create projection screen wash out and reflected glare from computer displays.



The recessed "basket" (sometimes called "recessed indirect") is a direct luminaire in which the lamps are shielded from view by a perforated metal basket that in more expensive versions may also contain a parabolic louver or other optical element. Like the lay-in coffer, these luminaires produce good vertical surface illumination, but may also produce unwanted brightness with respect to computer monitors and projection screens. Perhaps the most attractive troffers, but not as efficient as the lay-in coffer, above.

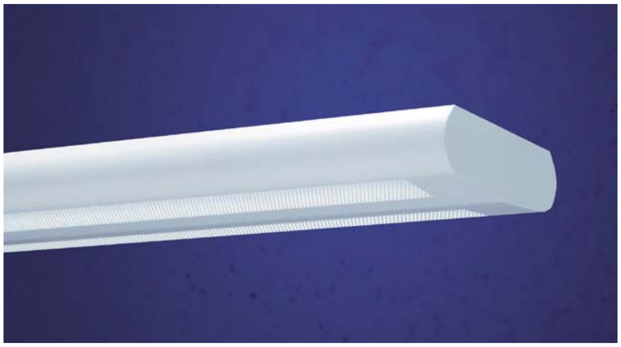


The parabolic troffer has been a popular choice for schools and commercial buildings for over three decades. The lamps are well shielded by the louvers, and the fixtures are relatively efficient and attractive. The downlight is controlled and parabolics generally work well near projection screens and computers, especially if dimmed. However, they produce very poor vertical surface illumination.

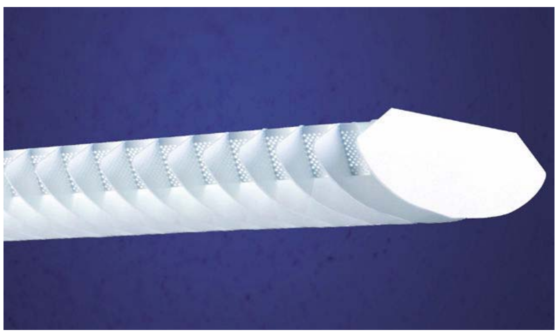
The recessed lens troffer is the least expensive energy efficient lighting system short of strip lights. It offers high efficiency, good vertical surface lighting, and very low cost. But as with other recessed systems, it will cause projection screen washout and computer screen glare. Perhaps its biggest drawback is that the lens troffer fail to illuminate the ceiling and generally don't do a good job of lighting the upper walls. In general recessed troffers should NOT be used in used in classrooms unless conditions do not permit the use of suspended lighting systems. However, consider troffers as a primary lighting system in many other areas of the school, including locker rooms, kitchens, industrial arts rooms, storage areas, and similar spaces.

Figure 53—Recessed Luminaire Types

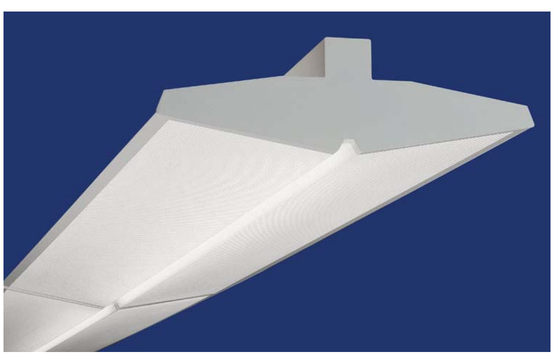
Source: Acuity Brands Inc.



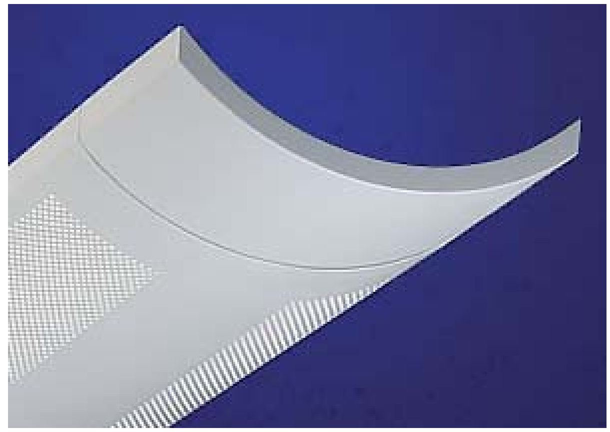
Basic indirect and semi indirect luminaires in sheet metal. Available in T-5, T-5HO and T-8 versions, these fixtures offer low cost lighting systems that look good, operate efficiently and permit flexible controls through alternating lamp row switching. Requires a flat, white ceiling.



Direct/indirect lighting systems that are reminiscent of traditional school lighting, producing efficient lighting in spaces with less-than-perfect ceilings. The downward light component helps compensate for ceilings that are irregular and/or extremely high.



For extremely low ceilings, a new generation of indirect and semi-indirect luminaires is now on the market. State of the art fluorescent optical systems permit high efficient and wide throw uplight with suspension lengths of 6" or less. A flat white ceiling is tantamount.



Upgraded versions of basic indirect and semi- indirect luminaires introduce style and other features. Still relatively low cost and generally of sheet metal construction, variations like this allow architectural expression. Also requires a flat, white ceiling. Available in T-5, T-5HO or T-8 versions.

Contemporary lighting systems available in indirect, semi indirect, direct-indirect or separately compartmented semi-indirect and direct components (see PIER lighting systems, below). Also available in a T-5, T-5HO and T-8 versions. This version illustrates a very thin and flat profile this is becoming increasing popular. Depending on the version, this luminaire might be used with a variety of ceilings

Figure 54—Suspended Luminaire Types

Source: Finelite. Inc.

Suspended High Ceiling Luminaires

Both fluorescent and HID suspended luminaires are commonly used for high spaces such as gymnasiums. HID luminaires can be classified as either high bay (>25-ft mounting height) or low bay, depending on the configuration. T-5HO, T-8 and compact fluorescent high bay luminaires are also available to light high ceiling spaces. Fluorescent versions employ up to eight lamps to approximate the light output of an HID luminaire, while allowing for additional control flexibility.

Presently, the trend is toward T-5 and T-8 high bay lighting systems, which offer the highest efficacy, dimming or multiple level control, instant on/off switching, and superior color rendering. Specific versions of fluorescent luminaires designed specifically for gyms are available; they are designed to handle physical abuse while addressing the thermal stratification of the space.

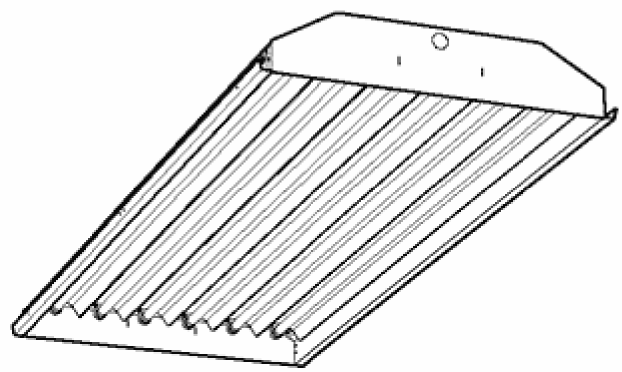


Figure 55—Gym with fluorescent high bay T-5 luminaires.

Photo: H. E. Williams

Recessed Downlights

Downlights, wallwashers and other common recessed luminaires are important in school design. To meet the CHPS criteria, most recessed lighting employ compact fluorescent or HID lamps. In very few instances where full range dimming is required or where a specific “social mood” is the design goal, halogen downlights might be considered.

Keep in mind the advantages of compact fluorescent lamps when using recessed lighting in schools. Compact fluorescent lamps can be turned on and off without a restrike delay, and can be dimmed using a dimming ballast and suitable controls. With compact fluorescent lamps now rated up to 70 watts, most downlighting applications can be met using a compact fluorescent. HID downlights should be limited to long operating hour locations, outdoor lighting, and for downlights in high ceilings.

Open cone compact fluorescent downlight with "turbo" louver and horizontal lamp

Compact fluorescent wallwasher, rectangular

Open compact fluorescent downlight, standard open cone with horizontal lamp

Lensed rectangular compact fluorescent downlight

Figure 56—Recessed Luminaire Types

Photos Courtesy Lightolier

Surface-and Pendant-Mounted Luminaires

Surface- and pendant-mounted fluorescent, compact fluorescent, and HID luminaires are valuable for surface mounting situations, particularly when ceiling access is a problem. Among the many types include sconces, wall brackets, vanity lights, and a number of special purpose luminaires.

Quite a few of these luminaires are designed to be attractive and used in public or high finish areas like main lobbies, libraries, auditoriums and commons. There is a wide range of choices from low wattage compact fluorescent sconces to large luminaires having up to eight 50-55 watt compact fluorescent lamps or even 400 watt metal halide lamps. Consider these luminaires carefully, however—they tend to be more expensive than more typical school lighting.

School designs sometimes require vandal resistant and high abuse construction. Toilet rooms, locker rooms, and certain exterior locations Wall and ceiling luminaires specifically designed for these applications are readily available, and many of them are reasonably attractive as well.

Figure 57—Decorative Compact Fluorescent Luminaires

Source: Lightolier

Electric Lighting Controls

Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Control techniques range from simple to extremely sophisticated. Lighting control strategies are most successful when the occupants can easily understand their operating characteristics. Another critical factor is the proper commissioning of lighting control systems so that they operate according to design intent. Finally, regularly scheduled maintenance of control equipment will improve the long-term success of the system. Poorly designed, commissioned, or maintained automatic lighting controls can actually increase lighting energy use and cause user dissatisfaction. Also, avoid automatic controls in task-oriented spaces where users need personal controls.

This section provides a brief overview of lighting control hardware. Also, see the *Advanced Lighting Guidelines* chapter eight for more extensive descriptions and applications.

Switches

Manual switches are the simplest form of user-accessible lighting control. Manual switches are especially valuable in daylit building spaces because they allow people to turn off electric lights when daylight is adequate. Manual switches should also be installed in spaces with occupancy sensors to increase the energy savings by allowing people to turn off the lights when they are not needed.

Occupancy Sensors

Occupancy sensors employ motion detectors to shut lights off in unoccupied spaces. The primary detection technology can be either passive infrared (PIR) or ultrasonic. Some sensors employ both passive infrared and either ultrasonic or microphonic detection. Mounting configurations include simple wall box sensors appropriate for small spaces such as private offices, and ceiling- or wall-mounted sensors that provide detection of areas up to 2,000 ft^2.

Figure 58–Occupancy Sensor

Occupancy sensors are most effective in spaces that are intermittently occupied or where the lights are likely to be left on when unoccupied. The best applications include classrooms, private offices, restrooms, and storage areas. Wall box occupancy sensors for use in private offices should require a manual touch to turn the lights on. Automatic on sensors may result in lights being energized when they are not required, e.g. an assistant momentarily enters an office to drop off paperwork.

Use occupancy sensors in combination with manual overrides whenever possible to maximize energy savings, space flexibility, and occupant satisfaction. Including manual off override in the control scheme allows the occupant to turn the lights off for video presentations or other situations requiring the lights to be off.

Time Controls

Figure 59–Digital Time Switch

Time controls save energy by reducing lighting operation hours through use of a preprogrammed scheduling. Time control equipment ranges from simple devices designed to control a single electrical load to sophisticated systems that control several lighting zones.

Time controls make sense in applications where the occupancy hours are predictable, and where occupancy sensor automatic control is either impractical or undesirable. Candidate building spaces include classrooms, offices, library stacks (local digital time switches), auditoriums, corridors, lobbies, and exteriors.

Energy Management Systems (EMS)

Typically an EMS controls lighting via a time clock. However, many building operators take advantage of the built-in EMS functions to monitor lighting usage on a space-by-space basis. EMS control of lighting systems may also allow building operators to shed non-essential lighting loads during peak demand periods.

Manual Dimmers

Next to standard wall switches, manual dimmers are the simplest of lighting control devices. Manual dimmers serve two important functions. First, dimming lights reduce lighting demand and energy usage. With incandescent and halogen sources, there is the additional benefit of extended lamp life. However, more importantly, dimmers allow people to tune the lights to optimum levels for visual performance and comfort.

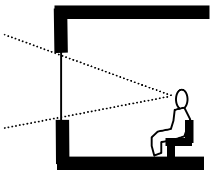
Photosensor Controls

Photosensor control systems are used to control electric illumination levels in daylit spaces. A photosensor detects the daylight illumination level and sends a signal to a logic controller to switch off or dim the electric lights in response. In *open-loop* systems, the sensor is placed so that it “sees” a representative daylight level, such as looking up into a skylight or out a window. In a *closed-loop* system, the sensor is placed so that it “sees” both the daylight and electric illumination level combined. Closed-loop systems tend to be more difficult to calibrate since they are partially responding to the light source that they are also controlling; however, they offer superior functionality when installed and commissioned properly. Different photosensors are designed to be used as open- or closed-loop systems, and should be selected specifically by their intended use and location. Compatibility between photosensor, logic controller, and ballasts should also be carefully reviewed. Finally, calibration is important and should be done after the space is painted and furnished with carpets, blinds, and furniture, so that illumination levels are as the occupants will experience them.

Occupant Education

It is extremely helpful to educate the building occupants in how lighting controls work, so that they are less likely to be surprised or annoyed by their operation. A brief tutorial for occupants, a one-page explanation taped to the light switch, or best yet, some type of permanent explanation affixed to the wall will greatly aid in the acceptance and appropriate use of the controls.

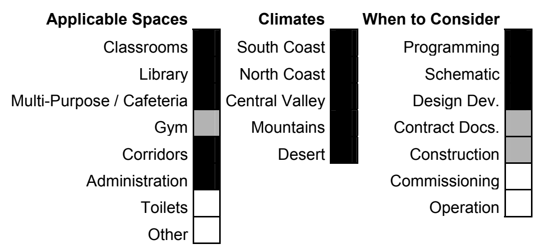
GUIDELINE LG1: VIEW WINDOWS



Recommendation

Provide access to exterior views through view windows for all interior spaces where students or staff will be working for extended periods of time.

Figure 60—View Windows at Cameron Library expand the space outward and connect the reading area with the natural landscape. Source: Lisa Heschong.



Description

A view window is vertical glazing at eye level, which provides a view to the outside. View area is generally considered the wall area between desk height (typically 2'6") and door head height (typically 7'0"), although higher and lower windows can also contribute to view in large spaces.

To be useful, a view window should provide at least a 10° angle from the eye of the beholder located at any normal working station in a room. A view window should be optimized for the visual comfort of the occupants, rather than for provision of daylight illumination. Useful daylight illumination is typically limited to a few feet from the window. Operable blinds, curtains or shades allow occupants to control window brightness for their visual preferences.

Applicability

View windows are essential in all routinely occupied spaces to give students, teachers and school staff a view to the outside. Ample and interesting views have consistently been found to contribute to both better student performance and better office worker performance.[24] Interesting views are generally considered to include some vegetation and/or human activity in the distance. Young children,

[24] See Daylighting Primer for more detail.

especially, are still developing their visual capabilities, and benefit from having distant views to relax their eye focus. Distant views also reduce eye strain and fatigue among computer users.

The recommendation for view windows is applicable to all climate regions and should be planned in the schematic design phase.

Applicable Energy Codes

The California Energy Efficiency Code specifies minimum performance of fenestration products and it limits window area to a maximum of 40% of the exterior wall area. Various credits are provided for fixed and movable shading in both the overall envelope approach and the performance approach.

The 2005 standards prescriptive glazing requirements mandate double low-e glazing throughout the state. Specific prescriptive requirements change relative to glazing area, orientation, and climate zone, The performance approach provides more flexibility, with trade offs between more or less aggressive glazing performance and other energy features of the building.

The code requires that at least half of the electric lighting power within the daylight area be separately circuited and switched.

Integrated Design Implications

Design Phase Criteria

To function well, view windows must be at eye level, glare-free, oriented toward interesting views, and designed to reduce building energy loads. Other district concerns, such as reducing distractions for students and preventing damage from vandalism must be carefully addressed. A requirement for view windows should be identified in the initial building program; their location and design objectives should be determined in the earliest phases of schematic design.

Site Planning

North and/or south facing windows are easiest to control for sun penetration and glare. Plan the layout of the school to maximize north and south facing view windows and minimize east and west facing windows. East facing windows have actually been found to be associated with reduced student performance[25] most likely due to glare from the low early morning sun. West facing windows are less problematic for glare during typical school hours, but are difficult to shade on hot summer afternoons.

25 See Daylighting Primer for more details.

Site Landscaping

Plan for shade trees and bushes outside of view windows to reduce sun penetration and reduce glare from sunlight bouncing off of adjacent buildings and paving. Keep school walkways a few feet away from classroom view windows to reduce distractions and noise from children passing by outside.

Mechanical Ventilation

Operable view windows can be used to allow the opportunity to naturally ventilate the space and reduce mechanical ventilation needs during benign climate conditions. Evaluate prevailing wind conditions and local air quality to assess the feasibility. A statistical analysis of 650 schools by the Florida Solar Energy Center found a strong correlation between the presence of operable windows and a decrease in indoor air quality complaints.[26] See also the guidelines on natural ventilation.

HVAC

View windows should be designed to minimize impacts on seasonal heating and cooling loads on the building. HVAC systems should have separately controlled zones for each window orientation. The analysis of Florida schools noted above also found that the presence of windows strongly correlated with an overall reduction in total building energy use.

Thermal Comfort

Window surfaces that are considerably warmer or colder than other room surfaces will be uncomfortable for occupants adjacent to them. Use high performance glazing (see building envelope chapter), shade the windows, and design HVAC to minimize radiant thermal discomfort due to windows. In cold climates this may mean installing supplemental heating at the building perimeter where the windows are located.

Space Planning

Stationary tasks, such as desks, teaching wall, computer locations, and reading areas should be located so that occupants can best benefit from the window views. Locate computers and white boards to avoid reflected glare from windows. The best location for the main whiteboard is perpendicular to a window wall. Computers monitors can be located perpendicular to a window, or facing away from the window at a 45 degree angle.

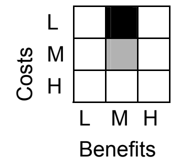
Interior Design

Interior design decisions directly affect the visual quality in the space. Excessive contrast between windows and adjacent surfaces can potentially cause eye strain. Room surfaces which are directly around and adjacent to windows should be painted white or a very light color to reduce contrast glare between the brighter windows and darker interior surfaces. Provide blinds or curtains to allow occupants

[26] M. Callahan et. al. Energy Efficiency for Florida Educational Facilities: 1996 Energy Survey of Florida Schools Final Report. Report # FSEC-CR-951-97. Florida Solar Energy Center. Submitted to Florida department of Education, July 1997.

variable control of privacy, sun penetration, glare, and reduce view in for potential vandals during un-occupied periods. Horizontal blinds located between two panes of glass can provide all of these functions and reduce maintenance costs.

Cost Effectiveness



View windows are (or should be!) standard practice for classrooms and offices, and thus included in the base cost estimate. The incremental cost of energy-efficient glazing ranges from $\$0.75/ft^2$ to $\$2.50/ft^2$ of window area, but this is already required by California standards. Horizontal blinds located between glazing layers may increase the cost of a window assembly by 25%-50%, but greatly reduces costs for exterior shading, interior curtains or blinds, and long term maintenance.

Daylight energy savings from view windows are greatest for north facing windows, and can amount to 60-80% for the first row of electric lights next to the windows. Energy savings for other orientations are negligible because the shading elements required to minimize glare usually render them unreliable for reducing electric light consumption.

Benefits

View windows provide numerous benefits, serving a broad range of important functions for physiological and mental stimulation, eye health, social communication, egress, ventilation, and energy conservation.

Perhaps most important, recent studies have shown that ample views to the outside are associated with measurable improvements in student and teacher performance. Students performed better on math and reading tests when they had larger and/or more distant views in their classrooms, views of nature or human activity[27]. Similarly, office workers performed better on cognitive tests when they had a better view, and had fewer complaints of fatigue, head aches and eye strain[28].

There are many hypotheses for why views may function to improve performance. One hypothesis is that a bright view of the outside stimulates the body's circadian system, resulting in better regulation of the various hormones and neurotransmitters needed for peak mental and emotional performance. It is known that light received by the eye, primarily in the daylight spectrum, is the primary stimulus of the circadian system that influences the production of seratonin, dopamine, cortisol, and many other important hormones and neurotransmitters. The actual requirements for intensity, duration, and spectral content, which most likely vary by time of day and the age and health of the observer, are not yet well understood[29].

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[27] See the Lighting and Daylighting Overview for more details.

[28] Windows and Offices: A Study of Office Worker Performance and the Indoor Environment www.h-m-g.com/Daylighting/A-9_Windows_Offices_2.6.10.pdf.

[29] New Buildings Institute (NBI). *Advanced Lighting Guidelines: 2003 Edition.* www.newbuildings.org/lighting.htm

Other research findings have suggested that natural views reduce stress by allowing momentary, but frequent, mental relaxation which contributes to better sustained, focused attention. Consistent with this theory, teachers have reported a reduction in stress levels when they have access to a relaxing view from their classroom.

Distant views are also essential for relaxation of the eye muscles. Optometrists recommend access to long views (of interesting objects at least 20 ft to 30 ft away) for any sedentary workers (such as students) for frequent shifting of eye focal length, which promotes eye health and good vision. This may be especially important for young children while their eyes are still developing.

View windows, especially on the first floor of school buildings, also provide an important social communication function, allowing teachers, administrators, and parents to quickly assess what is going on inside a classroom. When installed with clear glass, they are often used to display art work and current student projects, contributing to both pride and awareness of other's efforts.

Operable view windows can also provide emergency egress and natural ventilation. Studies shown that natural ventilation in classrooms is associated with higher student test scores.[30]

Figure 61—View Windows at RI Library

Windows are separated from the daylight feature overhead and use lower transmission glass to reduce glare. Source: Lisa Heschong.

Design Tools

The physical models and daylight simulation tools noted in the Overview can be used to evaluate potential daylight levels, and energy analysis software can be used to understand building energy implications.

For critical view areas, access to views and view angles from various positions in the space can be evaluated graphically with scaled drawings or with the use of a scale physical model. For a physical model analysis, it is helpful to have a "lipstick" video camera head, which can be moved around inside the model to record the views available at each location. Three dimensional computer renderings of a space can also allow early assessment of view potentials.

[30] See the Daylighting Primer for more details..

Design Details

Orientation

Orient view windows toward the north or south to avoid low angle east/west sun. Up to 15° variance from true north or south is acceptable, but will reduce performance. Avoiding east orientations is especially important since school is in session in the morning and glare and solar gains are more of a problem.

Shading Devices

Use exterior shading devices (overhangs, fins, etc.) and/or landscaping to eliminate direct sun penetration into classrooms.

Glare Control

Since view windows are within the occupants' normal field of view, the contrast between the bright window view and other interior surfaces is an important glare consideration. Add an interior shades (blinds, curtains or shade screen,) so the teacher can adjust brightness and sun penetration as needed. Mesh see-though roll down blinds reduce glare from overly bright views of the sky or outside reflective surfaces, but do not eliminate sunlight penetration and so should not be used for solar shading. Micro-blinds located between panes of glass provide a particularly attractive solution to glare control and sun protection in schools, reducing long-term maintenance costs by eliminating dust and dirt accumulation. Blinds should have a non-shiny white surface. In situations where operable blinds or curtains are not possible, use a lower transmission glazing adjusted for the window orientation. In general, visible transmission of view glazing should not be reduced below 30% in clear sky climates or below 50% in heavily overcast climates. If tinted glazing is used, evaluate its effect on distortion of colors (for example, the graying of greens and blues in the landscape) in both overcast and clear skies.

Figure 62—Microblinds

Micro-blinds located between two panes of glass provide excellent glare and solar control, while being protected from dust and abuse. Source: Lisa Heschong

Interior Surface Reflectance

Deep splayed walls or mullions will also reduce contrast glare. Paint all surfaces near windows white or off-white to further reduce contrast between the brightness of the window and its surrounding wall, and help distribute the daylight. Place view windows adjacent to a perpendicular surface to reflect daylight onto adjacent surfaces. Avoid "punched holes" in walls, as they create the worst glare conditions.

Outside Reflective Surfaces

Be aware of bright reflective surfaces outside the view window that may create glare when they are in sunlight. Reflected sun off a car windshield can be especially troublesome. Light-colored exterior walls to the north of a window can also create glare sources when the wall is in direct sun. Plant hedges or trees to reduce the glare potential from these exterior sources. Operable binds or curtains also allow occupants to adjust to varying glare conditions as the sun moves through the sky.

Thermal Comfort

Windows can become substantially colder or hotter than other surfaces in a room, causing thermal discomfort. High performance glazing, with a low U-factor will mitigate this problem. Avoid using tinted glazing that will receive direct sunlight, as it tends to become very hot. In very cold or hot climates (desert, mountain and Central Valley), use a low-e coating to maximize comfort and energy efficiency.

Computer Screen Location

Orient computers at a 45° angle from view windows to avoid glare from reflections of the window in the VDT screen. Flat screen computers and adjustable-angle LED screens also help to reduce glare.

Security

Provide operable interior shades and/or laminated glass for security in ground level rooms that contain computers or other valuables. Keep school walkways some distance from view windows.

Durability and Accessibility

Use sturdy mechanisms for all operable ventilation and shading devices. Make them easily accessible to the teacher and easily repairable.

Noise Transmission

Windows are frequently the "weakest link" acoustically in a building structure. Double glazed windows, required by Title 24, also help reduce transmission of exterior noise. However, normal double paned windows with ¼ in. or ½ in. airspace are not as acoustically effective as those with a bigger air space between window panes. For the best acoustic performance, windows should have laminated glass on at least one pane, as well as significant airspace between the two panes. In high noise areas (from exterior traffic, trains and/or aircraft), it is not uncommon to require thicker laminated glass and 2 in. to 4 in. of airspace between the panes. See also the acoustic guideline on sound transmission coefficients in the building envelope chapter.

Figure 63—View Windows

View windows promote communication between interior and exterior spaces. Lisa Heschong, photographer.

Operation and Maintenance Issues

View windows should be cleaned on a schedule. Internal shading and glare control devices need to be durable, and will need to be cleaned and replaced over time. Blinds or curtains that are replaced are often less optimum than the original design. Those that are the least likely to break or need cleaning will have the longest life span, ensuring the continued performance of the daylight design and reducing life-cycle costs.

Coordinate selection of glazing materials with the maintenance staff to ensure ease of cleaning and replacement. Some districts have district-wide standards for glazing size, tint and strength of glass to ensure quick replacement of broken glass that may reduce selection options for windows.

Design ventilation devices to prevent physical entry as well as any rain or maintenance water penetration.

Commissioning

Ensure that operable shading and glare control devices operate as intended.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG2: HIGH SIDELIGHTING—CLERESTORY

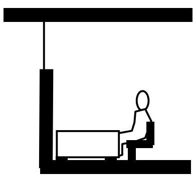


Figure 64—Classroom with high clerestory window.

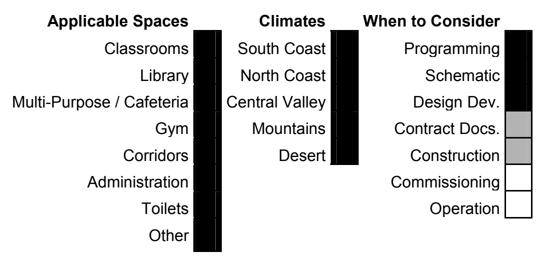
Source: Lisa Heschong.

Recommendation

Use high clerestories in perimeter walls to increase daylight delivery deep into classrooms, offices, libraries, multipurpose rooms, gymnasiums, and administrative areas.

Description

High sidelighting clerestories are vertical glazing in an exterior wall above eye level (usually above 7 ft). Since the penetration of daylight from vertical glazing is about two times the window head height, moving the window higher in the wall increases daylight penetration in the space.



Applicability

High clerestory windows can be used in all school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

Applicable Energy Codes

The California Energy Efficiency Code does not require that high side lighting with light shelves be installed. However, the code does specify the minimum performance of fenestration products and it limits window area to a maximum of 40% of the exterior wall area. Various credits are provided for fixed and movable shading in both the overall envelope approach and the performance approach. The prescriptive approach only gives credits for overhangs.

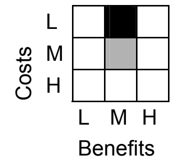
The 2005 standards prescriptive glazing requirements mandate double low-e glazing throughout the state. Specific prescriptive requirements change relative to glazing area, orientation, and climate zone. The performance approach provides more flexibility, with trade offs between more or less aggressive glazing performance and other energy features of the building.

At least half of the electric lighting power within the daylight area, as defined by the code, must be separately circuited and switched.

Integrated Design Implications

- *Design phase.* High sidelighting requires high ceilings and perimeter walls. North and (shaded) south orientations are preferable, although east, and west orientations can be acceptable if diffusing glazing is used, or if low-angle sun penetration will not be bothersome in the space (probably not classrooms). High sidelighting is most appropriate for open plan interior layouts that allow unobstructed daylight penetration. It should be considered in the early schematic design phase.
- *Balance with other daylight needs.* Applied to one wall, this approach creates a decreasing gradient of useable daylight about two times the clerestory head height into the space. For spaces of 20 ft to 40 ft in width (classrooms, etc.), it can be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire space. View windows should also be provided. The total glazing area should be apportioned among these needs.
- *Reduced plenum space*. Clerestory sidelighting requires ceiling heights of 9.5 ft or more at the window wall. This extra ceiling height may be accomplished with minimal increase of the floor-to-floor height by careful integration of the structural system, HVAC ducts and electric lighting in the plenum space. Sloping (or stepping) the ceiling upward at the perimeter (see figure)—essentially reducing the plenum space there—can also yield additional perimeter ceiling height. For ceiling-ducted HVAC systems, this requires routing ducts away from perimeter walls.
- *Natural ventilation*. High windows can be especially beneficial for natural ventilation, by allowing heated air to escape out near the ceiling. The ideal location for high operable windows is on the leeward side of a building.
- *HVAC*. High sidelighting glazing impacts HVAC loads by its vulnerability to solar gains during the cooling season and heat loss in the heating season. Good design (appropriate glazing orientation, size, glazing materials, shading and photocontrol of electric lights) can reduce the overall HVAC loads and potentially reduce HVAC system size and first costs.
- *Duct work*. Keep ductwork away from high windows to avoid blocking daylight.
- *Electric lighting*. High sidelighting creates linear zones of daylight that run parallel to the clerestory windows. Electric lighting should be circuited parallel to this and photocontrolled (or manually controlled) in response to available daylight.

Cost Effectiveness



Costs for high sidelighting are low to moderate. Windows are standard practice for classrooms. A balance of view and clerestory windows can be provided for each classroom with minimal increase to the overall glazed area. The incremental cost of energy efficient glazing ranges from $0.75/ft^2–$2.50/ ft^2.

Benefits

High sidelighting provides a moderate level of benefits. The general energy saving, productivity and visual comfort benefits of daylighting are discussed in the Overview section to this chapter. Clerestory sidelighting both saves energy and improves lighting quality. Energy savings come from reduced electric lighting energy use. Lighting quality is improved by a more uniform distribution of daylight across the space.

Design Tools

Computer simulation programs and scale models as outlined in the Overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can accommodate these. Check for daylight levels across the space under both clear sky and overcast sky conditions and check direct sun penetration through the clerestory glazing for the lowest expected sun angles. Even occasional penetration of low sun angles can be extremely bothersome to occupants and may lead to blocking a window.

Energy savings from minimized HVAC loads and control of electric lighting in response to daylight can be estimated with the DOE-2, EnergyPlus, and Energy-10 programs available.

Design Details

- *Ceiling height*. High sidelighting glazing works best in spaces with high ceilings, of 11–12 feet. Generally, the higher the ceiling, the better.
- *Balancing with view windows*. Lower view windows are frequently coupled with high sidelighting schemes, but they do not have to coincide for the whole perimeter. The high glazing should be continuous along the whole area to be daylit. View windows can be selectively spaced beneath these high windows as needed. This balance between high clerestories and view windows can leave lower perimeter wall space available for other uses.
- *Shading devices*. Design high sidelighting clerestories with exterior shading, diffusing glazing, operable blinds, or light shelves to eliminate direct sun penetration. A light shelf or louver system may also be used; see Guideline Guideline LG3: High Sidelighting—Clerestory with Light Shelf or Louvers. Dedicated blinds or shades for the upper clerestory glazing can be optimized for daylight distribution while allowing the lower view windows to be controlled separately for glare. Mini-blinds

positioned between the panes of glass in a double glazed window accomplish this with minimal maintenance. Some manufacturers will provide “inverted” blinds, with the concave side installed facing up. This provides somewhat better daylight distribution to the ceiling. Blinds should have a non-shiny white surface. Mesh see-though roll down blinds reduce glare from overly bright views of the sky or outside reflective surfaces, but do not eliminate sunlight penetration and so should not be used for solar shading.

- *Orientation*. Clerestories are most effective on south and north orientations, but should be carefully evaluated on east and west orientations to assure that low sun angle penetration and direct solar gain into the space is minimized. Shade exterior glazing with an overhang on east-, west-, and south-facing glazing to minimize solar gain or use a selective low-e coating (SHGC less than .45).
- *Visible transmission*. Use high transmission, clear glazing (visible transmission 60% to 90%) on the upper window to admit the maximum daylight to the space. Clear low-e glazing is recommended in the desert, mountain and Central Valley climates.
- *Stepped ceiling*. Clerestories may create a comparatively dark area along the wall directly beneath them. An interior stepped ceiling in a multi-story building can create a clerestory that reflects daylight back onto the wall to brighten it and deliver reflected daylight to the space.
- *Reflectance*. Paint all surfaces near the clerestories white or off-white to reduce contrast between the brightness of the clerestory and its surrounding wall. The adjacent ceiling should also have a highly reflective (>70%) white or off-white surface to help diffuse a maximum amount of daylight into the space. Use specially designed “high reflectance” ceiling tiles if the budget allows.
- *Teaching surface*. In classrooms, the teaching surface should be perpendicular to the window wall for best illumination. Avoid orientations that will put students’ or teachers’ faces in silhouette or cause reflected glare on whiteboards or computer screens.

Operation and Maintenance Issues

For operable louvers, it is best to have preset angles that are seasonally adjusted by maintenance staff so the louvers are not inadvertently closed and forgotten or left at a non-optimal angle.

For shades or blinds that are operated by teachers, ensure that their control mechanisms are accessible, robust, and easily repaired.

Clerestory windows should be washed on a regular schedule.

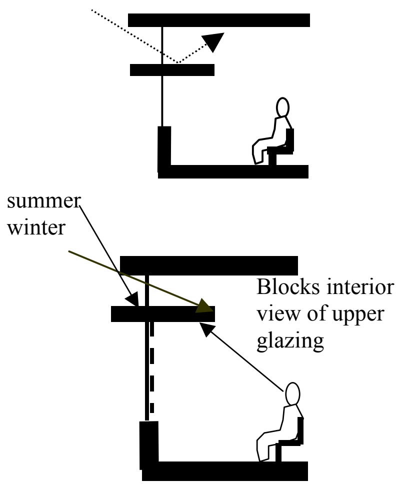
Commissioning

Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

References/Additional Information

See the Overview section of this chapter.

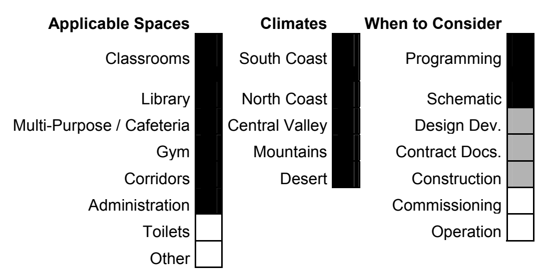
GUIDELINE LG3: HIGH SIDELIGHTING—CLERESTORY WITH LIGHT SHELF OR LOUVERS



Exterior light shelves shade lower window and reflect summer sun into room. Interior shelves reflect winter sun while reducing glare.

Figure 65–Exterior Light Shelves

Photo of Liberty Elementary School with exterior light shelves to reflect sunlight onto classroom ceilings. Source: Liberty Elementary, Boise School District, Boise, ID



Recommendation

Use light shelves or louvers with high clerestory glazing in south facing perimeter walls to improve daylight distribution, block direct sun penetration, and minimize glare in classrooms, offices, libraries, multipurpose rooms, gymnasiums, and administrative areas.

Description

A light shelf is a horizontal reflecting panel placed below high clerestory glazing (with a view window generally below it) to bounce sunlight deeper into the space. Daylight distribution is improved as sunlight reflects off the top surface of the light shelf or louver and diffuses onto the ceiling.

Light shelves and louvers can be located on the exterior, interior, or both. Exterior shelves shade the lower window from solar heat gain and reflect high angle summer sun into the room. Interior shelves reflect lower angle winter sun while blocking the penetration of direct sun and reducing glare from the upper glazing.

A series of smaller horizontal louvers can replace a single large light shelf as long as the geometry is maintained. Horizontal blinds can function similar to light shelves. Ideally, blinds should be painted white and be inverted (concave side up) to have optimal performance. While blinds and louvers can have the advantage of being adjustable relative to solar angle, this is rarely done in actuality. Thus, it may be a realistic assumption that they will remain at a fixed angle throughout the year.

Applicability

High clerestory windows with light shelves or louvers can be used in most south facing school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

Applicable Codes

The California Energy Efficiency Code does not require that high side lighting with light shelves be installed. However, the code does specify the minimum performance of fenestration products and it limits window area to a maximum of 40% of the exterior wall area. Various credits are provided for fixed and movable shading in both the overall envelope approach and the performance approach.

The 2005 standards prescriptive glazing requirements mandate double low-e glazing throughout the state. Specific prescriptive requirements change relative to glazing area, orientation, and climate zone location. The performance approach provides more flexibility, with trade offs between more or less aggressive glazing performance and other energy features of the building.

At least half of the electric lighting power within the daylight area, as defined by the code, must be separately circuited and switched.

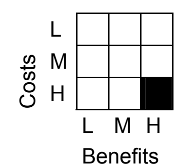
Integrated Design Implications

- *Design Phase.* Clerestories with light shelves require perimeter access to south-facing (+/- 15°) sidelighting and impact many aspects of building massing. They also benefit from open plan interior layouts that allow unobstructed daylight penetration. They should be considered in the early schematic design phase. Calculation of the size and cutoff angles of the light shelf or louver system is essential.
- *Balance with Other Daylight Needs.* Applied to one wall, this approach creates a decreasing gradient of useable daylight about two times the clerestory head height into the space. Wider spaces can be balanced with a daylighting scheme on the opposite wall to provide even lighting

across the entire space. Lower view windows are frequently coupled with light shelf schemes, but they do not have to coincide for the whole length of the light shelf. The high glazing with light shelf should be continuous along the whole area to be daylit. View windows can be selectively spaced beneath the light shelf as needed. This balance between high sidelighting and view windows leaves some lower perimeter wall space available for other uses. Total glazing area should be apportioned among these needs.

- *Integration with Ceiling Plenum.* Clerestories with light shelves require ceiling heights of 9.5 ft or more at the window wall. This extra ceiling height may be accomplished with minimal increase of the floor-to-floor height by careful integration of the structural system, HVAC ducts, and electric lighting in the plenum space. Sloping (or stepping) the ceiling upward at the perimeter—essentially reducing the plenum space there—can also yield additional perimeter ceiling height. For ceiling-ducted HVAC systems, this requires routing ducts away from perimeter walls.
- *Integration with HVAC*. Glazing above a light shelf impacts HVAC loads by its vulnerability to solar gains during the cooling season and heat loss in the heating season. Good design (appropriate glazing orientation, size, performance, shading, and photocontrol of electric lights) can reduce the overall HVAC loads and potentially reduce HVAC system size and first costs. Light shelves also must be designed so as not to interfere with circulation of air from the HVAC system.
- *Integration with Electric Lighting.* Clerestories with light shelves create linear zones of daylight that run parallel to the clerestory windows. Electric lighting should be circuited parallel to this and automatically controlled in response to available daylight. Light shelves and louvers deliver daylight indirectly to the space; they work well when coupled with direct/indirect pendant electric lighting. Sometimes the first row of electric lighting is incorporated into the light shelf itself.
- *Integration with Other Mechanical Systems.* Design light shelves so they do not interfere with the operation of a fire sprinkler system.

Cost Effectiveness



Clerestories with light shelves or louvers are relatively expensive, but downsizing cooling systems may offset some cost (if electric lights are automatically switched or dimmed in response to daylight). Energy savings from reduced lighting and cooling energy are adequate to recover the initial investment in about 8 to 12 years.

Benefits

Clerestories with light shelves or louvers produce a high level of benefits. The general energy saving, productivity, and visual comfort benefits of daylighting are discussed in the Overview section to this chapter. Clerestories with light shelves or louvers both save energy and improve lighting quality. Energy savings come from reduced solar gains (when an exterior light shelf shades lower glazing) and reduced lighting energy use.

Lighting quality is improved because daylight is delivered deeper in the space, creating a more even distribution of daylight. Interior light shelves and louvers restrict the view of the bright upper glazing, eliminating glare.

Design Tools

Computer simulation programs and scale models as outlined in the Overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can accommodate these. Check for daylight levels across the space under both clear sky and overcast sky conditions, and check direct sun penetration through the upper glazing for the lowest expected sun angles.

Most whole-building energy simulation programs (like DOE-2 and EnergyPlus) do not accurately represent the increased daylight distribution from a light shelf or louver system. For more accurate simulations of electric lighting energy savings, the daylight distribution should be simulated with a physical scale model or daylight simulation program and then input to the energy program.

Design Details

Ceiling height. Provide a minimum perimeter ceiling height of 9.5 ft (the higher, the better). Position the light shelf at 7 ft or more above the floor. Coordinate shelf position with pendant electric lighting, door headers, shelving, fire sprinklers, and other interior features.

Orientation. Light shelves are most effective on south orientations, and occasionally on the north (to reduce glare from the upper glazing). They should be avoided on east and west orientations.

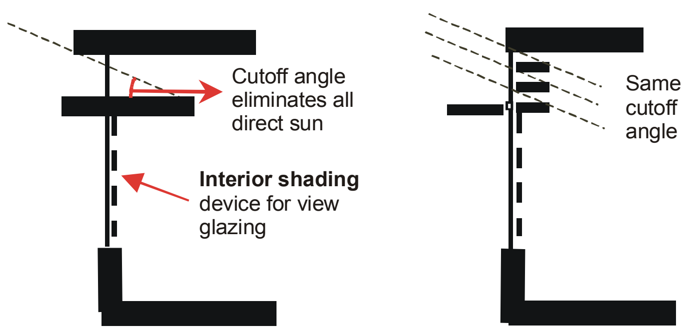


Figure 66—Cutoff Angle of Light Shelves

Set the cutoff angle of light shelves or louvers to eliminate direct sun penetration during normal school hours.

Cutoff angle. Set the cutoff angle of the light shelf or louvers (see the figure above) to eliminate direct sun penetration during normal school hours. (Use a cutoff angle of 27° for latitudes north of Chico. Use a cutoff angle of 23° for latitudes between Chico and Bakersfield. Use a cutoff angle of 20° for latitudes south of Bakersfield.) Cutoff angle can be increased by 10° if there are operable shades on the upper glazing, and increased by 20° if operable louvers will be seasonally adjusted.

Visible transmission. Use high transmission, clear glazing (visible transmission 70%–90%) on the upper window to admit the maximum daylight to the space. with a Low-e coating is recommended in the desert, mountain and Central Valley climates.

Reflectance. The top surface of the light shelf or louvers should be highly reflective (greater than 80% reflectance and with a diffuse, not mirrored, surface). Paint all surfaces near the clerestories white or off-white to reduce contrast between the brightness of the clerestory and its surrounding wall. The adjacent ceiling should also have a highly reflective (>80%) white surface to help diffuse a maximum amount of daylight into the space. Use specially designed "high reflectance" ceiling tiles if the budget allows.

Materials. Light shelves and louvers may be opaque or translucent and constructed of wood, metal panels, GFRC (glass fiber reinforced concrete), plastic, fabric, or acoustic ceiling materials. Choice of material should include consideration of reflectivity, structural strength, cost, ease of maintenance, and durability. Some curtain wall or window manufacturers can assist in developing details for light shelves and offer add-on products as part of their service. Fabric "shelves" can be suspended from the ceiling at their interior edge.

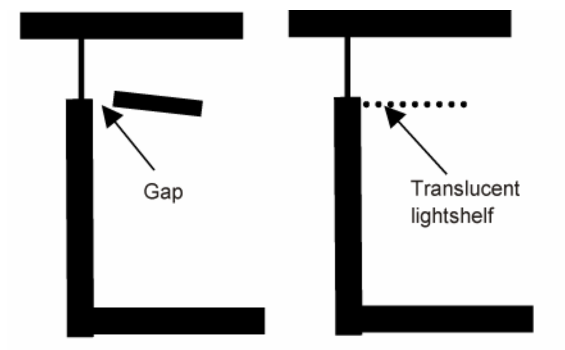


Figure 67—Creating a Wall Wash

If opaque light shelves aren't coupled with view windows, consider leaving a gap between the light shelf and the wall to create a wall wash. Translucent shelves provide a soft light under them.

Top surface. The top surface of a row of lockers or casework that lines a perimeter wall can also be used as a light shelf if its reflectivity and dimensions are appropriate. Slope the top surface so it will not be used for storage.

Opaque vs. translucent shelves. Opaque shelves may create a dark space along the wall directly under them if they are not coupled with a view window. Leave a gap between the light shelf and the wall to create a wall wash or use electric lighting to brighten this wall. Translucent shelves provide a soft light under them but must be carefully evaluated so the direct view of the under side does not create glare. See Figure 67 above.

Dirt accumulation. To reduce accumulation of dirt, exterior shelves should be sloped at least 0.25 in./ft so that rain can help keep it clean and not pool on the shelf. Also slope interior shelves so they are not used for storage. Fabric construction is another way of preventing this.

Accessibility. Both exterior and interior light shelves can be an "attractive nuisance" in school buildings, inviting students to climb or hang on them. Minimize access to the shelf, or use a series of horizontal louvers or blinds instead.

Figure 68—The CTAC High Performance Classroom

The high performance classroom at Southern California Edison's Customer Technology Application Center (CTAC), Irwindale, CA. (Left) Exterior light shelf and sun shade (Right) Classroom with skylights, windows, clerestories and PIER lighting system. Photos: J. Benya

Access for cleaning. Detail the light shelf or louver system so it is easy to clean the glass above it, both inside and out. Large light shelves may need to be moved away from the window by six inches to allow for window cleaning equipment to be inserted from below the shelf. Blinds set in between double panes of glazing allow the glass to be cleaned without dirt accumulation on the blinds.

Teaching surface. In classrooms, the teaching surface should be perpendicular to the window wall for best illumination.

Operation and Maintenance Issues

The glazing and light shelf/louver system forms a light delivery system that must be kept clean to ensure maximum delivery of daylight to the space. The top surface of the shelf or louvers should be cleaned each time the windows are washed. Make sure light shelves or louvers are detailed correctly to allow easy window cleaning. For operable louvers, it is best to have preset angles that are seasonally adjusted by maintenance staff so the louvers are not inadvertently closed and forgotten or left at a non-optimal angle.

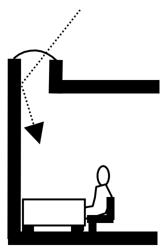
Commissioning

Unless the light shelf or louvers are moveable, commissioning should not be necessary. Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG4: CLASSROOM DAYLIGHTING—WALL WASH TOPLIGHTING



Skylit wall wash delivers daylight across two-thirds of this classroom. Lisa Heschong, photographer.

Recommendation

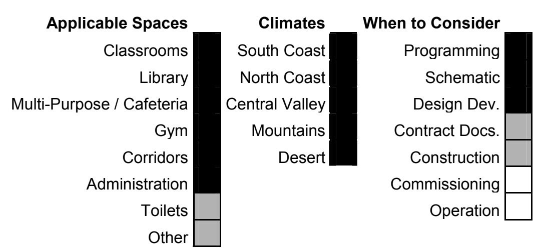
Use wall wash toplighting for interior classroom walls to balance daylight from window walls, brighten interior classrooms, and make them seem more spacious.

Description

Wall wash toplighting provides daylight from above through a linear skylight or monitor to wash an interior wall. The glazing is obscured from direct view by the skylight or monitor well. Daylight is diffused with diffusing glazing, baffles or reflections off of the matte surfaces of the light well and interior walls.

Applicability

A toplighting scheme applies to single-story buildings or the top floor only of a multistory building. Appropriate spaces for wall wash toplighting may include classrooms, libraries, multipurpose spaces, gyms, corridors, and administration offices. It is applicable to all climate regions, and must be planned for in schematic design.



Applicable Energy Codes

The California Energy Code specifies the minimum performance of fenestration products and it limits skylight area to a maximum of 5% of the exterior roof area (unless they are over a high atrium).

The 2005 standards prescriptive glazing requirements mandate double glazed skylights throughout the state. Specific prescriptive requirements change relative to glazing area, glazing and curb type, and climate zone location. The performance approach provides more flexibility, with trade offs between more or less aggressive glazing performance and other energy features of the building.

Fifty percent of the electric lighting power within the daylit zone, as defined by the code, must be separately circuited and switched. When the continuous daylight area is greater than 2500 ft^2 the automatic daylighting controls are required.

Integrated Design Implications

Site plan. This toplighting scheme applies to single-story buildings or the top floor only of a multi-story building. It must be planned for in the schematic design.

Space Planning. Wall wash toplighting works best along display walls and in the center of a space. It can be used for the interior walls of classrooms or along a linear corridor. Ideally the illuminated wall will be used for display of visually interesting materials and will be kept clear of attachments which will cause shadowiong, like cabinets or ducts.

Balance with other daylight. Applied to one wall, this approach can provide even daylight across approximately two-thirds of a classroom. It should be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire classroom. View windows should also be provided. The total glazing area should be apportioned among these needs.

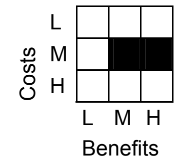
HVAC. Placement of skylights and monitors and their associated light wells must be coordinated with the location of rooftop HVAC equipment and interior duct runs. If it is oriented, glazed, shaded, and integrated with electric lighting controls, toplighting should decrease overall energy use of the building. This can reduce the initial size of the HVAC system and annual energy costs.

Mechanical ventilation. Operable rooftop fenestration can be used to naturally ventilate the space. Evaluate thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.

Structural system. Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity.

Safety and security. A safety/security grating can be placed in light wells directly under the glazing to protect against falls and vandalism. (Light control louvers or baffles can also serve this function.) Paint the grating white to minimize its visual presence.

Cost Effectiveness



Costs for wall wash toplighting are moderate to high, depending on design. Commercial, single glazed skylights are usually the least expensive approach.

Benefits

Wall wash toplighting provides a moderate to high level of benefits. This approach washes a wall with light, and bounces glare-free daylight into the classroom. It will make the space appear larger and brighter. The uniform light from this approach can easily light the inner two-thirds of a classroom. It is excellent when combined with another wall wash or a sidelighting technique that increases daylight on the opposite side of the room (for example, a perimeter window) to create even, balanced daylight across the whole room.

This approach saves electric lighting energy if the first row or two of lights adjacent to the wall wash are switched off or dimmed in response to the daylight. Savings for controlled fixtures may be 40%–80% during daylight hours.

Operable louvers can provide variable amounts of daylight for different activities. Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance, and has been correlated with lower energy use in schools.

Design Tools

The computer simulation programs and scale models described in the Overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can handle this situation.

Design Details

Skylight vs. vertical glazing. The glazing for these patterned toplighting schemes may be either horizontal or vertical (preferably facing north or south). Orientation is very important for roof monitors. It is not important for skylights. Skylights with a projecting shape, such as barrel vaults or pyramids, capture more low-angle sun in the early mornings and late afternoons, and thus extend the amount of time during the day that they provide useful daylight. Rectangular skylights should be oriented with the long dimension north-south to optimize low angle sunlight collection.

Diffusion. Diffuse the daylight before it washes the wall. Eliminate direct sun patches with diffusing glazing, baffles, or a deep well. For skylights, use a high performance diffusing material, such as prismatic acrylic, to maximize light transmission while minimizing hot spots. For clear glazed, baffled systems, design fixed baffles to cut off all expected sun angles or provide adjustable baffles.

Visible transmittance. Use glazing with the highest visible transmittance to bring in the most daylight relative to the glazed area. For vertical glass, use a low-e coating to minimize heat loss; use a selective low-e coating to minimize solar gain on solar orientations.

Light wells. A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Diffusely reflecting light wells should be less than 8 ft deep; mirrored reflecting wells can be used for deeper wells when necessary.

Surface colors. The top of the wall that is washed should be ideally be painted white, or at minimum a light color (>70% reflectance) so it can reflect daylight into the space. It should not have protrusions that will cast objectionable shadows.

Balancing daylight. Combine wall wash toplighting approach with another linear approach on the opposite wall to balance daylight in the space.

Insulation. Insulate light well walls to minimize thermal losses and reduce condensation.

Task and accent lighting. In addition to ambient lighting, this approach can be used for task lighting on the wall (lighting lockers) or accent lighting (lighting artwork). It is excellent for corridors and other circulation spaces.

Blackout capability. Many school districts request “black-out” capability, especially for multipurpose rooms which may be used for performances. Most often in these cases it is sufficient to dim the daylight to low ambient levels. Operable louvers or roller blinds can be added to to modulate the daylight levels. For small rooms with low ceilings these can be operated with manual pulls or cranks. For very large rooms and/or those high ceilings motorized controls are recommended.

Integrating with electric light. Consider an electric lighting wall wash luminaire to illuminate the wall at night, or during heavily overcast conditions. Photoswitch this light in response to daylight levels.

Safety and security. Operable mechanisms should prevent any physical entry. A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles may also serve this function.) Make sure this grating does not create a shadow pattern on the wall.

Leakage. All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer. Any operable opening should prevent rain penetration.

Operation and Maintenance Issues

Educate teachers about how wall wash toplighting delivers daylight to the space; discourage them from placing dark colored artwork and posters high on the washed wall.

Clean glazing on a schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

The mechanisms for operable louvers and blackout shades should be robust, accessible to the instructor and easily repaired.

The janitorial service should check all operable windows or skylights for closure daily.

Commissioning

Check to ascertain that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG5: CENTRAL TOPLIGHTING

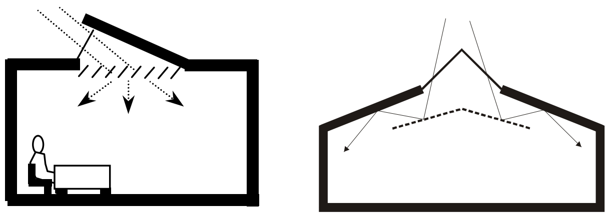


Figure 69—Sawtooth Monitor

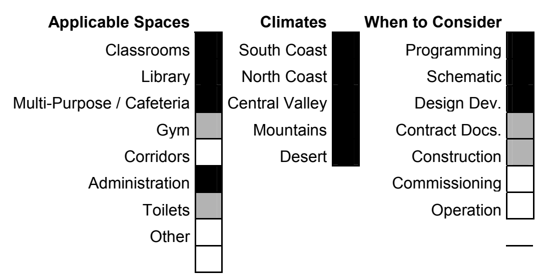
Central sawtooth monitor provides even illumination across desktops in this classroom. Source: Barbara Erwine.

Recommendation

Use central toplighting in single-story classrooms to provide high levels of even, balanced daylight across the entire room.

Description

Central toplighting uses a central monitor or skylight (or cluster of skylights) to distribute daylight evenly across the room. Daylight is diffused with diffusing glazing or baffles that can be fixed or operable. Daylight levels are highest directly under the aperture and gradually reduce toward the perimeter of the space.



Applicability

Central toplighting is applicable in single-story or top floor spaces including classrooms, libraries, multipurpose spaces, and administrative offices. It is appropriate for all climate regions, and should be considered during the programmatic, schematic, and design development phases of a school building project.

Applicable Energy Codes

The California Energy Code specifies the minimum performance of fenestration products and it limits skylight area to a maximum of 5% of the exterior roof area (unless they are over a high atrium).

The 2005 standards prescriptive glazing requirements mandate at least double glazed skylights throughout the state. Specific prescriptive requirements change relative to glazing area, glazing and curb type, and climate zone location, The performance approach provides more flexibility, with trade offs between more or less aggressive glazing performance and other energy features of the building.

Fifty percent of the electric lighting power within the daylit zone, as defined by the code, must be separately circuited and switched. When the continuous daylight area is greater than 2500 ft² then automatic daylighting controls are required.

Figure 70—Central Skylight and Splayed Light Well Walls
Source: PJHM Architects

Integrated Design Implications

Integration with site plan. This toplighting scheme applies to single-story buildings or the top floor only of a multi-story building. It must be planned in the schematic design.

Skylight vs. vertical glazing. The glazing for a central toplighting scheme may be either horizontal or vertical (facing north, east, south, or west).

Balance with other daylight. This scheme should be combined with view windows in perimeter walls. Since the toplighting aperture provides most of the ambient daylight, smaller windows can be judiciously spaced in exterior walls to optimize views and save wall space for other needs. The total glazing area should be apportioned among these needs.

Integration with HVAC. Placement of skylights and monitors, and their associated light wells, must be coordinated with the location of rooftop HVAC equipment and interior ducts.

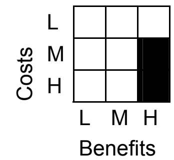
Integration with structural system. Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity.

Integration with electric lighting. Central daylighting schemes often fail to provide bright illumination on interior walls. Electric lighting wall wash fixtures may be needed to supplement the daylight.

Integration with mechanical ventilation. If the toplighting fenestration is operable, it can be used to naturally ventilate the space. Evaluate the thermal stratification of air in the space and the prevailing wind conditions to assess the feasibility.

Safety and security. Toplighting scenarios on relatively flat roofs have both safety and security issues that should be considered. The Daylighting Design Considerations in the on-line Appendix discusses these concerns in more detail.

Cost Effectiveness



Costs for central toplighting are medium to high, depending on design. Commercial, double glazed skylights or a diffusing, double wall panel system with a sheetrocked well will be the least expensive. Site-built monitors with vertical or sloped glazing will cost more.

Costs for skylights include unit skylight, curb and flashing, any dampers, louvers or burglar bars, the skylight well and a diffusing system at the base. Costs for monitors include additional structure and finishes around the monitor, glazing, roofing, flashing, any louvers or baffles or diffusers at the base.

Benefits

Central toplighting provides a high level of benefits. With good diffusion, this approach creates even, balanced daylight across the classroom, which has been correlated with higher standardized test scores. This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40% to 80% during daylight hours. Operable louvers can provide variable amounts of daylight for different types of classroom activities. Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance, and has been correlated with lower energy use in schools.

Design Tools

The computer lighting simulation programs and scale models described in the Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check that the simulation program can handle this.

The SkyCalc program can be used to optimize the size and annual whole building energy performance of a central skylight scheme. DOE-2 should be used for any designs using vertical glazing.

Design Details

General

Placement. Placing a diffusing central toplighting opening in the center of the room will provide the most uniform horizontal daylight levels across the room, but may leave key wall areas comparatively dark. It may be more appropriate to locate the lightwell opening closest to the primary teaching wall in a classroom (or a display wall in other spaces) in order to create a bright wall wash on that surface. It is also useful to consider the orientation of the opening relative to this surface, since daylight from even the most diffusing design will change in intensity over the course of the day as the sun moves through the sky. In general, the brightest surfaces will be to the north of the opening, especially when the sun is to the south during midday.

Visible transmittance. Use high visible transmission glazing materials (greater than 60%) to maximize daylight while minimizing the size of the glazed area with its relatively low U-factor. Alternatively, larger areas of low-transmission glazing with high insulation levels, such as insulated fiberglass panels, may be used successfully. The balance between visible transmittance and insulation levels is best studied with an hourly climate simulation software tool.

Reflective materials. A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Bright white, flat paint works best. Diffusely reflecting light wells should be las wide and shallow as possible. Specular reflecting wells can be used when deep or narrow wells are necessary. A diffusing glazing panel should be placed at the bottom of a specular well.

Diffusion. Diffuse any direct beam sunlight with diffusing glazing or or by bouncing off of another surface, such as reflectors or baffles Avoid placing any diffusing glazing within the normal field of view, as it will cause excessive glare.. Design reflectors or baffles to intercept all expected sun angles or else to be adjustable.

Splayed light wells. Splay light well walls to allow daylight to spread more effectively in the space and reduce glare. A 45° angle works best.

Insulation. Insulate light well walls to an R-value at least equivalent to the code requirement for wall insulation to minimize thermal losses and reduce condensation.

Daylight illumination levels: Many school districts request “black-out” capability, especially for multipurpose rooms which may be used for performances. Most often in these cases it is sufficient to dim the daylight to low ambient levels. Operable louvers or roller blinds can be added to modulate the daylight levels., For small rooms with low ceilings these can be operated with manual pulls or cranks. For very large rooms and/or those high ceilings motorized controls are recommended.

Integration with electric lighting. See the Electric Lighting and Controls chapter for information about control of electric lights in response to available daylight. Electric lighting should be designed to both supplement the daylight during the day, and also provide good quality lighting in the space at night. With central toplighting, care should be given to how to provide sufficient vertical illumination around the walls of the room and also provide electric uniform illumination under the light well at night.

Safety and security. A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.) Make sure this grating does not create a shadow pattern on the wall. Paint it white to reduce its visual presence.

Leakage. All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

Reflectors. A reflecting device may be placed below the light well to redirect daylight onto the ceiling or walls of the space. This ceiling/wall wash will make the space appear larger and brighter. Even though horizontal footcandles measured at desk height may be reduced, uniformity will be improved. The reflector may consist of flat or curved mirrored or matte reflective surfaces. It may also be partially translucent (fabric, plastic, or perforated metal). This device will require extra floor to ceiling height and should be studied with a physical scale model to evaluate daylight distribution.

Skylights

Use a glazed area of about 3%–6% of the floor area. Use SkyCalc or other tools to calculate the optimum size and glazing properties to balance annual energy use. Because it if difficult to provide light to a large area from a single source, this pattern for a central skylight should be used only for relatively small areas, i.e. classroom size or smaller.

Monitors

Orientation is very important for roof monitors. Roof monitors facing south can have the smallest glazing area, but should have baffles, reflectors and or shading to diffuse direct sunlight. Roof monitors facing north will provide the most uniform illumination throughout the day, but need to have a substantially larger glazing area to provide similar light levels. High performance glazing with high visible light transmittance, should be used in both cases. South facing monitors should have a lower SHGC (less than 0.45) to reduce solar gains in the cooling season. North facing monitors should optimize the U-value of the glazing and roof assembly to minimize heat loss. Avoid roof monitors with glazing oriented east or west; they will show large variations in light level from morning to afternoon, and poor energy performance.

Operation and Maintenance

Clean glazing on a regular schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

Mechanisms for operable louvers and blackout shades should be robust, accessible to the teacher, and easily repaired.

Spiders love high bright spaces, so provide a way to remove spider webs if they accumulate.

Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG6: PATTERNED TOPLIGHTING

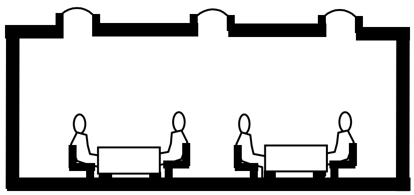


Figure 71—Grid Skylights

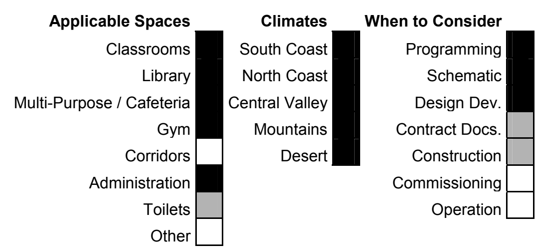
Grid of skylights in Peoria Gymnasium provide even illumination across the space. Source: Lighting Co., Inc.

Recommendation

Use patterned toplighting in interior spaces that need even, low glare illumination across a large area.

Description

Patterned toplighting provides daylight through a two-dimensional grid of skylights or rows of roof monitors . It provides even, glare-free daylight across large areas. Spacing of the pattern is largely a function of the ceiling height and aperture size.



Applicability

This daylighting pattern is useful for any large area that needs even daylight levels. It is especially good for gymnasium, library, multipurpose, or cafeteria spaces. For gymnasium ball courts, add baffles or high light well cutoff angles to minimize direct views of bright glazing surfaces during ball games (See Design Details below). Patterned toplighting is appropriate for all climate regions, and should be considered during the programmatic, schematic, and design development phases.

Applicable Energy Codes

The California Energy Code specifies the minimum performance of fenestration products and it limits skylight area to a maximum of 5% of the exterior roof area (unless they are over a high atrium).

The 2005 standards prescriptive glazing requirements mandate double glazed skylights throughout the state. Specific prescriptive requirements change relative to glazing area, glazing and curb type, and climate zone location, The performance approach provides more flexibility, with trade offs between more or less aggressive glazing performance and other energy features of the building.

Fifty percent of the electric lighting power within the daylit zone, as defined by the code, must be separately circuited and switched. When the continuous daylight area is greater than 2500 ft² the automatic daylighting controls are required.

Very large spaces, with continuous open areas greater than 25,000 ft² and with ceilings above 15 ft high, the California standards require the use of diffusing skylights combined with automatic daylight controls. For school districts, this is most likely to apply to large field houses, or maintenance sheds.

Integrated Design Implications

Integration with site plan. This toplighting scheme applies to single-story buildings or the top floor only of a multi-story building. It must be planned for in the schematic design.

Skylight vs. vertical glazing. The glazing for these patterned toplighting schemes may be either horizontal or vertical (preferably facing north or south). Orientation is very important for roof monitors. It is not important for skylights. Skylights with a projecting shape, such as barrel vaults or pyramids, capture more low-angle sun in the early mornings and late afternoons, and thus extend the amount of time during the day that they provide useful daylight. Rectangular skylights should be oriented with the long dimension north-south to optimize sunlight collection.

Balance with other daylight. At a minimum, this scheme should be combined with view windows in perimeter walls. Since the toplighting aperture can provides very uniform daylight throughout the space, smaller windows can be judiciously spaced in exterior walls to optimize views, and save valuable wall space for other needs. The total glazing area should be apportioned among these needs.

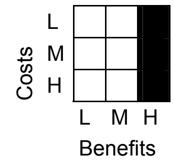
Integration with HVAC. Placement of skylights and monitors and their associated light wells must be coordinated with the location of rooftop HVAC equipment and interior duct runs. Skylights should be kept way from rooftop maintenance areas.

Integration with mechanical ventilation. If the toplighting fenestration is operable, it could be used to naturally ventilate the space. Evaluate the thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.

Integration with structural system. Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity.

Safety and security. Toplighting scenarios on relatively flat roofs have both safety and security issues that should be considered. Check the Daylighting Design Considerations in the on-line Appendix for further discussion of these.

Cost Effectiveness



Costs for patterned toplighting range from low to high, depending on design. A grid of skylights in an exposed ceiling will be the least expensive; a suspended ceiling requires additional skylight wells and splays which can double the cost; monitors with reflecting devices are likely to be the most expensive due to additional structural and finishing costs.

Costs include the expense of the skylight or monitor device; rooftop installation; curbs and waterproofing; interior well construction and finish; and electric lighting controls to switch or dim in response to daylight.

A patterned daylighting system that provides uniform illumination across the space combined with automatic daylight control of the electric lights can save 40% to 80% of the electric lighting energy use in the space during daylight hours. Properly sizing the skylights or roof monitors will minimize impacts on the heating and cooling loads of the building and provide net whole building energy savings in every California climate.

Benefits

Patterned toplighting provides a high level of benefits. This approach creates even, balanced, low-glare daylight across the space, which has been associated with better student performance

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40% to 80% during daylight hours.

Operable louvers can provide variable amounts of daylight for different activities. Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance, and has been correlated with lower energy use in schools.

Design Tools

The computer lighting simulation programs and scale models described in this chapter's Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check to ensure the simulation program can handle this.

The SkyCalc program can be used to optimize the size and specification criteria of skylight schemes, looking at annual whole building energy use. DOE-2 should be used to simulate annual energy use for roof monitors or designs with vertical glazing.

Design Details

General

Visible transmittance: Use high visible transmission glazing materials (greater than 60%) to maximize daylight while minimizing the size of the glazed area with its relatively low U-factor.

Diffusion: Diffuse the daylight with diffusing glazing or baffles. If using clear glazing, design baffles or reflectors to cut off all expected sun angles. Avoid placing vertical diffusing glazing within the normal field of view. Diffusion of daylight can be increased with white painted wells and/or by adding additional diffusing glazing at the bottom of the light well.

Splayed light wells: When placing skylights in a space with a hung ceiling, splay the bottom of the light well walls to spread the daylight more effectively in the space and reduce glare. A 45° angle works best.

Reflectance: A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Bright white flat paint works best. Diffusely reflecting light wells should be as wide and short as possible. Specular reflecting wells can be used when deep or narrow wells are necessary, but should be combined with a diffusing panel at the base of the well.

Insulation: Insulate light well walls to minimize thermal losses and reduce condensation. Use an R-value at least equivalent to the code requirement for wall insulation.

Daylight illumination levels: Many school districts request “black-out” capability, especially for multipurpose rooms which may be used for performances. Most often in these cases it is sufficient to dim the daylight to low ambient levels. Operable louvers or roller blinds can be added to to modulate the daylight levels., For small rooms with low ceilings these can be operated with manual pulls or cranks. For very large rooms and/or those high ceilings motorized controls are recommended.

Safety and security: A safety/security grating can be placed in light wells directly under the glazing to protect against falls and vandalism. (Light control louvers or baffles can also serve this function.) Paint the grating white to minimize its visual presence.

Leakage: All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

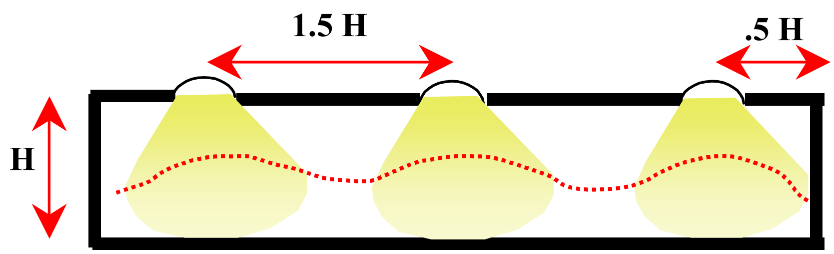


Figure 72—Skylight Grid Spacing

Skylight Grid

As a rough rule of thumb, skylights should be spaced from about one to one-and-a-half times the floor-to-ceiling height (H in Figure 72 above). Their glazing area should be about 3% to 12% of the floor area to be lighted. (Use SkyCalc or other tools to optimize the design.)

Series of Monitors

Orientation is very important for roof monitors. Roof monitors facing south can have the smallest glazing area, but should have baffles, reflectors and or shading to diffuse direct sunlight. Roof monitors facing north will provide the most uniform illumination throughout the day, but need to have a substantially larger glazing area to provide similar light levels. High performance glazing with high visible light transmittance, should be used in both cases. South facing monitors should use a lower SHGC (less than 0.45) to reduce solar gains in the cooling season. North facing monitors should optimize the U-value of the glazing and roof assembly to minimize heat loss. Avoid roof monitors with glazing oriented east or west; they will show large variations in light level from morning to afternoon, and provide poor energy performance.

Operation and Maintenance

Clean glazing on a regular schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

Mechanisms for operable louvers and blackout shades should be robust, accessible to the instructor, and easily repaired.

Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers or baffles to eliminate direct sun penetration.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG7: LINEAR TOPLIGHTING

Recommendation

Use linear toplighting as a single downlighting element in a long, linear space (such as a corridor) to direct movement or establish a visual orientation. Use it on two sides of a space to define separate functions or activities, to define edges in a larger space, and/or to downlight the space from two directions.

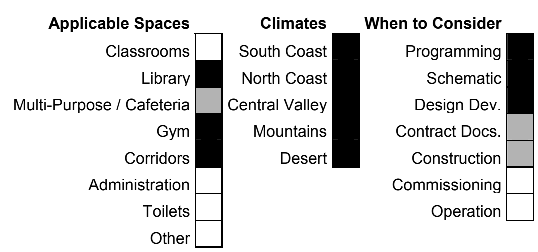
Figure 73—Linear Skylight

Daylight spreads to adjacent spaces and organizes the circulation

Description

Linear toplighting is a downlighting scheme that provides a line of high intensity daylight directly under it, which diminishes as an individual moves perpendicularly away from it. It establishes a strong longitudinal orientation in the space and is best coupled with a corresponding circulation pattern or linear visual cue. It is most efficient at distributing the daylight broadly when located as high as possible, such as along the ridge of a gable roof (as in photo to right).

Linear toplighting can be created with skylights arranged in a row, or roof monitors. Skylights will provide the most uniform levels of daylight through out the year. South facing roof monitors can be designed with shades and reflectors that maximize winter daylight and minimize summer heat gain.



Applicability

This daylighting pattern is useful for enclosed hallways and linear walkways within a larger space, or for use bilaterally to frame centrally focused areas like gymnasiums, libraries, and multipurpose areas. Linear toplighting may also be used in covered exterior walkways to minimize their shadow, especially in covered walkways adjacent to rooms with sidelighting.

Applicable Energy Codes

The California Energy Code specifies the minimum performance of fenestration products and it limits skylight area to a maximum of 5% of the exterior roof area (unless they are over a high atrium).

The 2005 standards prescriptive glazing requirements mandate double glazed skylights throughout the state. Specific prescriptive requirements change relative to glazing area, glazing and curb type, and climate zone location, The performance approach provides more flexibility, with trade offs between more or less aggressive glazing performance and other energy features of the building.

Fifty percent of the electric lighting power within the daylit zone, as defined by the code, must be separately circuited and switched. When the continuous daylight area is greater than 2500 ft^2 the automatic daylighting controls are required.

Very large spaces, with continuous open areas greater than 25,000 ft^2 and with ceilings above 15 ft high require the use of diffusing skylights combined with automatic daylight controls for the base case design. For school districts, this is most likely to apply to large field houses, or maintenance sheds.

Integrated Design Implications

This toplighting scheme applies to single-story buildings or the top floor only of a multistory building. It should be integrated with the site plan, building massing and circulation pathways, and thus should be planned for in the schematic design phase. This approach is best applied in coordination with the roofing plan of the building, and works well with sloped roofs.

Balance with other daylight. Since overall glazing area is limited, the amount of glazing in a linear toplighting scheme must be balanced with the need for view windows and other apertures in the space.

Integration with electric lighting. Electric lighting should be aligned with the toplighting without blocking it or causing shadows on the floor. Electric lighting circuits should be laid out parallel to the daylight contours, so that each circuit can be progressively switched off or dimmed when there is ample daylight underneath.

Integration with structural system. Skylights and monitors can interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity. A monitor system will involve more structural See Daylighting Design Considerations in the on-line Appendix for more about integrating toplighting with structural systems.

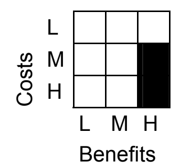
Integration with HVAC. Placement of the linear toplight and its associated light well must be coordinated with the location of rooftop HVAC equipment and interior duct runs. Interruptions in the linear run of this toplight may be required to accommodate these other needs. The interruptions should be sequenced in a regular manner to prevent a random pattern of light and dark.

Integration with mechanical ventilation. If the toplighting fenestration is operable, it could be used to naturally ventilate the space. Evaluate thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.

Integration with interior design. This daylighting strategy will be most effective if the adjacent wall and ceiling surfaces are painted white or a very light color. Partitions or high obstacles in the space (such as library stacks) should run perpendicular to the linear daylighting, in order to allow the furthest spread of the daylight and avoid creating shadows.

Safety and security. Toplighting scenarios on relatively flat roofs have both safety and security issues that should be considered.

Cost Effectiveness



Costs for linear toplighting range from moderate to high, depending on design. A linear row of skylights will be the least expensive; monitors with reflecting devices will be more expensive. Costs include the expense of the skylight or monitor device; rooftop installation; curbs and waterproofing; interior well construction and finish; and electric lighting controls to switch or dim in response to daylight.

Benefits

Linear toplighting provides a high level of benefits. This approach creates bright, welcoming corridors that link important functions in the building. It can provide a strong visual cue for circulation that guarantees daytime egress lighting independent of electric power. In a bilateral scenario, it can provide balanced daylighting that graduates from high at the perimeter to moderate between the two linear toplights.

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40%–80% during daylight hours.

Operable louvers can provide variable amounts of daylight for different activities. Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance, and has been correlated with lower energy use in schools.

Design Tools

The computer simulation programs and scale models described in the Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check to ensure the simulation program can handle this. The SkyCalc program can be used to optimize the size of a skylight scheme.

Design Details

Visible transmittance. Use high visible transmission glazing materials (greater than 60%) to maximize daylight while minimizing the size of the glazed area with its relatively low U-factor. Alternatively, larger areas of low-transmission glazing with high insulation levels, such as insulated fiberglass panels, may be used successfully. The balance between visible transmittance and insulation levels is best studied with an hourly climate simulation software tool.

Glazing area vs. floor area. Use a glazed area of about 3% to 12% of the floor area. Use the lower end of this range for spaces with high air conditioning or heating loads, and the higher end for temperate climates with more overcast weather, or when using highly insulated panels.

Circulation. When applicable, coordinate linear toplighting with major circulation areas in the school. Increase light levels at major intersections and hallway ends to draw students in that direction.

Diffusion. Either diffuse daylight or direct sun may be used in circulation and transition areas. Daylight diffused with translucent glazing or baffles will spread the daylight evenly in the space, making the most effective use of the light. Occasional patches of direct sun can create a vibrant splash of light to emphasize major intersections and circulation spines. Some designs have successfully combined patterns of diffusing glazing with smaller areas of transparent glazing to animate a circulation space.

Glare control. Structural elements or banners mounted perpendicular to the glazing will help diffuse the daylight and reduce the contrast between bright, sunlit glazing and the interior space. Baffles can be designed to help bounce direct sunlight and minimize glare.

Shared daylighting. Consider sharing diffuse corridor daylight with adjacent spaces by glazing the upper portion of the wall. Avoid this in areas where acoustic separation is important. In multistory buildings, consider sharing daylight from the top floor corridor with the lower floor by periodically cutting light wells to the lower level. Daylight illumination levels from these strategies will be modest at best, but still contribute to a sense of lightness and transparency in the building design.

Splayed light wells. For diffusing skylights with deeper, narrow light wells, splay the light well walls to spread the daylight more effectively in the space and reduce glare. A 45° angle works best.

*Insulation***.** Insulate light well walls to an R-value at least equivalent to the code requirement for wall insulation to minimize thermal losses and reduce condensation.

Safety and security. A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.) Make sure this grating does not create a shadow pattern on the wall. Paint the grating white to minimize its visual presence.

Leakage. All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

Operation and Maintenance

Clean glazing on a schedule. Horizontal glazing (and clear glazing) needs more frequent cleaning in climates with low rainfall.

Spiders love high bright spaces, so provide a way to remove spider webs if they accumulate.

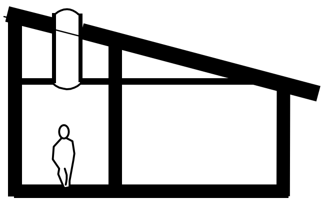
Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers or baffles to eliminate direct sun penetration.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG8: TUBULAR SKYLIGHTS



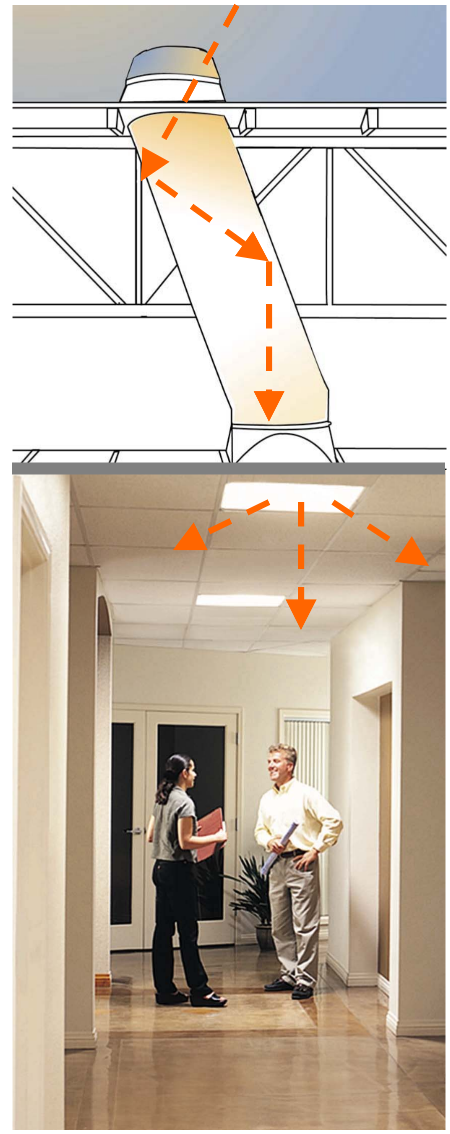


Figure 74—Tubular skylight.

Source: Solatube, Inc.

Recommendation

Use tubular skylights for toplighting in areas with relatively deep roof cavities and for low-cost retrofits to existing spaces with a suspended ceiling.

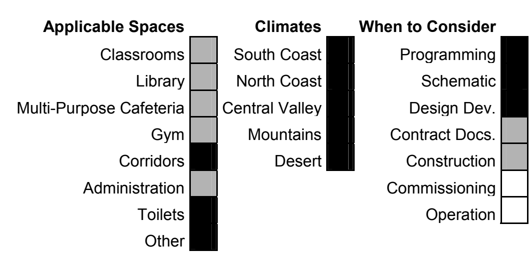
Description

Tubular skylights are small clear-domed skylights with mirrored reflective ducts connecting them to the ceiling plane of the space. They have an interior diffuser at the ceiling plane to spread daylight in the space. They are typically designed to fit between the framing of the roof, so that structural modifications are not necessary.

Applicability

Tubular skylights are especially good for small spaces, such as toilet rooms, locker rooms, kitchens, interior corridors, enclosed staff work areas, and other interior spaces that are sporadically occupied. They are also good for retrofit into an existing school space that needs extra daylight or needs to balance an existing asymmetric daylight distribution.

These units will work significantly better in clear sky climates than in overcast climates. As the duct gets longer, less daylight is delivered; so they should be limited to spaces with roof cavities of 8 ft or less.



Applicable Codes

The California Energy Code specifies the minimum performance of fenestration products and it limits window area to a maximum of 5% of the exterior roof area.

Integrated Design Implications

Integration with site plan. This toplighting scheme applies to single-story buildings or the top floor only of a multistory building. It should ideally be planned for in schematic design, although of all daylighting options considered in this manual, tubular skylights are the easiest to add to an existing building.

Ceiling heights. Tubular skylights will diffuse daylight to a larger space the higher they are located in a space. When ceilings are below 9' high, consider adding a "splay" at the bottom of the tube to allow the daylight to spread out more broadly

Balance with other daylight. At a minimum, this scheme should be combined with view windows in perimeter walls. Since the toplighting aperture provides most of the ambient daylight, smaller windows can be judiciously spaced in exterior walls to optimize views and save wall space for other needs..

Integration with HVAC. Placement of tubular skylights must be coordinated with the location of rooftop HVAC equipment and interior duct runs. Although the reflective ducts can jog somwhat to avoid barriers in the ceiling plenum space, the efficiency of daylight delivery is reduced with each bend.

Integration with structural system. The small diameter of these units reduces their impact on the structural system relative to larger framed skylights. They are typically designed to fit between framing members, thereby reducing the need for specially blocking As with any roof penetrations, the structural engineer should review the impact on the roof's structural integrity. See Daylighting Design Considerations in the on-line Appendix for more on integrating toplighting with structural systems.

Integration with electric lighting. Tubular skylight should be placed on an appropriate grid to provide uniform illumination in the space. This should be carefully integrated

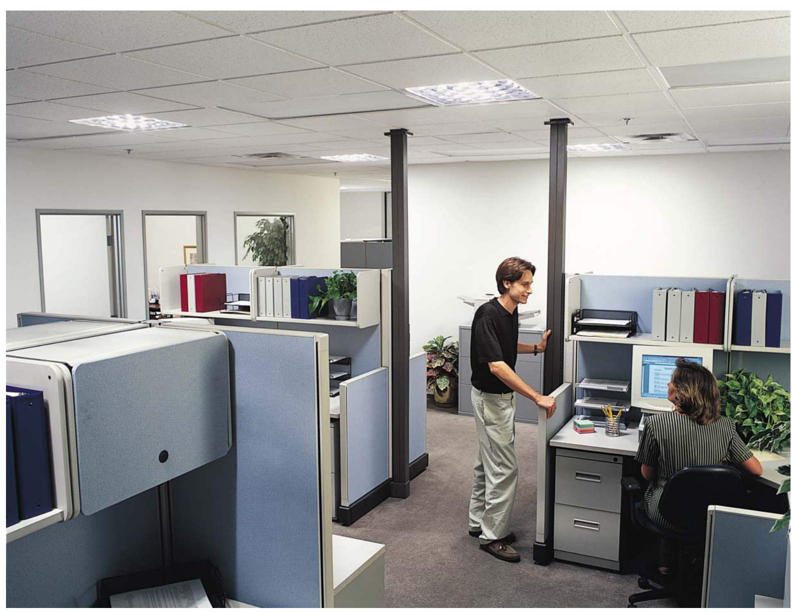


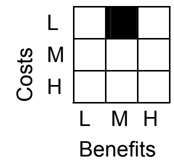
Figure 75—Tubular Skylights in Interior Office

Skylight diffuser panel fits into a standard suspended ceiling system. Special lenses distribute the daylight broadly, as seen on the far wall. Source: Solatube.

with the placement of electric lights, so that placement of both are optimized. Typically there will be fewer tubular skylights than electric luminaires for an equivalent amount of light in a space. Electric lights should be on automatic controls so that they are switched off or dimmed when there is sufficient daylight in the space (see Guideline E4 on lighting controls).

Safety and security. Unless these skylights are larger than 16 in. in diameter, they should not pose a security liability. They should be located to the roof to avoid a tripping hazard to maintenance crews.

Cost Effectiveness



For smaller spaces like hallways and offices, 10 in. and 14 in. diameter tubular skylights cost approximately $300 and $400 (not including installation costs), respectively. Larger 22” tubular skylights are available that provide daylight illumination comparable to a 2 ft x 2 ft unit skylight. While cost per square foot of aperture are high compared to unit skylights, savings can be had in simplifying installation and minimizing structural impacts.

Benefits

Tubular skylights provide a moderate level of benefits. This approach provides daylight “fixtures” that deliver daylight through a ceiling plenum to an interior space. Arranged in an appropriately dimensioned grid, they can provide even, balanced daylight across the space. As with any daylighting system, daylight levels and appearance will fluctuate with time of day and climate conditions. Daylight in classrooms has been correlated with higher standardized test scores. See this chapter’s Overview for details.

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 20% to 60% during daylight hours, depending on the aggressiveness of the daylighting and lighting control systems.

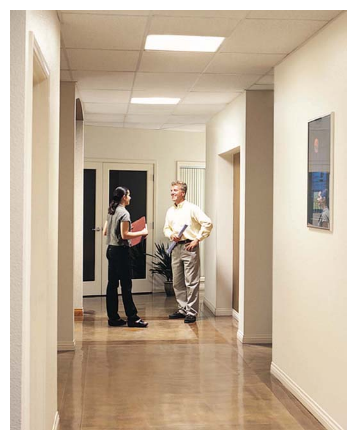


Figure 76—Solar Tube Skylight

Photo taken by Bullard, Kent, of the National Park Service. Courtesy NREL PIX 05546.

Design Tools

The specular reflective tube makes it difficult to simulate the performance of these skylights with physical scale models and computer tools. Local case studies, test installations, and estimating tools from the manufacturers currently are the best tools for evaluating performance. Designers should take note that some manufacturers of tubular skylights have made exaggerated claims about both daylight delivery and R-value of their products.

Energy performance of these skylights is also handicapped by the lack of verified U-factor and SHGC data. A few manufacturers are starting to engage third party testing labs to verify the performance of their products. Others have created in-house computer simulations of their thermal and photometric performance, the next best alternative. As this information becomes available, hourly building energy evaluation programs like DOE-2, EnergyPlus, and Energy-10 can be used to evaluate the annual energy impacts.

Design Details

Length and bends. Minimize the overall length and minimize bends in the reflective duct running from the skylight to the ceiling plane.

Reflective ducts. Use a product with a highly reflective cylindrical duct. Do not use a corrugated duct; the corrugations trap light. Minimize bends and joints.

Half dome vs. full dome. In predominantly sunny climates, use a tubular skylight with a south-facing, reflective half-dome under the skylight "bubble" to increase the reflection of low angle sun into the skylight (see Figure Figure 77—Section of Reflective Half Dome below). Special lenses or geometric shapes can also help to catch low angle sun and direct it downward. The average elevation of the sun in California is about 30 degree above the horizon, Furthermore, daylight is more valuable in the morning and evening at low sun angles, so maximizing the penetration of low angle sun is an important feature. In predominantly overcast climates, use a full clear dome.

Diffusers. Some products have a flat bottom diffuser that fits into a standard 2 ft x 2 ft or 2 ft x 4 ft dropped ceiling grid. It is important that the diffusers minimize glare to the room occupants, especially on the brightest, sunniest days. Dropped or pyramid diffusers can become excessively bright under these conditions. Diffusers with a special Fresnel lens are available that help diffuse the daylight widely and minimize glare.

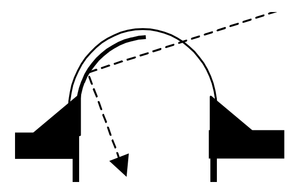


Figure 77—Section of Reflective Half Dome

Daylight dampers. Some products have integrated dampers inside the tube that control the amount of daylight delivered to the space. These dampers can be on manual or automatic control. They will add to the cost of the system, so first be sure that they are really necessary. When dampers are needed, manually controlled dampers are recommended for their simplicity, lower cost, and ease of occupant control and maintenance.

Integral electric lighting. Some products have electric lighting within the duct or diffuser that is switched or dimmed in response to the available daylight. Such electric devices will lower the efficiency of the daylight distribution, and also are rarely optimum for electric light distribution. Thus, they are only recommended when there is not sufficient ceiling space to install both a tubular skylight and a luminaire. Special coordination is needed for both installation and maintenance when there are electric wires to connect.

Insulation. For ducts installed in uninsulated ceiling or attic spaces, insulate the duct to an R-level at least equivalent to the code requirement for air ducts to minimize thermal losses and reduce condensation.

Leakage: Any roof penetration has the potential for leaks. Use well-tested curb design details and flashing kits provided by the manufacturer. Check with other customers on their experience with the particular product. A warrantee by the general contractor is recommended.

Operation and Maintenance

Clean glazing on a schedule, especially in dry, dusty climates. Dust and bird droppings on the skylight dome are the biggest cause for reductions in daylight transmission.

If the diffusers at the bottom of the tube are not air tight, the skylight tubes should be checked periodically for dust or moisture accumulation.

Commissioning

Any dampers or electric lighting on automatic controls need to be commissioned, and their performance verified.

If a solar reflector is installed in the skylight dome, it should be checked for proper orientation.

References/Additional Information

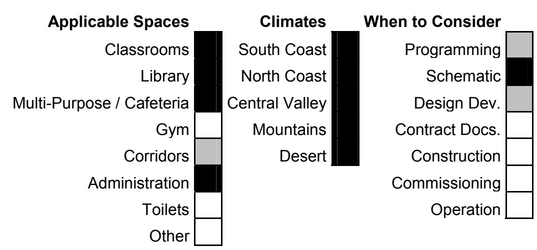
See the Overview section of this chapter.

GUIDELINE LG9: CLASSROOM LIGHTING—CONVENTIONAL TEACHING

Recommendation

For general illumination in a conventional classroom, provide a flat, white acoustical tile or wallboard ceilings at least 9 ft 6 in above the finished floor, and then employ suspended lighting systems with at least some portion of the lighting being indirect. This lighting system should operate at lighting power density of 0.80-0.90 W/ft² if used with supplemental whiteboard lighting (see Guideline LG11: Teaching Board Lighting), and 0.85–0.95 W/ft² without additional lighting systems. Choosing among the many options includes consideration of the grade level, teaching technology, budget and white board relevance.

Figure 78—Indirect/Direct Lighting System



Description

The recommended lighting system consists of either two or three rows of suspended linear fixtures. These lighting systems are typically suspended from the ceiling by 15-18 in. depending on the specific luminaire. Products are available with a wide range of quality, performance and appearance. For projects on tight budgets, formed steel indirect luminaires are sufficiently inexpensive and efficient to compete with parabolics and many other types of lay-in direct lighting. For projects with slightly higher budgets, designers can choose from a variety of attractive, high performance lighting systems. Applicability

Pendant mounted lighting is appropriate for all classrooms, libraries, multi-purpose spaces, and administration spaces.

Applicable Codes

See the Applicable Codes section in the Overview. The California Title 24 Energy Code (2005) limits the lighting power per classroom to 1.2 W/ft². Even with supplemental blackboard lighting, the recommended system results in a connected load is still under 1.0 W/ft^2. Title 24 also requires switching (see Guideline LG12: Lighting Controls for Classrooms).

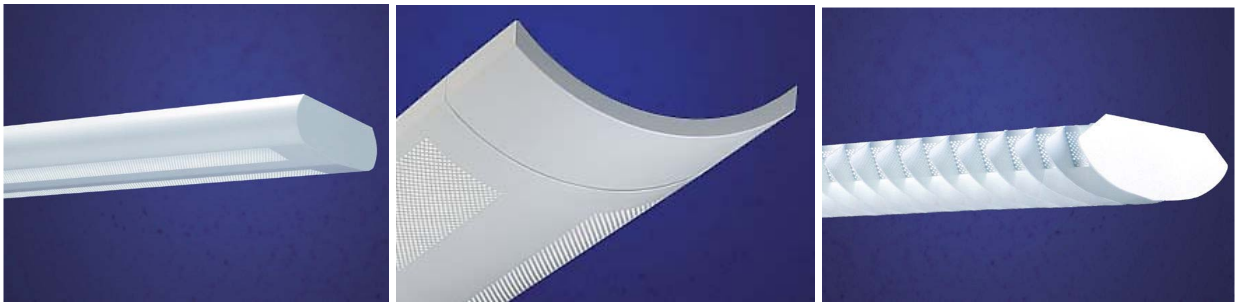


Figure 79—Three common generic luminaire styles typically used in classrooms

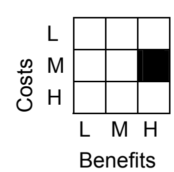
Photos courtesy of Finelite, Inc

Integrated Design Implications

Suspended lighting systems can work well with almost all ceiling systems that are at least 9 ft-6 in. high. However, ceilings with dark stained wood or dark colored paint must be avoided. For direct/indirect luminaires, ceilings should be light colored; for indirect fixtures, ceilings must be white or off-white, as should upper walls. A direct/indirect luminaire with a greater percentage of downlight (50% or more) should be used for rooms with extremely high ceilings, such as above 14 ft. Note that for maximum efficiency with indirect and semi-indirect lighting systems, it is best to employ ceiling systems with very high reflectivity. Modern white paints and certain ceiling tiles with reflectance of 90% or greater can dramatically increase system performance.

Pendant indirect or direct/indirect lighting systems are particularly well suited for integration with daylight systems, since both approaches require higher ceilings and the use of secondary reflective surfaces. In daylit rooms, pendant systems should be run parallel to the primary windows or daylight source, so that they can be switched or dimmed in response to daylight gradients. In a classroom, three rows of pendants will allow a more gradual response to daylight than just two rows. Daylight controls can then switch or dim each row separately.

Cost Effectiveness



Suspended lighting systems costs are shown in Table Table 18—Indirect/Direct Lighting Costs. Suspended lighting systems provide a high degree of cost effectiveness in most applications. Non-dimming, indirect steel luminaires are the lowest cost, but optimum solutions are generally steel luminaires with steel or plastic louvers providing 35%–50% downlight.

Table 18—Indirect/Direct Lighting Costs

Lighting System Type	Cost per Lineal Foot, Installed*
Competitive Steel Indirect Luminaires, T-8 Lamps, Non-dimming	$35
Competitive Steel Semi-indirect Luminaires with Louvers, T-8 Lamps, Non-dimming	$40
Steel Direct/Indirect Luminaires with Louvers, T-8 Lamps, Non-dimming	$45
Extruded Aluminum Luminaires with Louvers, T-5 or T-5HO Lamps, Non-dimming	$50
Add for Dimming Ballasts Using Standard 0–10 volt type	$12–$15

Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting, including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on January 2005 prices. Costs can vary depending on market conditions.

Benefits

Suspended lighting systems generally offer an optimum combination of efficiency and visual comfort, and make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 0.85 W/ft² to 0.9 W/ft² will generate between 30 and 50 footcandles throughout a typical classroom with excellent uniformity.

Design Tools

See the Overview section of this chapter.

Design Details

This type of lighting provides good, general lighting throughout the room and is suitable for most types of classroom work. It may be necessary to provide separate chalkboard illumination (see Guideline LG11: Teaching Board Lighting), especially if the suspended lighting system is dimmed. Be certain to employ the high performance T-5, T-5HO or T-8 lamp and ballast systems (see Electric Lighting Primer earlier in this chapter). Choice of color is important but not a major issue. Use 830 or 835 lamp colors to favor skin tones and to counteract cold gray environments, but also consider 841 and even 850 lamps in warmer climates. For non-dimming applications, luminaire light and power can be varied through choice of ballast factor.

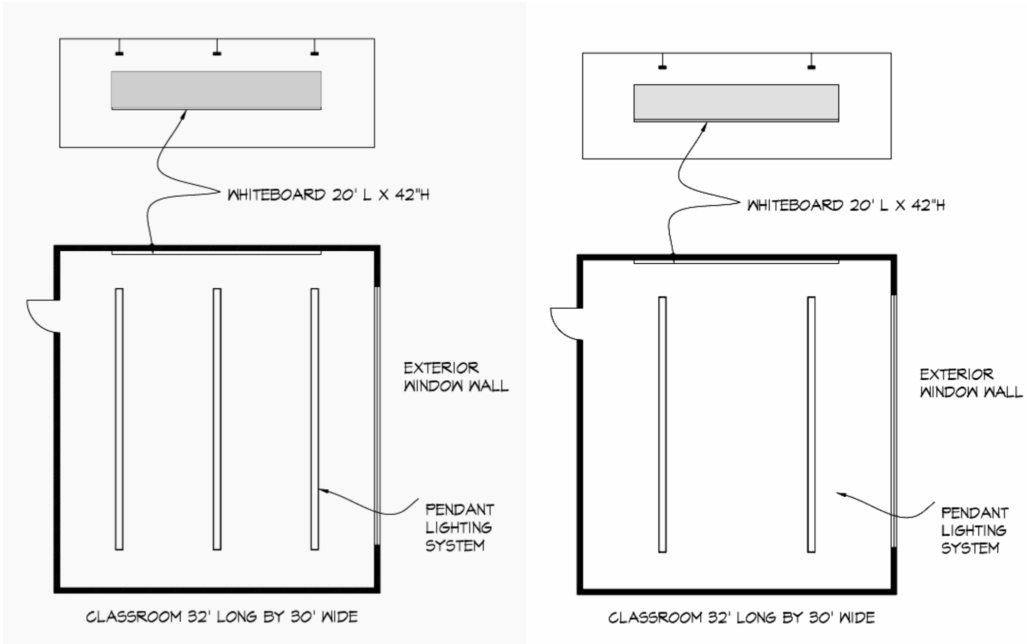


Figure 80—Classroom Pendant Mounted Options

This classroom design may use either two or three rows of suspended fluorescent luminaires. An optional blackboard light can be mounded at the teaching wall.

Either a two-row or three-row system can meet recommended lighting levels with properly chosen luminaires, lamps and ballasts (see **Table 41**). However, many other options exist and should be considered.

Table 19—Design Details for Indirect Lighting Systems

Two Rows of Suspended Lighting			**Three Rows of Suspended Lighting**		
Option A	Option B	Option C	Option D	Option E	Option F
Indirect	Direct/indirect	Semi-indirect	Indirect	Direct/indirect	Semi-indirect
2-F32T-8 per 4 ft section	1-F54T-5HO per 4 ft section	2-F32T-8 per 4 ft section	2-F32T-8 per 4 ft section	1-F54T-5HO per 4 ft section	2-F32T-8 per 4 ft section
High Ballast factor	High Ballast Factor	High Ballast Factor	Low Ballast Factor	Normal ballast factor	Low ballast factor
0.9 W/ft²	0.88 W/ft²	0.9 W/ft²	0.9 W/ft²	1.12 W/ft²	0.9 W/ft²

Operation and Maintenance Issues

Luminaires should be cleaned annually. Open louvered luminaires, especially using plastic louvers, require less cleaning and are the most tolerant of poor maintenance and abuse. Indirect fixtures require more regular cleaning and dusting.

As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation, which, with normal school use, could be as seldom as every six years. (Use of certain lamps and ballasts can extend this period to 20,000 to 22,000 hours).

Commissioning

No commissioning is needed, other than pre-seasoning of lamps in dimming applications.

References/Additional Information

See the Overview section of this chapter, and:

Windsor High School, Windsor CA. Windsor Unified School District. Quattrocchi / Kwok Architects.

GUIDELINE LG10: MULTI-SCENE CLASSROOM LIGHTING

Recommendation

For classrooms in which advanced teaching technology like video and computer projection are to be used, use indirect/direct lighting systems that provide two scenes: one for general lighting and one in which stray light is controlled to permit maximum screen contrast. This approach may also be used for all classroom types and is valid in primary classrooms where the ability to create a darkened room, such as for student calming and story time is desired. Employ pendant luminaires similar to Guideline LG9: Classroom Lighting—Conventional Teaching, but equipped with optical controls and/or dimming ballasts allowing relatively precise low light level settings. The general lighting system should not exceed 0.85–0.95 W/ft², and the highly controlled lighting system should use less, with switching to prevent simultaneous use.

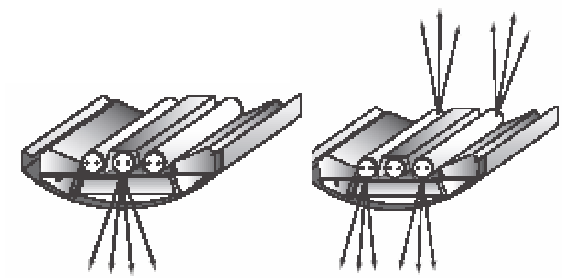
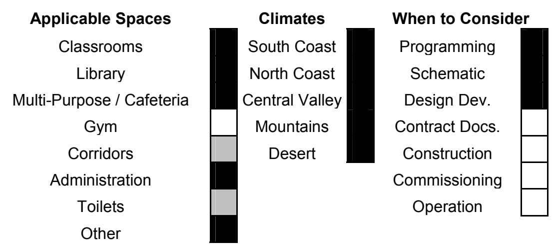


Figure 81—Multi-Scene Luminaire

Left, direct; Right, Semi-Indirect



Description

This recommended system incorporates a semi-indirect lighting system as described in Guideline LG9: Classroom Lighting—Conventional Teaching, plus a separate direct system by partitioning the luminaire and separately switching the two sections. The lighting system is controlled so it operates in indirect mode or direct mode, but not both at the same time. The necessary room darkening can be achieved without dimming.

The recommended luminaire has two compartments: a general lighting compartment, in which two lamps produce semi-indirect lighting, and a downlight compartment, in which one lamp produces highly controlled light suitable for AV and note-taking.

Figure 82—Dual Mode Classroom Lighting System

The PIER Classroom Lighting System's Two Scenes: (Left) the Low Light Level Scene, suitable for video screen and "quiet time"; (Right) the High Light Level Scene without daylight, suitable for general teaching. Source: Architectural Energy Corp./PIER 4.5 Project Report

The key to achieving a suitable design is, to reduce the ambient light level on the projection screen to 5 vertical footcandles or less. Almost any daylighting will create too much vertical illumination so the ability to darken the room using window shades is critical.

Applicability

This guideline is suitable for any classroom, lecture hall, commons area, multi-purpose room, seminar room, or other teaching space where two different lighting scenes are needed for Audio visual presentations, or for creating space with distinct moods needed for room uses.

Applicable Codes

The 2005 California Title 24 energy efficiency standards limit the amount of lighting power per classroom to 1.2 W/ft^2, so this recommendation complies as long as the general lighting system and downlighting system are never energized at the same time. Title 24 also requires switching (see Guideline LG12: Lighting Controls for Classrooms).

Integrated Design Implications

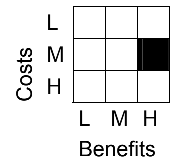
This type of lighting should only be used in flat light colored (white) ceilings at least 9'6" above finished floor.

This system lends itself to three principal control scenes as follows:

- Night, general lighting scene. All general lighting system lamps "on".

- Daytime, general lighting scene. General lighting system lamps affected by available daylight, either switching or dimming. It is possible to create switched daylighting scenes by switching luminaire rows and/or by switching rows of lamps.
- Any time, low level scene. General lighting system is off and the downlight lamps are on or on with possible dimming controls.

Cost Effectiveness



Overall the system is very cost effective compared to other options. Some products are available with integrated controls (built into the luminaires) so wiring is simplified.

Benefits

This lighting system provides all necessary flexibility in a unified solution that meets energy efficiency goals. It is possible to achieve these results with many lighting designs, but in most cases the result will be higher costs, less integration and the possibility of loss of functionality.

Design Tools

See the Overview section of this chapter.

Design Details

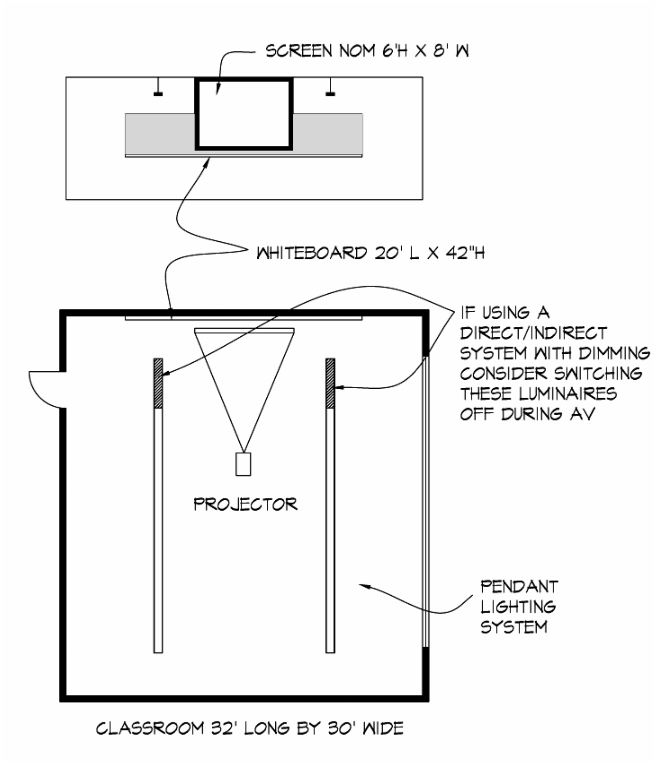


Figure 83—Dual Mode Lighting System

To coordinate with a ceiling mounted computer video projector, two rows of luminaires are recommended for classrooms up to about 30 ft wide. (For larger classrooms, consider these principles and make the necessary adjustments.)

Design Scheme "A"	Design Scheme "B"
Luminaires with separate general lighting and AV lighting compartments	Direct/indirect luminaire with parabolic louver downlight and high efficiency uplight
(2) F32T-8 lamps per 4 ft section for general lighting using a high ballast factor efficient electronic ballast	(1) F54T-5HO lamp per 4 ft section using an electronic dimming ballast
(1) F32T-8 lamp per 4 ft section for AV lighting using a normal ballast factor efficient electronic ballast or a dimming ballast	No other lamps. Consider separate switching for the luminaires at the end of the rows nearest the screen

This design assumes that the video projector is rated about 3000 ANSI lumens and it produces a full 8 ft x 6 ft screen video image of at least 10:1 contrast. Smaller projectors can be used but screen size or image size must be reduced proportionately.

Operation and Maintenance Issues

Luminaires should be cleaned annually. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation, which, with normal school use, could be as seldom as every six years (consider premium lamps and specific lamp/ballast systems for even longer life and less maintenance).

Commissioning

See Guideline LG12: Lighting Controls for Classrooms for more discussion about commissioning. With integrated control elements like motion sensors and daylighting sensors, luminaire pre-wiring and factory installed quick connectors can ensure error free field connections, virtually eliminating troubleshooting controls wiring issues.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG11: TEACHING BOARD LIGHTING

Recommendation

In schools where the teaching board (white board, gray board, greenboard or blackboard) is a principal teaching medium, consider adding lighting specifically for it. Encourage the use of dry erase boards (white boards or gray boards) in order to reduce lighting energy needs.

Figure 84—Various Linear Wall Wash Luminaires

Top row courtesy Elliptipar, lower row courtesy Lightolie

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	■
Library	□	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	□	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	□
Administration	□			Commissioning	□
Toilets	□			Operation	□
Other	□				

Description

The selection of a luminaire suited for the application requires careful consideration of location, aiming angle, and candlepower. The objective is to achieve at least 15–20 average vertical footcandles with uniformity across the board of 6:1 maximum to minimum or better. (For a chalkboard, the objective is to achieve 45–50 footcandles, average.)

It is not necessary to add a teaching surface light for dry erase boards when general illumination systems described inGuideline LG9: Classroom Lighting—Conventional Teaching are used. These general lighting systems will create 15–20 vertical footcandles on the teaching wall, which meets IESNA recommendations. Adding the teaching surface luminaire will add 20–30 vertical footcandles, giving the teaching surface a 2:1 to 3:1 contrast to the rest of the wall. It is this contrast that provides the "attractor" effect described by scientists.

Applicability

This guideline can be applied to chalkboards and dry erase boards in all applications. Note that a switch near the board is advisable so that the teacher can regulate use.

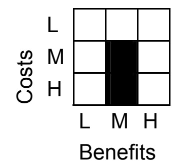
Applicable Codes

The 2005 Title 24 energy efficiency standards limit the amount of lighting power per classroom to 1.2 W/ft^2; because this load can be concurrent with general lighting, its power must be included in load calculations. In a typical classroom with teaching board, assuming a 16-ft wide teaching surface luminaire, the approximate added load of this light is about 0.12 W/ft^2. However, this load can be offset by reductions in overhead lighting.

Integrated Design Implications

The teaching surface luminaire needs to be coordinated with other elements occurring in the area of the teaching surface. For instance, it is desirable to coordinate the teaching surface luminaire with the video screen so that both might be used simultaneously.

Cost Effectiveness



It is a good idea to allow about $50 per linear foot, installed for a teaching surface light. The light does not have to run the full length of the teaching surface—for example, with a 20 ft long teaching surface, a 16 ft long continuous board light centered on the teaching surface will usually be acceptable.

Simply adding a board light to a general lighting system (Guideline LG9: Classroom Lighting—Conventional Teaching) or an AV-oriented classroom lighting system (Guideline LG10: Multi-Scene Classroom Lighting) is recommended. However, as described later under Design Details, it is possible to reduce the general lighting system and employ the teaching board light as part of overall illumination. This reduces the cost impact of a board light considerably. In the example, 16 ft of board lighting is added and 8 ft of suspended lighting is deleted. The cost per unit length is about the same for each system, so the net added cost of the board lighting is about $400 (8 ft x $50) per classroom. [31]

Benefits

Studies have shown a correlation between illumination of the teaching surface and retention of information. Researchers at the University of Illinois, Urbana, in studying the modern (2003) integrated classroom environment, determined that "attractors" aided in the learning process, and "detractors" had the opposite effect. If the teaching board is used, additional lighting—with either normal lighting or in a dimmed setting for the rest of the room—serves as a significant "attractor".

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[31] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

Design Tools

See the Overview section of this chapter.

Design Details

The specularity of dry erase boards is a major daylighting issue. Boards should never be on a wall opposite a daylighting source, especially windows, unless extraordinary measures are taken to prevent glare on the board. This is not nearly as true of chalkboards.

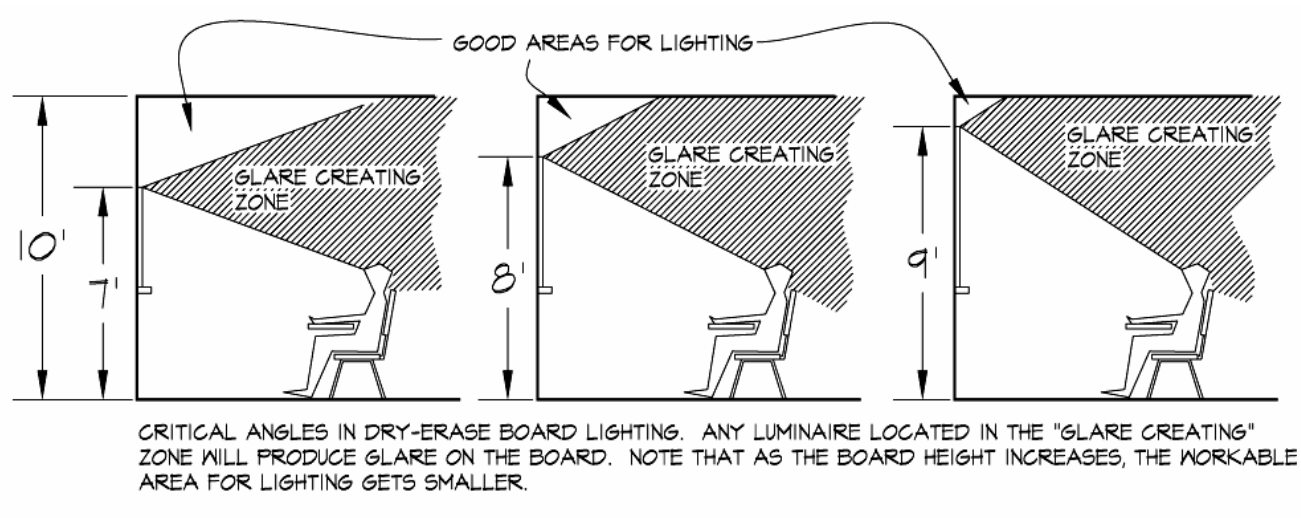


Figure 85—Guidelines for the Position of Teaching Surface Lighting

Modern dry erase boards (white and gray) and dry erase markers achieve significantly higher contrast and have the added benefit of positive contrast (dark letters, light background), all of which make the writing easier to see than chalkboards. Moreover, the dust and smudging of chalkboards reduces the contrast even further, and for these reasons, the IESNA recommends much higher light levels for chalkboards than for dry erase boards.

Boards that are too tall are almost impossible to light properly, forcing luminaires to be mounted too close to the board wall and therefore demanding extremely exacting candlepower. Conversely, short boards are very tolerant of almost any time of lighting system designed to accentuate them.

Evaluate the possible locations for luminaires by drawing a section similar to Figure 85. Note that it may be acceptable to make a small compromise and permit a stripe of glare at the top of the screen for front row students, in order to use a luminaire mounted directly above the board and mounted from the wall or suspended from the ceiling.

The best locations for luminaires 12 in., 18 in. and 24 in. out from the wall are shown for an 8 ft high teaching board and a 10 ft high ceiling. With a lower ceiling, the locations relative to the wall remain the same, although the luminaire 2 ft away from the wall may end up having to be surface mounted or even recessed.

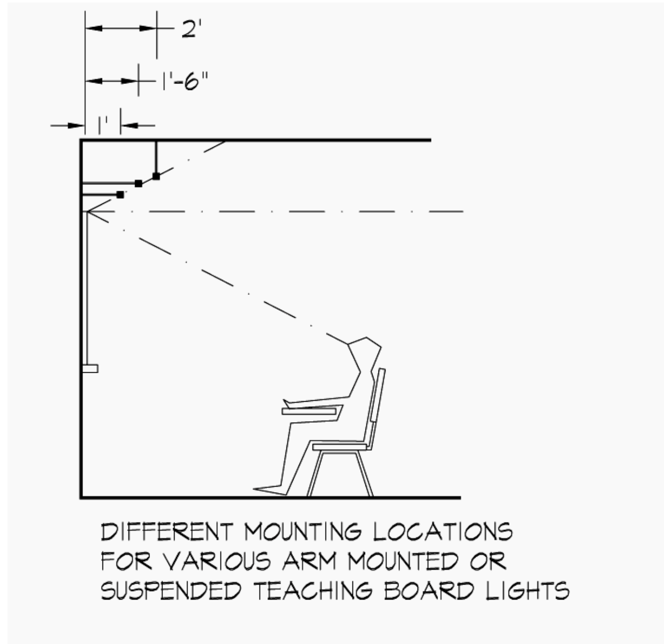


Figure 86—Recommended Teaching Surface Luminaire Locations

- A wall arm bracketed luminaire will probably look best and create the greatest drama by only lighting the board, and keeping the wall above the board dark. New T-5-based luminaires with extreme asymmetric optics make this approach feasible. Keep in mind that the lower a luminaire on a wall, the more likely it will be damaged at some point.
- A pendant mounted luminaire offers great mounting flexibility and, because it is suspended, some resilience in case it is struck. However, a hanging fixture can clash aesthetically with the general lighting system.
- A recessed luminaire is the safest approach, but its lighting effect will not be as dramatic as either of the other choices.

Coordination of the light with a screen is an interesting opportunity. Because of aspect ratios and computer data, most classroom screens will not be much larger than 8 ft, yet the board surface may be 12–20 ft wide. It is possible to have simultaneous use of both surfaces if the following considerations are addressed:

Darkened room. See Guideline LG10: Multi-Scene Classroom Lighting.

No teaching board light on screen surface. This can easily be accomplished by locating the lights behind the screen—this is where the new generation of board lights capable of being mounted 12 in. from the board is very handy. To a lesser extent, switching off the section of board light in front of the screen can also work.

It may be necessary to dim the board light in order to make the board illumination match the projection so that neither one dominates—although, in this condition, both will be very good in.attractors in..

In Figure 87, the layouts from Guideline LG9: Classroom Lighting—Conventional Teaching have been modified to include a board light, and each row of general lighting luminaires has been shortened by (1)

4 ft luminaire section. The overhead lighting systems have been shifted towards the back of the room. The combination of indirect light from the general lighting system and the bounced light from the teaching wall compensates for the loss of light for the teacher and front row of students. This design achieves approximately the same lighting power load and light levels as recommendations in either Guideline LG9: Classroom Lighting—Conventional Teaching or Guideline LG10: Multi-Scene Classroom Lighting, with slightly higher first cost.

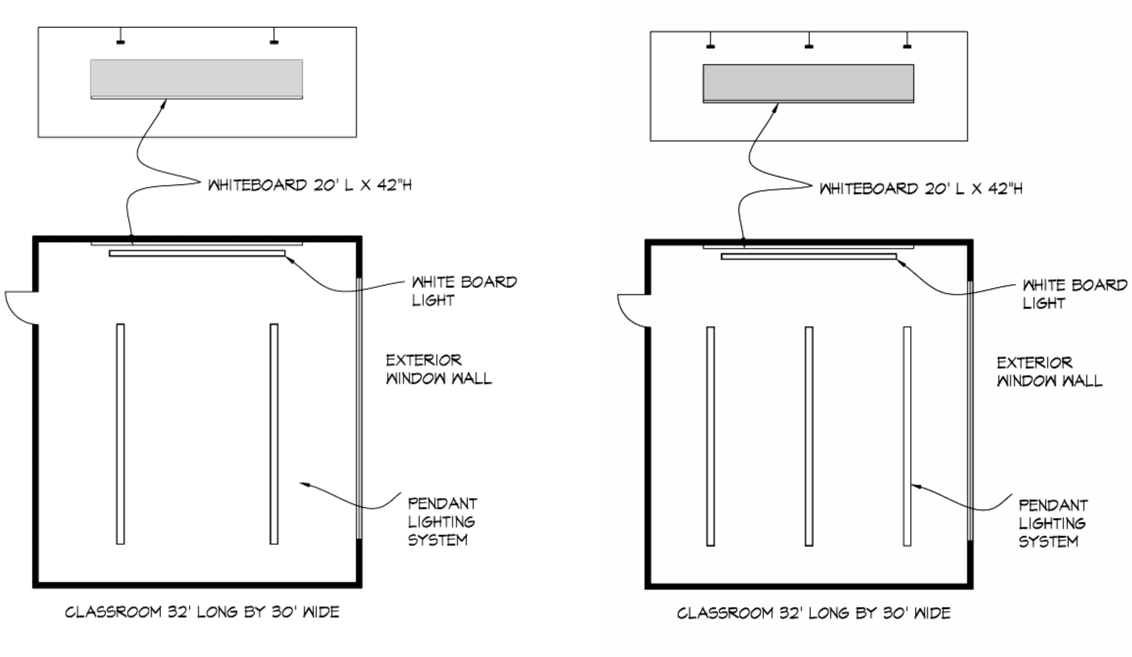


Figure 87—Integration of Teaching Surface Light with General Illumination

Anything that reduces the lighting in the room, such as dark finishes or a ceiling of lower reflectivity, can easily result in an unacceptable lighting situation, Even with an 80%+ white ceiling and light finishes, this design barely maintains 30 fc on all student desks. But the added benefit of board lighting at low added cost is often worth the extra effort.

Operations and Maintenance

As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation (longer with certain lamps and lamp ballast systems), which with normal school use could be as seldom as every six years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Open luminaires tend to require less maintenance.

Commissioning

No commissioning is generally needed.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG12: LIGHTING CONTROLS FOR CLASSROOMS

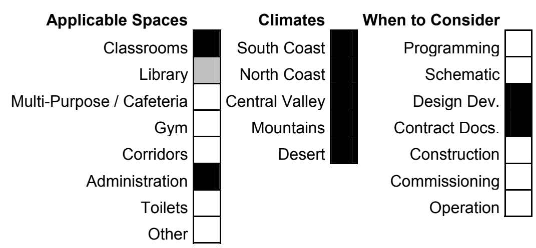
Recommendation

All lighting systems should be planned to allow teachers to choose multiple levels of illumination within the classroom. In addition to the multi-level illumination required by California's Title 24 energy efficiency standards, additional options of separately controlling illumination levels on the teaching wall, near windows, and other critical tasks should be provided. This can be provided with dimming or multi-level switching.

Figure 88—Ceiling Mounted Photosensor

Source: Evan Lesley

Automatic controls should be used to reduce energy use whenever cost-effective, such as with occupancy sensors and automatic daylight photocontrols. For the purpose of this guideline, we distinguish between two basic conditions: the average classroom and the daylit classroom.



All classrooms: Provide manual-on, automatic-off bi-level occupancy sensors for the main classroom lighting. Provide separately switched additional task lighting for the teaching wall, or other special task needs, and place the controls for these task lighting circuits near the task. Connect all classroom lighting to an upstream occupancy sensor.

Daylit classroom: In addition, the electric lights in the daylight zone (as defined by the code) should be separately circuited and provide multiple levels of electric illumination, with either dimming or multi-level switching. Provide the switch or dimmer controls for these lights near the window, rather than at the main classroom door. This way, a teacher first must walk over near the windows, and may choose not to turn on those lights if there is sufficient daylight. Connect to an automatic photocontrol when cost-effective energy savings can be achieved.

Description

Classrooms are used for many varied purposes, and one size does not fit all for illumination levels. With thoughtful planning, the provision of three or more illumination levels can dramatically increase the range and flexibility of the use of classroom, allowing the teacher to use the lighting to both “set the stage” for various types or modes of learning and avoid unnecessary energy use.

With the rapid evolution of audio-visual and computer-based teaching methods, it is difficult to predict what the lighting needs of classrooms may be 10 or 15 years from now. By providing a range of illumination options, the designer provides current teachers with more flexibility in their teaching options and allows for adaptation to evolving visual needs.

As a minimum, all classrooms should employ motion sensors, preferably in conjunction with a switch that can turn lights off regardless of sensor “state”. For maximum flexibility, manual switches should be wired in series with the motion sensor relay so that lights can be turned off manually, regardless of whether there is motion in the room.

The falling cost of dimming ballasts for T-8 lamps makes dimming possible for many projects. Dimming ballasts permit both manual dimming, allowing the teacher to adjust lighting levels, and automatic dimming, especially to respond to daylight. Ballasts should be specified in conjunction with an overall dimming system to ensure compatibility.

Spaces with audio/visual needs that require manual dimming should use a wall-mounted dimmer controller.

Applicability

These lighting control strategies are appropriate for classrooms and some areas in administration spaces and libraries.

Applicable Energy Codes

The California Title 24 energy efficiency standards require that all spaces have an occupant accessible switch with a time sweep or an occupancy sensor. The general lighting systems in any enclosed space must have at least two levels of operation, while maintaining uniform illumination levels. This is most easily achieved with two switches per space, but can also be achieved with a dimming control.

Title 24 also requires that at least 50% of the electric lighting power in a Daylit zone (area near window or under a skylight) have a separate control. This control can be switching or dimming, and automatic or manual.

Title 24 provides a controls credit for automatic daylight sensors. Control credits for side lighting are a function of the window to wall ratio, glazing visible light transmittance, and the control type (switching versus dimming).

Integrated Design Implications

Space Planning

Location of switches and sensors should be carefully considered relative to the use of the room, all potential furniture configurations, and location of other controls. Sensors need to "see" around any possible obstructions, such as high shelves, that teachers may choose to place in the room. Controls for the teaching wall lights should be grouped with any permanent audio visual controls. Controls for luminaires near windows should ideally be placed near the windows, but also convenient to the main teaching station.

HVAC

Controls are essential in achieving the overall goal of reduced energy consumption. The mechanical engineer should be informed of expected changes in the lighting system's pattern of operation due to automatic controls. Reduction in the hours of operation or the power of the lighting system will lower the internal heat gain in the space, changing the needs for heating or cooling.

Daylight Design

For spaces with daylight, automatic daylight sensors are recommended for lights near the window wall or underneath skylights. Lighting control circuits should be designed parallel to daylight contours.

EMS

If a school district is using an energy management system (EMS) the lighting controls should be considered in relationship to other automatic controls. School-wide time sweeps controlled by the EMS may be preferable to occupancy sensors. An EMS system may be able to provide a single photosensor input for daylight controls, reducing costs. However, with a centralized sensor, individual calibration of the response of the lighting system in each room becomes even more important.

Figure 89 shows a simple and cost effective classroom lighting control system. The switch near the door turns on the lights away from the window. The switch that controls the luminaires near the window should be located near the window. The lighting circuit next to the window should also be controlled by an "open loop" photosensor. "Open loop" sensors that are not affected by room light are strongly recommended since they are more reliable and easier to calibrate. A third "energy management" switch is recommended to toggle the central row of fixtures so that they can be grouped either on the photosensor circuit or the non-daylit circuit, depending on the season of the year and other factors that affect daylight availability..

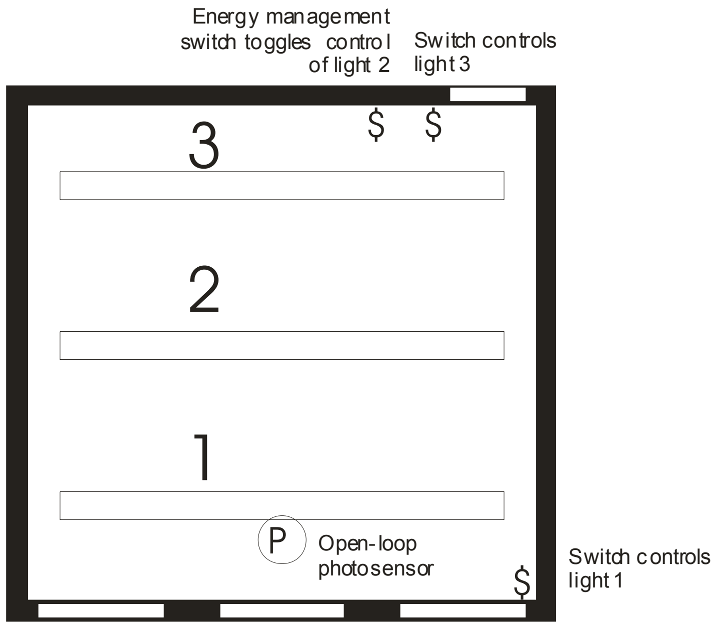
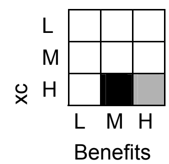


Figure 89—Simple Windowed Classroom Control



Cost Effectiveness

For motion sensing, cost effectiveness varies depending on the overall energy management skills of teachers and staff. People who are personally careful with energy outperform motion sensors, but for less well managed spaces, motion sensors are worthwhile.

Daylight sensors are generally worthwhile if there is sufficient daylight to turn off a given electric lighting circuit for more than 50% of school hours. The larger the daylight zone, the more cost effective the daylight controls will be. Systems employing manual dimming, daylighting, and motion sensing are presently only cost effective if audio/visual or computer requirements of the building use need to be met.

Controls are an evolving area of lighting technology for buildings. While cost effectiveness is good at present, costs remain relatively high.

Costs for lighting control systems potentially include some combination of the following: additional circuiting, additional switches, motion sensors, light level sensors, controllers, dimming ballasts, additional 10v wiring, connection to master control system, commissioning. A pair of motion sensors and one power pack adds about $200 per classroom. Dimming ballasts add approximately $40 to $50 per ballast, or up to $1,200 per classroom. Automatic daylighting control without manual dimming adds about $200 per classroom, in addition to the costs of ballasts. A control system that permits manual dimming in conjunction with motion sensing and daylighting will cost about $1,000 per classroom, in addition to the costs of the dimming ballasts. Control costs are highly variable but the following very general guidelines are provided. Use these data for rough estimates only and confirm costs with lighting control or electrical contractors in your area. [32]

Benefits

Each added control element saves energy. Depending on the school's operating months, the quality of daylight, the climatic zone, and other factors, energy cost savings can vary from good to dramatic.

Design Tools

Very few useful design tools exist for this evolving field. The best information is usually obtained from controls manufacturers and their representatives.

Design Details

Motion Sensor Location. Sensors located in the center of the ceiling are generally the best choice, as they can "see" the corners of the room and over high shelves. If locating sensors in an upper corner, often two sensors are needed for full coverage of the room. Wallbox sensors that replace wall switches are not a good choice for classrooms

Motion Sensor Type: Most sensors are passive infrared and respond to the movement of warm bodies. These need a full "view" of the entire classroom to function effectively. Dual mode sensors employing ultrasonic, microphonic, or another form of backup sensing cost more, but provide fewer false readings, thus are strongly recommended. These types of sensors generally require a power pack (transformer-relay) that actually switches the circuit. There is some concern that some types of ultrasonic sensors may affect very young children, or susceptible adults with hearing aides or other electronic health aides. Check the manufacturers' recommendations for use, and avoid use of any product not recommended for sensitive health care environments.

Time Delays; All motion sensors should have an adjustable time delay. Moving the setting to a shorter period will save more energy, while moving the setting to a longer period may avoid unnecessary frequent switching. Generally, 10 minutes is found to be a good compromise. Some manufacturers provide an option for an occupant override that will allow for an extra long delay, such as for up to an hour, that will keep the lights on even when there is little motion in the classroom, such as during parent teacher conferences, or while the teacher is alone in the room grading papers.

Dimming Ballast Controls. Use 0-10 volt dimming ballasts unless employing a complete manufacturer-integrated system of control. 0-10 volt controls are the most universal at present and there is more competition in the market.

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[32] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

Daylight Sensor Type. Open loop daylight sensors are preferred as they are easier to calibrate and commission. All daylight sensors should have an adjustable time delay. Daylight sensor types vary according to the type of lighting control provided—dimming or switching. For dimming, use a proportional controller that allows the set point for both the upper and lower response. For switching, the controller needs to have an adjustable "dead band."

Daylight Sensor Location. For skylights, the daylight sensor should be located inside the skylight well, looking up. For windows, the sensor should look at the most stable and representative source of daylight. If looking out the window, the sensor should not see occasional bright reflections off of cars or other buildings. If looking at a wall or other surface inside the classroom, the sensor should see the most uniformly Daylit surface. Check the manufacturer's literature to see what the "acceptance angle" is for the sensor's view of the room, and make sure that the sensor will not be influenced by extraneous light from luminaires.

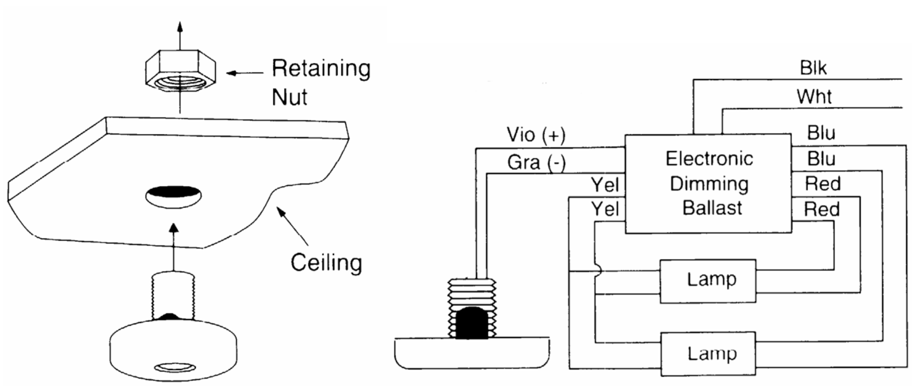


Figure 90—Wiring for a Ceiling Mounted Light Sensor

Sensor connects directly to the violet and gray terminals of industry standard 0-10 volt ballasts. Source: Wattstopper

Operation and Maintenance Issues

In operation, a properly commissioned system needs only periodic maintenance to ensure optimum performance. Refer to the manufacturer's recommended recalibration and cleaning cycle for sensors.

Commissioning

Commissioning of motion sensor systems and daylighting controls is critical to their success. Systems that work properly will be left alone; systems that have false tripping and other unwanted behavior will be disconnected or bypassed by occupants.

The sensitivity of motion sensors should be set according to the manufacturer's instructions. A proper setting will minimize false tripping and unwanted cycling. Because sensors are both physically and electronically adjustable, care should be taken to ensure the sensors are working as intended.

The time-out setting of motion sensors is also critical. A setting too short may cause false tripping; a setting too long may fail to save energy. A preliminary time-out setting of 10 minutes is a good place to start.

Daylight sensor settings should be made and checked several times. Use a good light meter (Minolta TL-1 or better).

References/Additional Information

See the Overview section of this chapter, and:

Controls: Patterns for Design. Electric Power Research Institute. www.epri.com/.

GUIDELINE LG13: GYM LIGHTING

Recommendation

Over basketball courts, volleyball areas, gymnastics areas, and other portions of the gymnasium with a high ceiling and structure, three choices for lighting exist:

T-5HO High-Bay Fluorescent. Use industrial high bay luminaires with T-5HO or T-8 lamps. Each luminaire should have symmetric reflectors for downlight distribution and a wire cage or lens should be used to protect the lamps from flying balls. Four-ft luminaires with four or six lamps and two-lamp ballasts produce similar results as a like number of metal halide luminaires, but with fewer watts and greater versatility.

Compact Fluorescents. Employ industrial-style luminaires having multiple compact fluorescent lamps in a single housing. Each luminaire should use eight 32-W or 42-W compact fluorescent triple-tube lamps, with electronic ballasts. The fixture should not have a lens, but consider adding a wire cage to open luminaires that may be exposed to flying balls or other damage.

Metal Halide. Use metal halide industrial-style "high bay" luminaires. The metal halide luminaires should employ 320-W to 450-W "pulse-start" lamps and 277-volt reactor ballasts, if possible. They will provide at least 50 footcandles of general lighting. Use a protected lamp suitable for open luminaries, not a lensed or enclosed lamp. Slightly higher light levels may be provided for the main basketball court in middle schools and high schools. Consider adding a wire cage to open luminaires that may be exposed to flying balls or other damage.

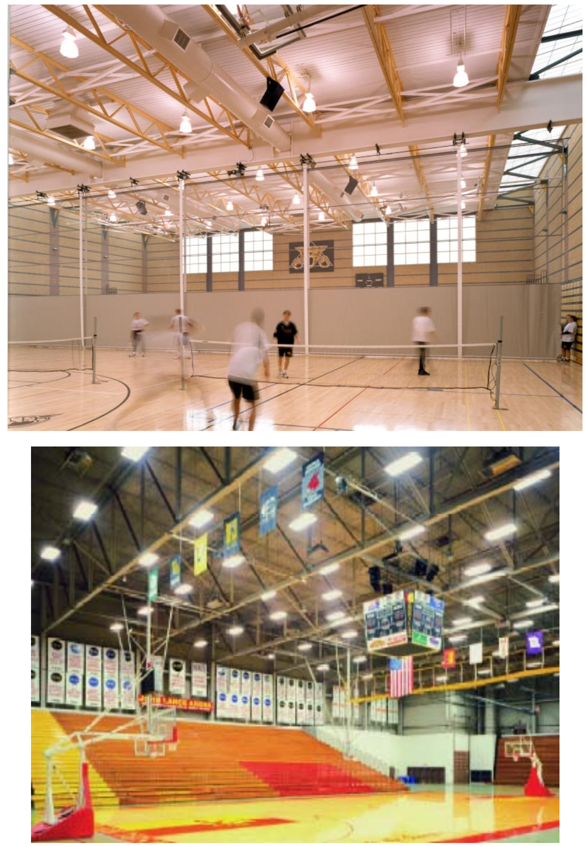


Figure 91—Metal Halide Gym Lighting

Windsor High School Gym, Source: Quattrocchi / Kwok Architects

Applicable Spaces		Climates		When to Consider	
Classrooms	☐	South Coast	■	Programming	■
Library	☐	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	☐	Central Valley	■	Design Dev.	■
Gym	■	Mountains	■	Contract Docs.	■
Corridors	☐	Desert	■	Construction	■
Administration	☐			Commissioning	☐
Toilets	☐			Operation	☐
Other	☐				

Whichever system is used, it will probably be necessary to design at about the Title 24 limit of 1 W/ft^2 to meet modern expectations for gym lighting. Gyms where significant television broadcasts occur may also employ a separate television lighting system that is exempt from Title 24 limits.

It will also be necessary to provide an *emergency lighting system*. In addition to self-illuminated exit signs, provide either:

Some luminaires powered by batteries or a generator, in a high bay fluorescent system or compact fluorescent system.

Use quartz auxiliary lamps powered from batteries or an emergency generator, in a metal halide system.

Also consider providing a separate halogen downlight system for "house" lighting during dramatic and social uses of the gym. This system may also be powered in-full or in-part from an emergency generator or battery backup power source. As a basic design, use suspended cylinder downlights with halogen IR PAR-38 flood lamps. Design the system to provide at least two footcandles of illumination with normal power and one footcandle from an emergency source. This system provides both egress lighting and serves other uses (see below). It must be controlled to prevent concurrent operation with the general lighting system.

Description

The height of the gym space's ceiling plays a major role in choosing gym lighting systems. This can be partly assessed by examining the coefficient of utilization (CU) at Room Cavity Ratio (RCR) =2.5 of candidate systems. It is also useful to examine their spacing to mounting height (S/MH) as well.

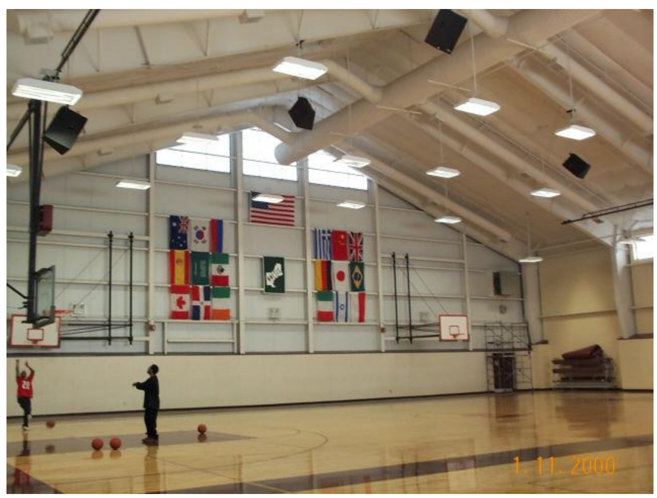


Figure 92—T-5HO Systems

Source: James K. Rogers

Fluorescent systems using multiple T-5HO or T-8 lamps are preferred for ordinary gyms and other high ceiling spaces. Superior color, elimination of flicker, and the ability to turn lights on and off as needed are major advantages over HID systems. The added cost of the fluorescent system is offset by much lower energy use, estimated to be as much as 50% less if the multiple light level capability of a fluorescent system is utilized. Systems using multiple compact fluorescent lamps also provide these benefits, although without the high efficacy of the linear fluorescent lamps.

In general, metal halide high bay lighting systems tend to be more appropriate when ceilings are especially tall, such as in a field house. Long lamp life and a minimum number of luminaires keep costs down. The color of metal halide is suitable for television as well as everyday use. The long warm-up and restrike periods of metal halide lighting are a drawback since switching lights off regularly is not recommended for these systems. Be certain to use pulse-start lamps. These systems are, however, compatible with daylit gyms if they have switched lighting levels.

Multiple compact fluorescent “high bay” lights are a distant third choice. These systems are less energy efficient and require more costly and frequent maintenance than the other choices.

A separate downlight system using halogen lamps is highly recommended for two reasons:

It is an instant-on, instant-off system that can be dimmed inexpensively. This feature is especially important if metal halide lights are accidentally extinguished, as they will require a five to 10 minute cool-off and restrike delay.

A dimmable tungsten downlighting system can make the gym more appealing for social events, and can also serve as a “house” lighting system for many of the gym’s performance and entertainment uses.

Lighting quality is a crucial issue in gym spaces. Avoiding direct view of an extra bright light source, such as a metal halide lamp, high output lamp, or skylight, can be especially critical in a gymnasium where athletes must scan for the ball and react quickly. Even though a luminaire may normally be out of the line of sight, it can still create a devastating glare source to a volleyball or basketball player.

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private, and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Applicable Codes

Electrical

The electrical portion of lighting installations is usually governed by the National Electric Code (NEC). Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24. Title 24 limits the amount of lighting power in a gym to 1 W/ft^2 (2001), so this recommendation meets the code. Title 24 also requires switching (see Design Details below).

Life Safety

As a place of assembly, the gym needs to be equipped with an emergency lighting system capable of producing at least 1 footcandle, average, along the path of egress. The emergency lighting system must be powered from an emergency generator or from a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

Seismic

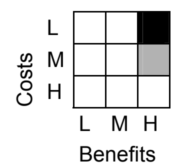
Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional safety cable independent of the fixture's ordinary support system.

Integrated Design Implications

High bay luminaires are easily attached to most structures. It is recommended that the luminaires be suspended within the "truss space" or in other words, with the bottom of the luminaire not lower than the lowest beam or truss member. In the rare instance where the gym has a finished ceiling, recessed lighting should be considered.

Daylighting design is especially well suited to the high ceilings and large open space of gymnasiums. Gentle diffuse systems, which avoid creating excessive bright spots within the athletes' critical viewing directions, are especially appropriate. For example, side lighting should be placed perpendicular to the primary basketball walls. Wall wash top lighting or high sidelighting with light shelves or louvers can be effective techniques for gyms, since both involve secondary reflections on room surfaces that prevent direct view of the window or skylight. Direct sun penetration into gyms should be prevented at all times.

Cost Effectiveness[33]



Each metal halide luminaire costs about $325, or about 79 mean lumens/dollar. A multiple compact fluorescent luminaire costs about $425, or about 52 mean lumens/dollar. A T-5HO 6-lamp luminaire costs about $375, or about 76 mean lumens/dollar. Each PAR38 downlight costs about $150. Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

The best solution for a particular gym depends on hours of use and other variables.

A metal halide lighting system has the lowest first cost. There is no less expensive way to provide the necessary quantity of light from this mounting height. The use of high Watt metal halide lamps minimizes the number of luminaires (first costs) and the number of lamps (maintenance costs).

A system employing multiple T-5HO or T-8 lamps offers the least energy use and longest life lamps (lowest maintenance costs). Multiple light level capabilities save additional energy and extend maintenance periods.

[33] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

A system using multiple compact fluorescent lamps combines the flexibility of fluorescent systems with the appearance of HID. While most costly to build and to operate, this approach results in a flexible design that can be energy effective if multiple light levels are used, and the system looks like a metal halide system.

Design Tools

See the Overview section of this chapter.

Design Details

Fluorescent high bay lighting is a relatively new solution. Consider both T-8 and T-5HO systems. This choice requires specific considerations for reflector shape, photometry, and lamp protection. Products are available from some major fluorescent manufacturers and several specialty fluorescent makers. Careful study to ensure proper lighting levels is recommended.

Any fluorescent choice permits the use of multiple level switching, including automatic daylight control. Take advantage of this feature in gyms with skylights and clerestories.

Metal halide “high bay” luminaires are commonly available in a number of reflector types including aluminum, ribbed acrylic, and ribbed glass. Among these, ribbed acrylic offers the best combination of efficiency and uplight, and is sufficiently durable for the application.

It is critical to specify the 320-W to 450-W, pulse-start, 277-volt reactor ballast system. If 277-volt (three-phase) power is not available, then use a 120-volt CWA ballast, although it is less energy efficient. Do not use the standard (probe-start) 400-W metal halide system, as it produces less maintained light than the 320 pulse-start system.

In gyms with skylights (highly recommended), the use of a two-level controller for the metal halide lamps should be considered. A photoelectric switch, sensing when adequate daylight is present to turn lights down to the low setting, should control the action.

Switches for metal halide lamps should NOT be readily accessible. They should be in a controlled location such as an electric room, press box, teacher/coach’s office, or other location where inadvertent operation of the lights will not occur. This adds support to the concept of a separate halogen system in which the switch is quite accessible. It would be a good idea to interlock the two systems so that the halogen system can not operate once the metal halides are at, or near, full light.

Operations and Maintenance

This design should be easy to operate and manage. Dimming on the halogen system (if used) will extend lamp life, and a metal halide system will require relamping every 12,000 to 14,000 hours (depending on hours of operation, this could be three to five years). System cleaning should be simple. Linear fluorescent systems require relamping every 15,000 to 20,000 hours, but compact fluorescent systems require relamping every 8,000 to 10,000 hours. However, if both fluorescent lamp systems rotate lamp operation at reduced light levels, relamping cycles can be very long.

The control system should be designed for easy use. Automatic time of day control with manual override is an acceptable means to control the metal halide lamps, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up.

References/Additional Information

See the Overview section of this chapter, and:

Windsor High School (Model), Windsor CA, Windsor Unified School District. Quattrocchi / Kwok Architects.

GUIDELINE LG14: CORRIDOR LIGHTING

Recommendation

There are two principal choices for illuminating corridors in schools:

Employ recessed fluorescent luminaires that have a means to both protect the lamp and create relatively high angle light perpendicular to the corridor axis.

Employ surface mounted corridor "wrap-around" fluorescent luminaires designed for rough service applications.

In either case, luminaires should use T-5 or T-8 lamps and electronic ballasts. Caution should be employed to ensure that the luminaires are not overly "institutional" in appearance. Align luminaires parallel to corridor walls to provide good quality of light and to make light useful for lockers.

Outdoor corridors and corridors with plentiful daylight should employ automatic daylight switching or dimming to reduce electric lighting by day.

It will be necessary to provide emergency lighting with this lighting system. Some of these luminaires must be powered from an emergency generator or battery backup power source.

Figure 93—Anzar High School

Source: Attrocchi / Kwok Architects

Applicable Spaces		Climates		When to Consider	
Classrooms	☐	South Coast	■	Programming	■
Library	☐	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	☐	Central Valley	■	Design Dev.	■
Gym	☐	Mountains	■	Contract Docs.	■
Corridors	■	Desert	■	Construction	■
Administration	☐			Commissioning	☐
Toilets	☐			Operation	☐
Other	☐				

Description

It is important to minimize downlighting so that the walls of the corridor will be better illuminated.
Lights that emit very well to the sides should be chosen. Choose from among the following types of products:

Interior corridors may employ "recessed indirect" luminaires. Luminaires should be oriented with the lamp long axis along the corridor long axis. This design is suited for all ceiling types.

As an alternative, especially for schools where vandalism is a concern, use surface ceiling wrap-around luminaires, preferably vandal-resistant or high abuse types.

Exterior corridors should employ surface-mounted wrap-arounds or ceiling-mounted, high abuse luminaires. In some cases, wall-mounted, high abuse luminaires may be acceptable.

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private, and parochial schools, and similar facilities such as churches, sports clubs and private institutions.

Applicable Codes

Electrical

The National Electric Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24. Title 24 limits the amount of lighting power in a corridor to 0.6 W/ft^2 (1999), so this recommendation exceeds the code limits. Title 24 also requires switching (see Design Details below).

Life Safety

As a path of egress, the corridor needs to be equipped with an emergency lighting system capable of producing at least 1 footcandle, average, along the path of egress. In general, the best way to do this is to power every third or fourth luminaire from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

Seismic

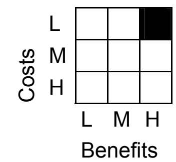
Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional hanger wire or support independent of the ceiling's support system.

Integrated Design Implications

Given the choices of luminaires that are available, it should be possible to find an attractive solution that is suitable for any type of corridor ceiling construction, including indoor and outdoor corridors, acoustical tile or wallboard ceilings, etc.

Corridors are generally excellent spaces for daylighting. Furthermore, daylight in corridors provides an important safety feature of guaranteed lighting during any daytime emergencies. For single story or top floor corridors, linear toplighting is especially appropriate. For corridors not directly under a roof or adjacent to an exterior wall, pools of light from intermittent sidelighting or toplighting borrowed from the floor above can create important social spaces, with higher levels of illumination than that provided by the electric lighting system. Daylight introduced at the end of a long corridor can have a glaring effect, making the corridor feel more like a tunnel. Daylight introduced from the side or above is generally more effective with less glaring. As with electric lighting, illuminating the corridor walls should be the primary objective.

Cost Effectiveness



The corridor lighting systems recommended here are very cost effective. Each corridor luminaire costs about $200[34]. Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

Fluorescent corridor lighting systems provide solid results for a modest investment. Long product life will result from carefully choosing a rough service grade luminaire.

Design Tools

See the Overview section of this chapter.

Design Details

The following are typical lighting layouts for corridors:

[34] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

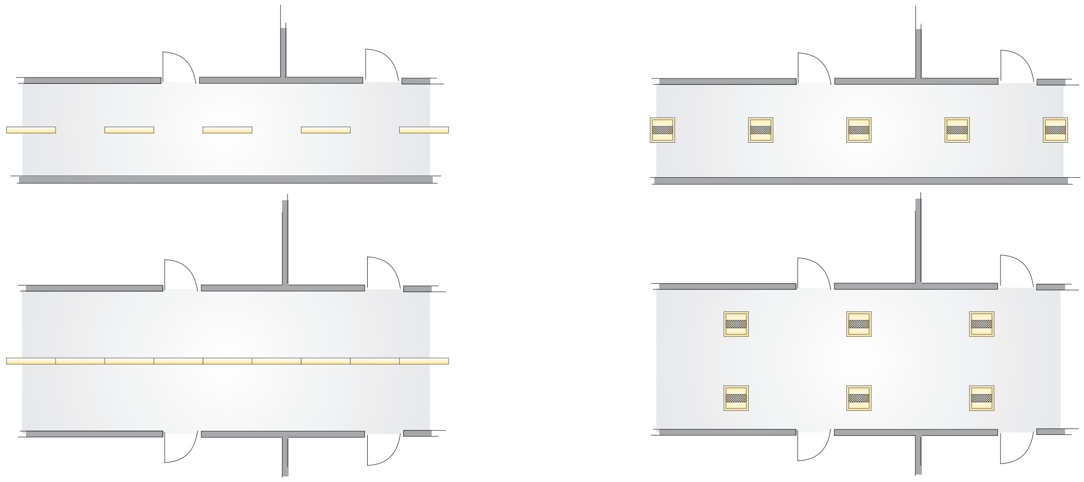


Figure 94—Corridor Lighting Designs

If required by the application, choose one of many modern “rough-service” luminaires that are attractive as well as durable.

In general, recessed downlights generally have insufficient vertical illumination to provide good service in corridors. However, recessed downlights using compact fluorescent lamps may be preferred for lobbies and similar applications where a dressier appearance is desired.

Switching of the lighting system should NOT be readily accessible. In general, switching should utilize an automatic time of day control system with motion sensor override during normally “off” hours.

In addition, provide automatic daylighting controls, including dimming or switching off lights in corridors having windows, skylights, or other forms of natural lighting.

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most fluorescent lighting systems, relamping every 12,000 to 14,000 hours is recommended. Ballast life extends 10 years or more. System cleaning should be simple.

The control system should be designed for easy management. Automatic time of day control with override is an acceptable means to control corridor lights, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG15: LIGHTING FOR A MULTI-PURPOSE ROOM

Recommendation

As a minimum, a multi-purpose room should have at least two independent lighting systems:

A general lighting system providing 20 to 30 footcandles of uniform illumination using standard T-8 lamps; and

A dimmable “house lighting” system supporting audio visual and social uses of the room, producing no more than 5 footcandles.

In addition, theatrical lighting may be added to illuminate specific stage or performance locations.

Figure 95—Gym Lighting

Source: SunOptics Prismatic Skylights

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	■
Library	□	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	■
Corridors	□	Desert	■	Construction	■
Administration	□			Commissioning	□
Toilets	□			Operation	□
Other	□				

Description

The general lighting system should probably be one of the types previously suggested for classroom lighting in Guideline LG9: Classroom Lighting—Conventional Teaching through Guideline LG11: Teaching Board Lighting. If suspended luminaires are chosen, be careful to locate luminaries so as not to interfere with audio-visual and other uses of the room. If the room’s uses include any sports or games, all lighting systems should be recessed or otherwise protected from damage.

The house lighting system should probably employ recessed or surface downlights. Narrow beam downlights should be chosen, and halogen lighting is recommended due to the superior color, inexpensive dimming, and good light control. Luminaires should use standard IR halogen PAR lamps. Black baffles or black alzak cone trims are recommended for audio/visual applications. The house lighting system should be laid-out to prevent light from striking walls or screens. Note that some general lighting systems might also serve as the house lighting system if properly laid out and equipped with electronic dimming ballasts, but most general lighting systems generate too much diffuse light, even when dimmed, for audio/visual use.

As with corridors and other common spaces, a control system that activates the general lighting system according to a calendar program and employs motion sensing for “off” hours should be used. Rooms with plentiful daylight should employ automatic daylight switching or dimming to reduce electric lighting by day. A manual override switch should be provided. Manual dimming of the house lighting system should be provided along with an interlock switch preventing simultaneous operation of both general and house lighting.

It will be necessary to provide emergency lighting with this lighting system. Some of these luminaires must be powered from an emergency generator or battery backup power source.

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Applicable Codes

Electrical

The National Electrical Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24. Title 24 limits the amount of lighting power in a cafeteria or multi-purpose room to 1.6 W/ft^2 (1999), so this recommendation is within the code limits. Title 24 also requires switching. Keep in mind that if the two lighting systems are interlocked as described above, only the higher wattage system is counted in energy code calculations.

Life Safety

As a place of assembly, the room needs to be equipped with an emergency lighting system capable of producing at least 1 footcandle, on average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires use of automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.

Seismic

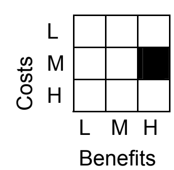
Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional hanger wire or support independent of the ceiling's support system.

Integrated Design Implications

Because multi-purpose rooms often serve as a cafeteria, study hall, social gathering spot, special event space, community meeting hall, and audio-visual facility, it is extremely important to ensure that the lighting and controls provide proper operation for every intended use of the room. Moreover, this room may benefit from greater architectural design than other spaces, and lighting designers should be prepared to creatively provide the functions of the lighting described here, but use other types of equipment better suited to the specific architecture.

Multipurpose rooms can be successfully daylit, either from high clerestories or toplighting approaches. However, near-blackout capability for the daylight system is probably most important in this type of space, so operable louvers or blinds are highly recommended. If the daylight system can be reduced to a minimum of one to three footcandles, most reduced light functions, including stage performances, can operate effectively. A small amount of sunlight can be a cheerful presence in multipurpose rooms used as a cafeteria, as long as it can be blocked when needed.

Cost Effectiveness[35]



In general, two separate lighting systems, with one being a dimmed halogen system, is the most cost effective. A single fluorescent lighting system with dimming system is usually more costly and less flexible.

Each downlight costs about $175 (see the other guidelines in this chapter for general lighting costs). Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

This "two component" lighting design approach, when combined with effective controls, permits a wide range of uses of the multipurpose room, exactly what these rooms are designed for.

Design Tools

See the Overview section of this chapter.

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[35] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

Design Details

The figure below shows a typical multipurpose room with two lighting schemes. The left side uses pendant-mounted luminaries, and the right side shows recessed troffers.

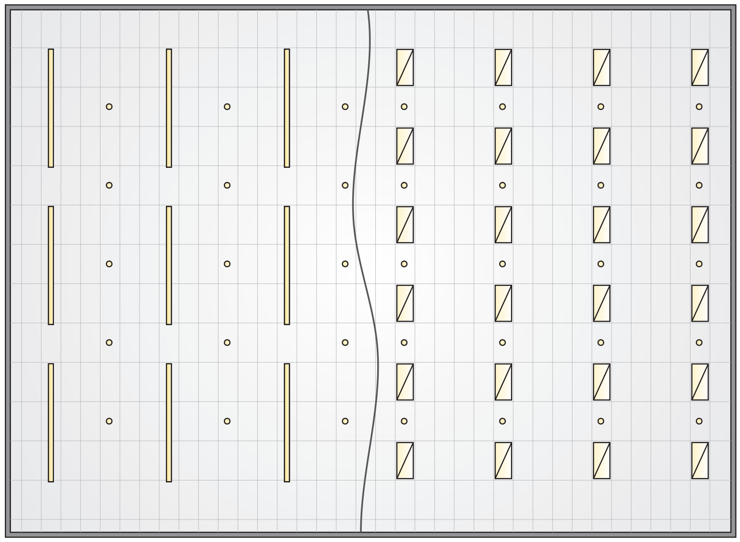


Figure 96—Multipurpose Lighting Designs

This figure shows two approaches to lighting multipurpose rooms. Both schemes have a separate system of downlights to serve as "house" lights for social and A/V use.

In this room, self-contained emergency ballast/battery units should be avoided unless specially designed to employ an external voltage sense connection. Leaving any general lighting luminaire operating in the dimmed mode is usually not acceptable.

Consider placing the lighting in zones that have individual manual override switches to permit de-activating a zone when not occupied.

Switching and dimming of the lighting system should NOT be readily accessible. Locate controls in a supervised location.

Consider a modern preset dimming or control system, especially if touch-screen control and other modern audio-video interfaces are planned.

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most fluorescent lighting systems, the general lighting system should be relamped every 12,000 to14,000 hours. Ballast life should cover 10 years or more. Spot relamping is recommended for the house lighting system. Cleaning of both systems should be simple.

The control system should be designed for easy management. Automatic time of day control with override is an acceptable means to control corridor lights, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up. Also, if fluorescent dimming is used, make sure that lamps are pre-seasoned, i.e., operated at full light for 100 hours prior to dimming them.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG16: LIGHTING FOR A LIBRARY OR MEDIA CENTER

Recommendation

Provide lighting for a library as follows:

- A lighting system providing 20 to 50 footcandles of general illumination in casual reading, circulation and seating areas using standard T-8 lamps.
- Overhead task lighting at locations such as conventional card files, circulation desks, etc.
- Task lighting at carrels and other obvious task locations, using compact fluorescent or T-8 lamps.
- Stack lights using T-8 or T-5 lamps in areas where stack locations are fixed, and general overhead lighting in areas employing high density stack systems.
- Special lighting for media rooms, as required.

Figure 97— Austin Creek Elementary School

Source: Quattrocchi / Kwok Architects

Applicable Spaces		Climates		When to Consider	
Classrooms		South Coast	■	Programming	■
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria		Central Valley	■	Design Dev.	■
Gym		Mountains	■	Contract Docs.	■
Corridors		Desert	■	Construction	■
Administration				Commissioning	■
Toilets				Operation	
Other					

Description

The general lighting system may be one of the types previously suggested for classroom lighting (Guideline LG9: Classroom Lighting—Conventional Teaching through Guideline LG11: Teaching Board Lighting and Guideline LG17: Lighting for Offices and Teacher Support Rooms). As long as adequate ceiling height is present, suspended lighting systems are preferable. Overhead lighting systems for task locations should also be selected from among choices suitable for classrooms or offices.

Task lighting at carrels and other spots should be selected according to architecture and finish details. Two common options include:

- Under-shelf task lights using T-8 or modern T-5 lamps (e.g., F14T-5/8xx, F21T-5/8xx, or F28T-5/8xx).
- Table or floor lamp equipped with a compact fluorescent lamp up to 40 W.

Stack lighting should utilize luminaires specifically designed for lighting stacks. A number of choices exist, but generally, a single continuous T-8 or T-5 lamp system will provide adequate illumination.

Media rooms, such as video monitoring and editing, sound monitoring and editing, distance learning, and video teleconferencing all have special requirements. It is important that lighting be designed to meet those specific needs and that lighting controls be provided to enable room use. No specific recommendations for those spaces are made here, but depending on the room, professional lighting design services may be needed to assist the standard design team.

A control system that activates the general lighting system according to a calendar program and employs motion sensing for "off" hours should be used. In areas with plentiful daylight, employ automatic daylight switching or dimming to reduce electric lighting by day. In addition, in areas of the library that are less frequently used, such as reference stacks, consider providing individual motion sensors or digital time switches for stack aisles that are connected to dimming ballasts, producing low light levels (but not completely off) until the aisle is occupied. Individual reading and study rooms should employ motion sensors, with "personal" motion sensors and plug strips used at study carrels, especially those with fixed computers.

It will be necessary to provide emergency lighting with this system. Some of the general lighting luminaires must be powered from an emergency generator or backup battery power source.

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities containing libraries, such as churches and private institutions.

Applicable Codes

Electrical

The National Electrical Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24. Title 24 limits the amount of lighting power in a library reading area to 1.2 W/ft^2 and a stack area to 1.5 W/ft^2 (1999), so this recommendation is within code limits. Title 24 also requires bi-level switching of library stacks.

Life Safety

As a place of assembly, libraries must be equipped with an emergency lighting system capable of producing at least 1 footcandle, average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

Seismic

Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional hanger wire or support independent of the ceiling's support system.

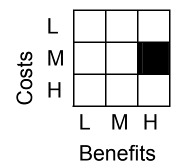
Integrated Design Implications

Libraries are often more highly designed than other spaces. In some designs, other lighting systems that integrate better with the architecture should be considered.

Daylight is an excellent choice for providing basic ambient light in a library. Reading areas and storytelling niches especially benefit from the presence of gentle daylight and view windows. With thoughtful daylight design, only the task lighting at checkout desks or stack areas needs to be on during the day. And these can be connected to occupancy sensors to reduce their hours of operation.

If the library has computers for research or card catalog searches, special care should be taken to avoid glare sources on the computer monitors from light fixtures or windows.

Cost Effectiveness[36]



Library spaces will tend to be among the most expensive to light. These recommendations provide a good balance between cost, energy efficiency, and good lighting practice.

A 4-ft long stack light is approximately $200. A 3-ft long undercabinet task light costs about $175. A high-quality compact fluorescent desk lamp falls in the $300 price range. Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

These recommendations provide proper light for a library and media center. Task light levels are provided only at task locations, while ambient and general light levels are lower to ensure energy efficient operation.

Design Tools

See the Overview section of this chapter.

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[36] Ibid.

Design Details

Below is a lighting design for a typical library:

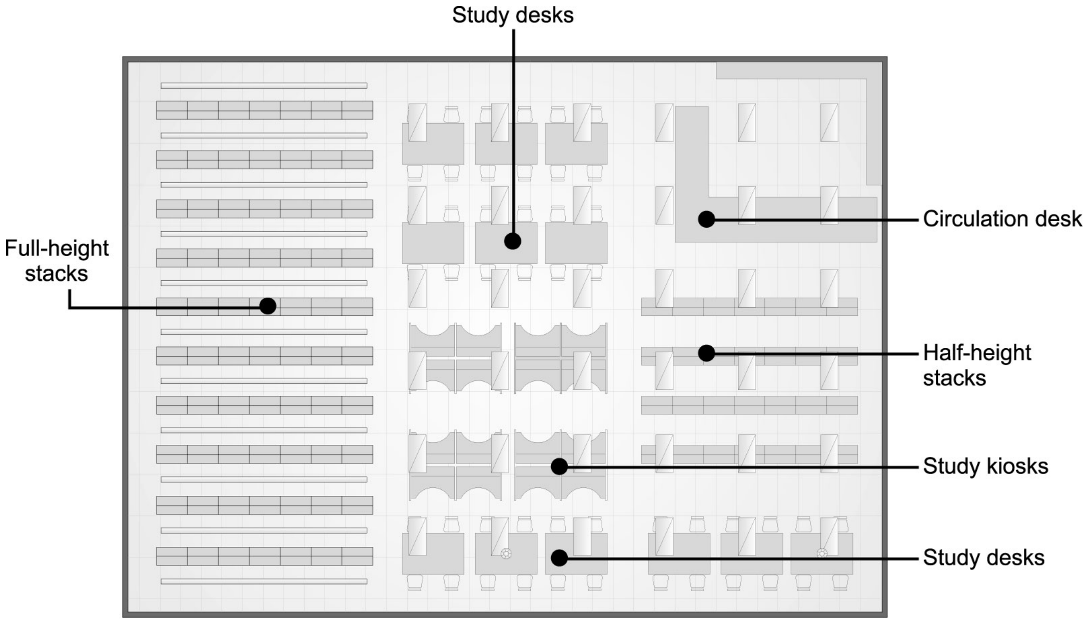


Figure 98—Library Lighting Design

This design illustrates general lighting using troffers, table lights for study desks, task lights at kiosks, and stack lights. Using high ballast factor 2-lamp troffers, this design works at an overall power density of 1.27 W/ft^2. Increasing stack lights to high ballast factor increases overall connected power to 1.38 W/ft^2. Note that the stacks to the right on the plan are half height.

The general lighting system can be designed to become more "dense" in task areas such as circulation desks, thus minimizing the number of different lighting types.

Undercabinet task lights should be specified carefully. Avoid traditional "inch light" systems with magnetic ballasts that use twin tube compact fluorescent lamps and old-style linear lamps like the F6T-5 (9 in.), F8T-5 (12 in.), and F13T-5 (21in.). Use tasks lights employing modern F14T-5 (22 in.), F21T-5 (34 in.), F28T-5 (46 in.), F17T-8, F25T-8, or F32T-8 lamps. Always use electronic ballasts, and consider dimming for all task lights.

Desk lamps and table lamps with compact fluorescent hardwired lamps should be used. Relatively few products exist. Medium based screw-in compact fluorescent lamps are not a good choice for new projects.

Switching and dimming of the lighting system should NOT be readily accessible. Locate controls in a supervised location.

In media rooms, consider a modern preset dimming or control system, especially if touch-screen control and other modern audio-video interfaces are planned.

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most fluorescent lighting systems, the general lighting system should be relamped every 12,000 to 14,000 hours. Ballast life lasts 10 years or more. Spot relamping is recommended for the house lighting system. Cleaning of both systems should be simple.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up. Also, if fluorescent dimming is used, make sure that lamps are pre-seasoned, i.e., operated at full light for 100 hours prior to dimming them.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG17: LIGHTING FOR OFFICES AND TEACHER SUPPORT ROOMS

Recommendation

This recommendation is for offices and teacher support rooms having a ceiling no more than 12 ft high and a flat suspended acoustical tile ceiling. There are two choices:

Use recessed fluorescent lens troffers having at least 78% luminaire efficiency, using T-8 premium lamps and electronic ballasts. The connected lighting power should be 0.9 W/ft^2 to 1.1 W/ft^2.

Use suspended indirect lighting to produce an ambient level of 15 to 20 footcandles (about 0.6 W/ft^2) and task lighting where required.

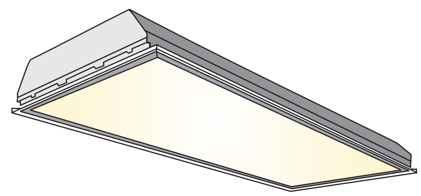
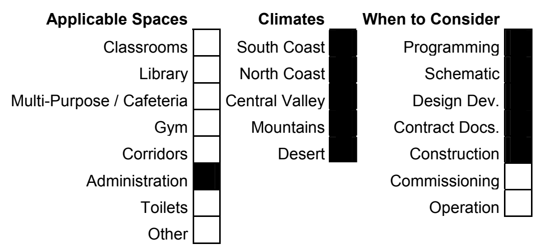


Figure 99—Recessed Fluorescent Lens Troffer



Description

For suspended lighting systems, see Guideline LG9: Classroom Lighting—Conventional Teaching and Guideline LG10: Multi-Scene Classroom Lighting.

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Applicable Codes

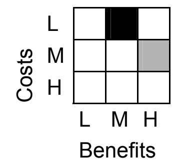
The National Electric Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24. Title 24 limits the amount of lighting power in offices to 1.3 W/ft^2 (1999), so this recommendation meets code limits by a considerable amount. Title 24 also requires switching (see Guideline LG12: Lighting Controls for Classrooms).

Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be hung from the structure with hanger wires independent of the ceiling system.

Integrated Design Implications

This type of lighting should only be used in flat acoustic tile ceilings, and then only when ceiling height and/or budget prevents consideration of other options.

Cost Effectiveness



Lens troffer lighting systems are low in cost, but their inexpensive appearance can be a drawback. Suspended lighting systems provide a high degree of cost effectiveness and improved appearance in most applications.

Benefits

Troffer lighting systems generally offer excellent efficiency, but with some loss of visual comfort. They make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1 W/ft^2 will generate between 50 and 60 footcandles maintained average, with very good uniformity. Separate task and ambient systems may create a more comfortable atmosphere.

Design Tools

See the Overview section of this chapter.

Design Details

See Guideline LG9: Classroom Lighting—Conventional Teaching and Guideline LG10: Multi-Scene Classroom Lighting.

For non-dimming applications, luminaire light and power can be varied through choice of ballast factor.

Operation and Maintenance Issues

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to16,000 hours of operation, which with normal school use could be as seldom as every six years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively inexpensive.

Commissioning

No commissioning is needed, other than pre-seasoning of lamps in dimming applications.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG18: LIGHTING FOR LOCKER AND TOILET ROOMS

Recommendation

Over mirrors and vanities, employ rough service grade fluorescent wall-mounted lights. Over stalls and locker areas, use recessed or surface-mounted rough service area fluorescent lights. In showers, employ ceiling-mounted, watertight, rough-service grade fluorescent lights.

In general, choose luminaires that are attractively styled to prevent an overly institutional appearance.

Figure 100—Toilet Lighting

Applicable Spaces		Climates		When to Consider	
Classrooms	☐	South Coast	■	Programming	■
Library	☐	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	☐	Central Valley	■	Design Dev.	■
Gym	▒	Mountains	■	Contract Docs.	■
Corridors	☐	Desert	■	Construction	☐
Administration	☐			Commissioning	☐
Toilets	■			Operation	☐
Other	☐				

Description

This guideline generally recommends fluorescent luminaires using standard T-8 or compact fluorescent lamps. These luminaires are part of a relatively new generation of “vandal-resistant” or “rough-service” lights that are considerably more attractive than previous products. These luminaires should be specified with UV-stabilized, prismatic polycarbonate lenses for maximum efficiency and resistance to abuse. The use of tamper resistant hardware is also recommended.

Wall mounted rough-service lights include:

- Linear lights using T-8 lamps and electronic ballasts.
- Rectangular, oval, and round lights that can be equipped with compact fluorescent lamps (low Watt HID lamps can also be used in these luminaries, but are not recommended).

Recessed ceiling lights are generally troffers (see Guideline LG10: Multi-Scene Classroom Lighting) that employ the polycarbonate lens and tamper-resistant hardware, as well as more robust components. These luminaires are available in 1 ft x 4 ft, 2 ft x 2 ft, and 2 ft x4 ft versions with standard T-8 lamps and electronic ballasts.

For showers, employ either surface or recessed luminaires designed for compact fluorescent lights. Due to the long warm-up and restrike times, HID lamps should not be used. In either case, luminaires should be listed for wet applications.

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Applicable Codes

Electrical

The National Electrical Code (NEC) usually governs the installation of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24. Title 24 limits lighting power to 0.9 W/ft^2 in a locker or dressing room to 0.9 W/ft^2, and to 0.6 W/ft^2 in rest rooms (1999). Title 24 also requires switching in these spaces (see Guideline LG12: Lighting Controls for Classrooms).

Life Safety

The room needs to be equipped with an emergency lighting system capable of producing at least 1.0 footcandle, average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

Seismic

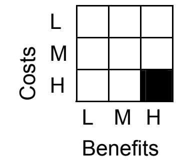
Luminaires need to be restrained in case of an earthquake. In general, this means that each suspended luminaire must be hung from the structure with hanger wires independent of the ceiling system.

Integrated Design Implications

These types of spaces are historically the most abused interior portions of school buildings. Durable lighting is unfortunately less attractive and less integrated than other lighting types.

Daylight is a welcome addition to any locker or toilet room. The high light levels from daylight promote good maintenance and sunlight can actually help sanitize the spaces by killing bacteria. For privacy and security reasons, daylight is often best provided in these spaces via diffusing skylights. Often these spaces can be designed to need no additional electric light during the day.

Cost Effectiveness[37]



The investment in rough-service equipment is paid back over time. In high schools and colleges, the payback can be rapid, especially if the students are particularly rough or abusive.

Rough-service lighting systems will cost about $200 to $300 per luminaire for the types listed above, with compact fluorescent or T-8 lamps and electronic ballasts.

Benefits

Rough service lighting will last longer in these applications while continuing to look good and not suffer from cracks and other signs of abuse.

Design Tools

See the Overview section of this chapter.

Design Details

Be certain to employ premium T-8 lamps with 835 or 841 color, rated at 24,000 hours. For non-dimming applications, luminaire light and power can be varied through choice of ballast factor.

Controls should perform in one of the following ways:

Continuously on during normal school hours, with a night/emergency light on all the time; or

Continuously on during normal school hours, with both a night/emergency light on at all times and a motion sensor override for full lighting during “off” hours.

Operation and Maintenance Issues

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation, which with normal school use could be as seldom as every six years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively cheap.

Commissioning

No commissioning is needed, other than pre-seasoning of lamps in dimming applications.

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[37] Ibid.

References/Additional Information

See the Overview section of this chapter.

GUIDELINE LG19: OUTDOOR LIGHTING

Recommendation

As a minimum, provide the following exterior lighting systems:

- Provide canopy or wall-mounted luminaires to illuminate the building entrances.
- Provide parking lot and driveway lighting only for areas that are expected to be used at night and control the lighting so that it operates only when the school is being used. Use pole-mounted, full cut-off luminaires to illuminate the parking as well as surrounding walks and other areas.
- For walkways intended for night use, use suitable walkway lighting systems, such as full cutoff pedestrian-scale light poles or bollards.

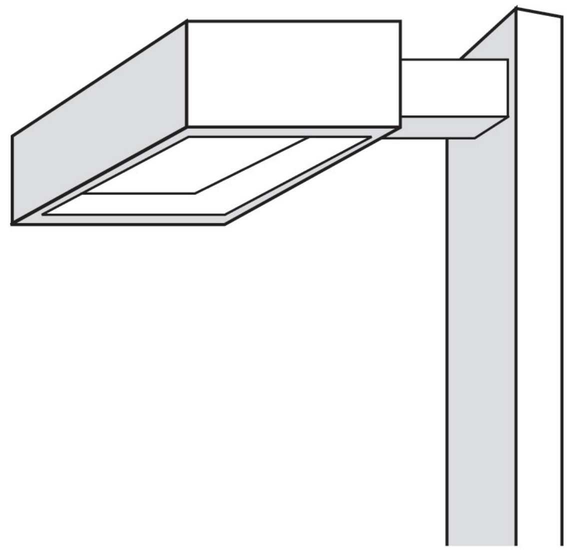


Figure 101—Outdoor Lighting

Description

Applicable Spaces		Climates		When to Consider	
Classrooms	☐	South Coast	■	Programming	■
Library	☐	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	☐	Central Valley	■	Design Dev.	■
Gym	☐	Mountains	■	Contract Docs.	■
Corridors	☐	Desert	■	Construction	■
Administration	☐			Commissioning	☐
Toilets	☐			Operation	☐
Other	■				

In general, school campuses should be dark at night. Exterior lighting should be provided only for special nighttime activities such as community use, sporting events or theatrical or music events. Light trespass to neighboring properties, especially residences, can be an issue with schools, so outdoor lighting should be minimized and when it is necessary, it should be designed to minimize trespass and pollution of the night sky. . If light is needed for security reasons, carefully located motion sensors can be used to activate low-cost compact fluorescent or quartz lights that serve as both safety lighting and as a deterrent against vandalism.

Many California schools have exterior pedestrian circulation between classrooms, gyms, administration and other spaces. Often canopies are provided to provide shelter on rainy days. Luminaires for these applications should be attractive, rough-service, semi-recessed, or surface mounted with durable lens. The lens should be an UV-stabilized polycarbonate prismatic lens. If mounted to walls, employ designs that direct light downward to minimize light trespass and light pollution.

Parking lots and driveways should be illuminated using pole-mounted full-cutoff luminaires. Luminaires should be at least 17 ft above grade; actual pole height depends on the type of pole and base. Direct burial, color-impregnated composition or fiberglass poles are recommended if soil and other site conditions are acceptable. If used in the center of a large parking area, however, consider steel or aluminum poles that are anchor-bolt mounted to concrete foundations. Typically, luminaires will employ 150-W or 175-W pulse start metal halide lamps, and in parking lots, two luminaires may be mounted to a single pole.

Lower mounting heights may be used for walkways, especially if located away from buildings and parking lots. Choose between short poles (8 ft to 12 ft) using compact fluorescent or low wattage HID lamps. Another option is to use knee high bollards with compact fluorescent lamps.

Ourdoor lighting for schools should be controlled by an astronomic timeclock instead of a photocells. The system should permit activation at sunset and deactivation at a programmable time, allowing the school to be "dark" and save energy through as much of the night as possible. Separate "off" times programmed for parking lot, driveway, and building lighting are highly desirable. This system should be located where they are accessible to administration personnel. The system must be easy to set and have the capability for temporary manual override.

Some outdoor lighting systems may be classified as emergency lighting for the purposes of egress. Such luminaires must be powered from an emergency generator or battery backup power source. See life-safety issues below.

All lights should be chosen with consideration of the climate conditions under which they will operate. In most cases, the primary consideration is lamp-starting temperature, which is a function of both the lamp and ballast. Compact fluorescent and HID lamp/ballast systems will start and operate at temperatures as low as -5°F.

Photovoltaic-powered lights should be considered for locations where grid power is not easily available.

Applicability

This outdoor lighting guideline is applicable for schools, including colleges and universities, that are operated at night.

Applicable Codes

California Energy Efficiency Standards (Title 24)

With the 2005 update, the scope of the California energy efficiency standards was expanded to include new requirements for outdoor lighting. The 2001 standards addressed only lighting efficacy and controls, while the 2005 standards also include lighting power limits for certain outdoor lighting applications, shielding requirements for luminaires and other measures. The California outdoor lighting requirements include both mandatory measures and prescriptive requirements.

Mandatory Measures. The mandatory measures require that outdoor lighting be automatically controlled so that it is turned off during daytime hours and during other times when it is not needed. The mandatory measures also require that most of these controls be certified by the manufacturer and listed in the Energy Commission directories. Luminaires with lamps larger than 175 watts must be classified as cutoff so that the majority of the light is directed toward the ground. Luminaires with lamps larger than 60 watts must also be high efficacy or controlled by a motion sensor. More detail on the mandatory measures is provided in Section 6.2.

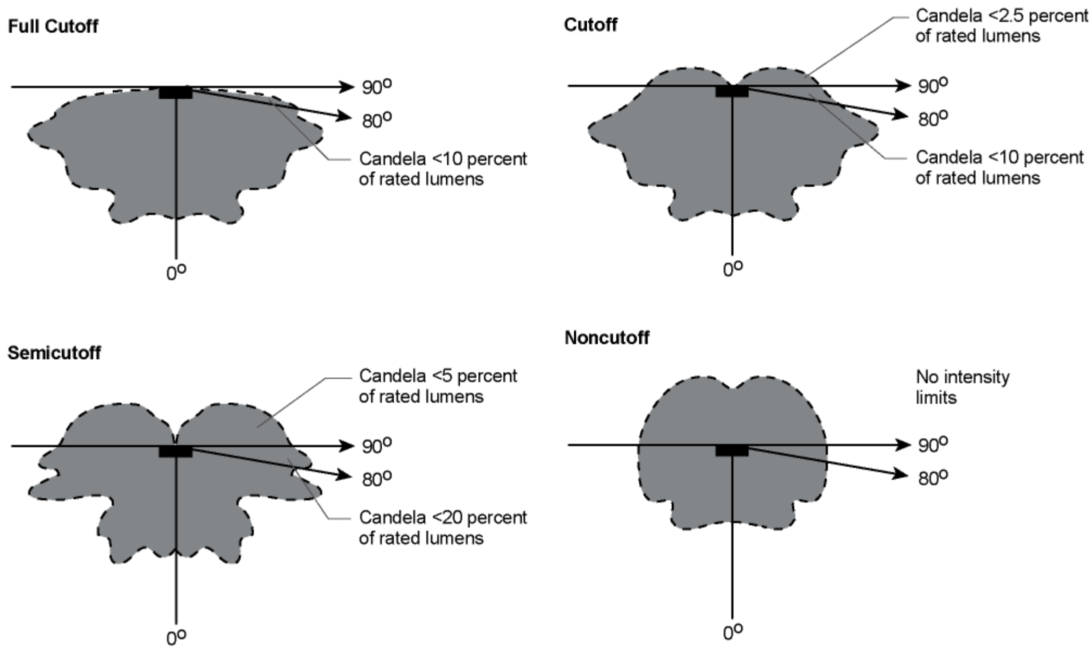


Figure 102—Cutoff Luminaire Classifications

The California standards require all outdoor luminaires greater than 175 W to be cutoff. fs

Lighting Power. The 2005 Standards limit the lighting power that may be used for many outdoor applications. Lighting for parking lots, driveways, uncovered walkways and uncovered building entrances is considered general site illumination, and a total outdoor lighting budget is calculated, enabling tradeoffs between the lighting applications. Lighting power is also limited for covered walkways, covered entrances and illumination of building facades, but these are considered specific lighting applications and each application must comply with its own lighting with no tradeoffs between applications. The standards do not limit lighting power for sports and athletic fields; children's playgrounds; temporary lighting (seasonal Christmas tree sales, for example); lighting of bridges, tunnels, stairs and ramps; landscape lighting; or lighting in or around swimming pools or other water features.

California has four lighting zones for use in determining the lighting allowance. The allowed lighting power is greater in urban areas (lighting zone 3) and less in rural areas (lighting zone 2). The U.S. census bureau defines what an urban and rural area is. In addition, lighting zone 1 includes national parks, wilderness areas that are inherently dark at night; and lighting zone 4 are special use districts with intensive commercial activity and street activity at night. It is unlikely that many schools will be located in zones 1 or 4. In fact the majority of schools are located in lighting zone 3 with a few in 2. Table 20 summarizes the power allowances for common school lighting applications.

Table 20—Outdoor Lighting Requirements for Schools

See Tables 147-A and 147-B of the California energy efficiency standards for more detail.

			Allowed Power		
Category	**Common Lighting Application for Schools**		**Lighting Zone 2 (Rural Areas)**	**Lighting Zone 3 (Urban Areas)**	**Notes**
General Site Illumination	Uncovered pedestrian walkways, sidewalks and plazas	Method 1	0.08 W/ft^2	0.15 W/ft^2	Area for calculations includes actual paved area plus 5 ft of unpaved land on either side of the path of travel.
		Method 2	1.5 W/ft	4.0 W/ft	Area includes a 25 ft wide path incorporating as much of the paved area of the site roadway or driveway as possible.
	Parking lots, driveways, and site roads	Method 1	0.09 W/ft^2	0.17 W/ft^2	Area for calculations includes actual paved area plus a 5 ft perimeter of adjacent unpaved land. It also includes planters and landscaped areas less than 10' wide that are enclosed by paving on at least three sides..
		Method 2	1.5 W/ft	4.0 W/ft	Area includes a 25 ft wide path incorporating as much of the paved area of the walkway or bikeway as possible.
	Uncovered building entrances		0.50 W/ft^2	0.70 W/ft^2	Area for calculations includes the width of doors plus 3 ft on either side times a distance of 18 feet away from the building.
Specific Lighting Applications	Canopies		0.25 W/ft^2	0.50 W/ft^2	Area for calculations includes just the space directly beneath the canopy.
	Facades		0.18 W/ft^2	0.35 W/ft^2	Area for calculations only includes portions of the building that are illuminated.
	Ornamental lighting		0.01 W/ft^2	0.02 W/ft^2	This is a general allowance for the whole campus.

Signs. The 2005 Standards contain either prescriptive or performance requirements for signs. Sign Standards apply to both indoor and outdoor signs. The prescriptive approach requires that signs use efficient electronic ballasts while the performance approach specifies a maximum power of 12 W/ft^2 of illuminated face for internally illuminated signs and 2.3 W/ft^2 for externally illuminated signs. See §148 of the California standard for more details.

Installed Power. In complying with the standards, the installed power for outdoor lighting applications shall include both the lamp and the ballast (the whole lighting system). Manufacturer's data or information from ACM Appendix NB-2005, may be used to determine the wattage of outdoor luminaires. Unlike interior lighting, no power credits are offered for automatic controls. However, the mandatory measures require certain automatic controls (see above)

Electrical

The Division of the State Architct (DSA) uses the California Building Code for public K-12 schools and community colleges that come under its jurisdiction. For private schools that must go through a local building department, the National Electrical Code (NEC) usually governs the electrical portion of lighting installations, however, some cities have unique electrical codes.

Life Safety

Because building codes consider the path of egress to continue outside the building, some exterior lighting, especially in exterior corridors, may need to be equipped with emergency backup power. The design requirement for the backup system is at least 1.0 footcandles, average, along the path of egress. In general, the best approach is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of operating for at least 90 minutes. Emergency power may also be required for exterior exit signs and they, too, must be powered for at least 90 minutes after a power outage.

Lighting controls must be designed such that, regardless of setting, if a power emergency occurs, the proper lights are illuminated. This often requires use of an automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.

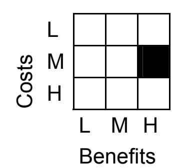
Seismic

Suspended luminaires need to be positioned such that they can swing at 45º in any direction without striking another part of the building. Alternatively, they may be restrained to avoid contact. Luminaires beneath a canopy must be secured to the structure with an hanger wire or support which is independent of the ceiling's support system.

Integrated Design Implications

Exterior lights should be chosen with the architectural impact to the building's exterior in mind. Select the proper color, shape, and style to reinforce architectural themes of the building.

Cost Effectiveness[38]



The cost of exterior lighting tends to be relatively high. However, compromising on costs, such as using lower quality products, will result in needing to replace the lighting system sooner, thus making it a poor choice when considering life-cycle cost.

- A typical pole luminaire, 17 ft high, 175 W, type III distribution, with steel pole and anchor base, costs approximately $1,500.
- A bollard, contemporary, with 42-W compact fluorescent and concrete anchor base costs $600.
- A canopy-mounted, rough-service luminaire, with two 32-W compact fluorescent, contemporary styled costs $300.
- A high quality motion sensor floodlight, 350-W quartz costs $250.

[38] Ibid.

Switching and emergency power costs vary and are in addition to the luminaire costs.

Benefits

Properly designed exterior lighting systems permit the extended use of the facility, promoting increased personal safety and security and reduced vandalism. Properly designed systems will also minimize light trespass and pollution.

Design Tools

Outdoor lighting analysis and design tools are more simple than indoor tools because it is not necessary to consider reflection for most applications. However, many of the same tools used for indoor lighting applications may also be used for outdoor lighting applications. See the Overview section of this chapter for more details.

Design Details

- Lighting layouts for parking lots and pedestrian access from the parking lot to the building should be performed using an outdoor lighting analysis computer program. At minimum horizontal illumination of 0.5 footcandles throughout the parking lot, with an average horizontal illuminance of 2.0 footcandles. Uniformity (the ratio between the maximum and minimum illumination) should not exceed 4:1.
- Pole lights should use a variation of the classic “shoebox” full cutoff lights. Avoid traditional lights or contemporary lights that do not produce full shielding.
- Many choices in wall-mounted luminaires exist, and this is one situation where aesthetics may be critical. Be certain to choose die-cast aluminum bodies, rough-service polycarbonate lenses or diffusers, and/or other heavy-duty construction. A number of look-alike products made of lightweight and inferior materials are on the market, so be especially wary of imitations and substitutes.
- If choosing a “dark” school approach to security, use of motion sensors and quartz floodlights may be warranted. Either separate or integrated units may be used. Quality is especially important in choosing exterior motion sensors, since a faulty sensor will give false indications and activate lights (and possibly concerned neighbors) needlessly.
- Consider zoning exterior lighting so that the parking lot zone nearest the building can be activated separately from the majority of the lot.
- Manual override switching of the lighting system should NOT be readily accessible. Locate controls in a supervised location. Use a digital controller, not a mechanical “time clock.”

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most HID and compact fluorescent lighting systems, the lighting system should be group relamped every 8,000 hours, or about every two years. Ballast life should cover 10 years or more. Spot relamping is recommended to ensure security and safety. The design should make cleaning of systems simple. See CHPS Maintenance and Operation, Volume IV for more details on maintaining lighting and electrical systems.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that the lighting controls are properly set and calibrated.

References/Additional Information

See the Overview section of this chapter.

Building Enclosure and Insulation

OVERVIEW

The design of the school building enclosure, or envelope, entails many considerations. The materials—both indoors and out—must be durable, resistant to vandalism, easy to clean, and inexpensive. They must be strong enough to meet seismic codes, yet appear inviting. Add energy efficiency and sustainability to this list and the job of the design team is even more complex.

This chapter provides technical guidelines for the school building enclosure, including:

- Guideline IN1: Wall Insulation
- Guideline IN2: Roof Insulation
- Guideline IN3: Cool Roofs
- Guideline IN4: Radiant Barriers
- Guideline IN5: Reduce Infiltration
- Guideline IN6: Slab on Grade Insulation
- Guideline IN7: Fenestration Performance
- Guideline IN8: Moisture Control
- Guideline IN9: Acoustic Design

The construction of the building enclosure, especially its color, levels of insulation, and thermal mass, has a significant effect on energy efficiency and occupant comfort. The building enclosure also affects acoustic comfort since it can attenuate site and traffic noise. The selection of materials for the construction of the building enclosure affects school resource efficiency, including transport energy, the volume, and type of raw materials that must be extracted from the earth, and the energy required for manufacturing and packaging. Building shell construction also affects thermal comfort. Even when heating and cooling systems are large enough to make up for poorly insulated components, the building's surface temperature may be cold or hot (depending on season), and this affects the radiant temperature of the space.

Heat Transfer through the Building Enclosure

Heat transfer through envelope components is quite complex and dynamic. The direction and magnitude of heat flow is affected by solar gains from the sun, outdoor temperature, and indoor temperature. Building envelope components have three important characteristics that affect their performance: their U-factor or thermal resistance (R-value); their thermal mass or ability to store heat, measured as heat capacity (HC); and their exterior surface condition/finish (for example, are they light in color to reflect the sun or dark to absorb solar heat?). These concepts are explained in greater detail below. Also discussed below is the use of radiant barriers and cool roofs to reduce heat transfer in certain situations.

U-factor

The U-factor is the rate of steady-state heat flow. It is the amount of heat in British thermal units (Btu) that flows each hour through 1 ft^2 of surface area when there is a 1°F temperature difference between the inside and outside air. Heat flow can be in either direction, as heat will flow from the warmer side to the cooler side. Insulation and most other building materials affect heat flow equally in both directions; some construction elements such as radiant barriers may reduce heat flow entering the building but have little impact on heat leaving the building.

Steady-state heat flow assumes that temperatures on both sides of the building envelope element (while different) are held constant for a sufficient period so that heat leaving one side of the assembly is equal to heat entering the opposite side. The concept of steady-state heat flow is a simplification because, in the real world, temperatures change constantly. However, U-factor can predict average heat flow rates over time and is commonly used to explain the thermal performance of construction assemblies. Because they are easy to understand and use, the terms for steady-state heat flow (R-values and U-factors) are part of the basic vocabulary of building energy performance.

With metal framing, thermal bridges have a significant impact on the performance of the overall assembly, sometimes reducing the insulation effectiveness to less than half. The U-factor accounts for thermal bridges and the conductance of every element of the construction assembly, including the air film conductance on the interior and exterior surfaces. The air film conductance quantifies the rate at which heat is transferred between the surface of the construction assembly and the surrounding environment. This conductance depends on the orientation and roughness of the surface and the wind speed across the surface.

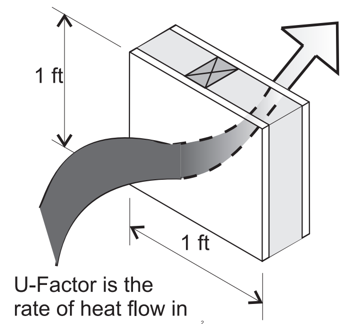


Figure 103—Concept of U-Factor

For light frame walls, U-factors provide an adequate description of heat transfer. For heavy concrete and masonry walls, however, this is only true under constant temperature conditions. The dynamic heat storage properties of concrete and masonry alter the thermal behavior of the wall, and the U-factor becomes less accurate as a predictor of heat flow (see discussion of HC below).

Heat transfer through slab-on-grade floors is a complex process. Most of the heat loss occurs at the slab perimeter. The “F factor” is a term analogous to U-factor that represents the rate of heat transfer from the perimeter of the slab to outdoors, except that F-factor is the rate of heat loss per linear foot rather than per square foot as with U-factor. The heat loss through the slab is proportional to the slab perimeter. Since the heat loss through slab-on-grade is a complex process, published values for F-factors should be used.

R-values

R-values are also used to describe steady-state heat flow but in a slightly different way. The R-value is a material property that is proportional to resistance to heat flow. A larger R-value has greater thermal resistance, or more insulating ability, than a smaller R-value. The opposite is true with U-factors: lower values mean more insulating ability.

R-values are widely recognized in the building industry and are used to describe insulation effectiveness. The insulation R-value does not describe the overall performance of the complete assembly, however. It only describes the thermal resistance of the insulation material. In contrast, the U-factor is a measure of the thermal performance of the entire construction assembly. The performance of the entire wall assembly can be significantly lower when metal framing or other elements penetrate the insulation.

Ratings for R-values of insulating materials are typically specified at 75°F. The insulating properties of the material are dependent on temperature. A specified insulation will have a higher R-value at low temperatures and a lower R-value at higher temperatures. This effect can be significant: for example, fiberglass batt insulation has an R-value (in IP units) of 3.2 per inch at 75°F, but 2.7 per inch at 115°F, which might be an attic temperature on a hot day. Insulation must also not be compressed near structural members, and must remain dry, to maintain its rated R-value. Insulation that is blown into a cavity may settle over time, reducing its effective R-value.

Most construction assemblies include more than one material in the same layer. For example, a wood stud wall includes cavity areas where the insulation is located and other areas where there are solid wood framing members. The wood areas have a lower R-value and conduct heat more readily than the insulated areas. Framing members must be considered when calculating the U-factor of a wall, roof, or floor assembly. See the Design Tools section below for more details.

Thermal Mass

Thermal mass is another important characteristic that affects the thermal performance of construction assemblies. Heavy walls, roofs, and floors have more thermal mass than light ones. Thermal mass both delays and dampens heat transfer (see Figure 104). The time lag between peak outdoor temperature and interior heat transfer is between four and 12 hours depending on the heat capacity of the construction and other characteristics.

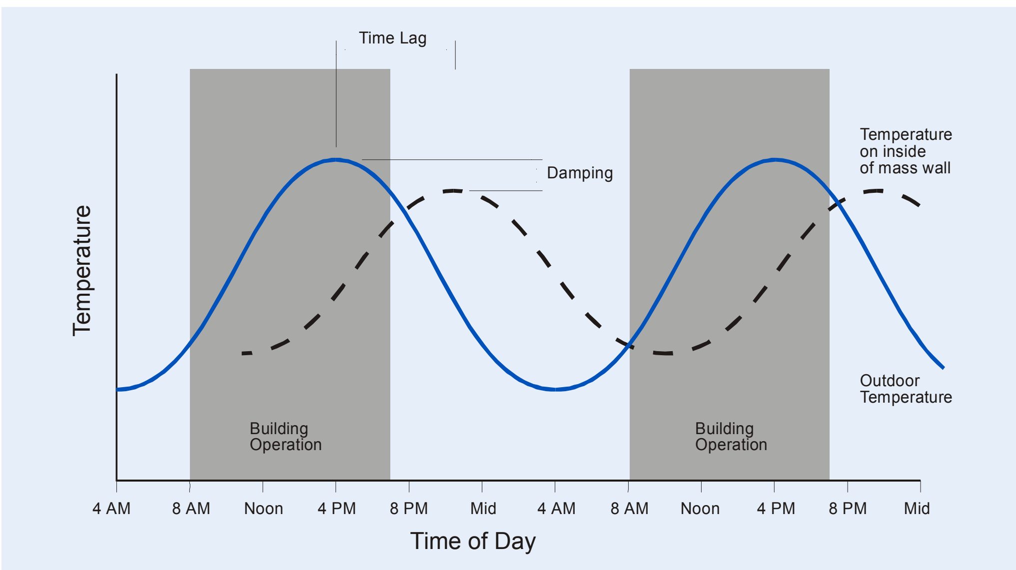


Figure 104—Temperature Swing

Thermal mass that is exposed to interior air has other benefits as well. If the mass is allowed to cool at night, it will absorb heat during the morning and reduce the cooling load. If the interior thermal mass is exposed to sunlight, it will warm during the day and release the heat at night. Thermal mass used this way is a basic principle of passive solar design and may be appropriate in the mountain climates of California.

Figure 105 shows examples of mass walls commonly used in school construction.

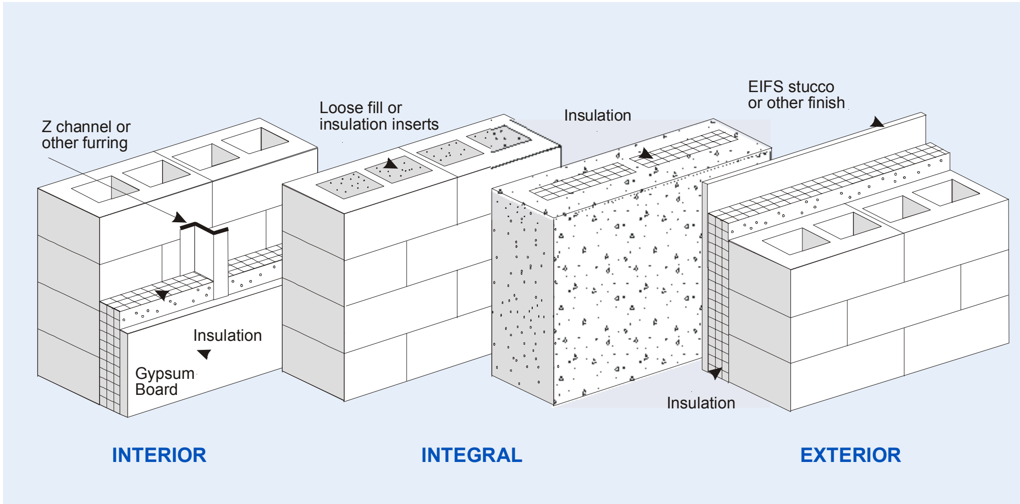


Figure 105—Mass Wall Constructions

Heat Capacity

HC is the metric used to quantify thermal mass. HC is the amount of heat in Btu that must be added to 1 ft^2 of surface area to uniformly elevate the temperature of the construction by 1°F. The units are $Btu/ft^2 \cdot °F$. HC is the sum of the heat capacity of each individual layer in the wall. The heat capacity of each layer is the density of the material times its thickness times its specific heat (all in consistent units). HC can be approximated by multiplying the weight of 1 ft^2 of wall, roof, or floor by 0.2. For example, a wall with a weight of 100 lb/ft^2 has an HC of approximately 20 $Btu/ft^2 \cdot °F$.

Many energy standards (including California Title 24) consider HC as a factor in the overall performance of a building envelope component. The California Nonresidential Standards, for instance, have separate U-factor criteria for different HC ranges.

Concrete is not a very good insulating material. However, some varieties are better than others. There is a class of materials called aerated concrete that has air bubbles entrained in the concrete, which makes the concrete lighter and also improves its insulating ability. Low-density aggregates such as perlite or vermiculite can be used to produce lightweight concrete.

Cool Roofs

Heat transfer is also affected by the exterior surface, which is particularly important for roofs. In fact, the term "cool roof" is used to describe those with favorable surface characteristics. Cool roofs have two key features. First, they have a high solar reflectance, which usually means that they are light in color. The high reflectance means that solar radiation is reflected rather than absorbed by the roof surface, keeping the surface temperature lower and reducing heat gain. Second, cool roofs have a high or normal emittance. Emittance is a little harder to understand than reflectance, but it can be just as important to energy performance. Emittance is that percentage of absorbed solar energy that would be radiated to the sky from a surface. Galvanized metal and other metallic finishes have a low emittance, which means that when they warm up, they cannot easily release their heat by radiating it back to the sky.

Radiant Barriers

One last feature of construction assemblies that deserves discussion is radiant barriers. Many construction assemblies have a large cavity. An attic, for instance, is a cavity separating the roof from the ceiling. Radiant barriers are not typically installed in walls. In construction assemblies that have a cavity, much of the heat transfer from the warmer surface to the colder surface is due to radiation. A radiant barrier can reduce this component of heat transfer. A radiant barrier is a shiny metallic surface on one or more sides of the cavity that has a low emittance. Radiant barriers are commonly installed in attics.

Fenestration Products

High performance fenestration products, that include features such as double-glazing and low-emissivity ("low-e") coatings, are an effective way to reduce both solar heat gains and winter thermal losses in modern construction. Fenestration has three principal energy performance characteristics, which have been identified by the National Fenestration Rating Council (NFRC) to be tested and labeled on manufactured windows: visible light transmittance, solar heat gain coefficient, and U-factor. Site-built windows and skylights may not have this information available.

- Visible light transmittance (VLT) is the fraction of light that is transmitted through the glazing. Light is that portion of solar radiation that is visible, meaning it has a wavelength between about 380 and 780 nanometers. Single clear glass has a VLT of about 0.9, while highly reflective glass can have a VLT as low as 0.05. The quantity of light that enters through a window or skylight is directly proportional to VLT. In general, the VLT should be as high as possible, provided it doesn't create glare or other visibility problems.
- Solar heat gain coefficient (SHGC) is the fraction of solar radiation incident on a window or skylight that is either transmitted, or absorbed and re-emitted, to the interior space. A window that entirely blocks all solar heat would have an SHGC of zero, while a perfectly transmissive glazing has an SHGC of one. A lower SHGC results in lower cooling loads for the space. Windows used for daylighting should ideally have a high VLT and a low SHGC. However, glazing materials with a low SHGC (like dark gray and bronze tints) may also have a low VLT, so the challenge is to identify spectrally "selective" low-e products and blue/green tints. Only 38% of solar energy that strikes the windows is visible light. The remainder is in the form of infrared heat and UV rays that can degrade fabrics and interior surfaces. Low-e windows have a very thin metallic oxide coating on the window surface that lets visible light in, but keeps infrared heat and UV light out.
- Relative Solar Heat Gain (RSHG) is a term used in the Title 24 Nonresidential Energy Efficiency Standards. It is very similar to SHGC, but also incorporates the effects of exterior overhangs on solar heat transmission. A window that does not have a low SHGC may still comply with the

standard if an overhang is used to block solar heat transmission during summer months, when space cooling loads are highest. The RSHG of a window shaded by an external overhang is determined by multiplying the SHGC by an overhang factor. If no overhang is present, the RSHG equals the SHGC. Details on this calculation procedure are provided in the 2005 Title 24 Nonresidential Compliance Manual. Overhangs are recommended on south-facing windows. For other orientations, the effects of overhangs on peak cooling loads and annual energy consumption are best analyzed using an energy simulation program.

- Interior shading devices will also reduce the solar heat transmission through windows. However, these are not considered when determining the energy performance of the building enclosure.
- U-factor measures the heat flow through a window assembly due to the temperature difference between the inside and outside. The lower the U-factor, the lower the rate of heat loss and of heating energy consumption. The fenestration frame and glazing edge spacers degrade the U-factor of an insulated glass assembly. So two U-factors are frequently specified: the center of glass (COG) value, which is the U-factor measured at the center of the assembly, and the whole-window value, which is the overall U-factor of the glazing plus the spacer and frame system. (The whole-unit value will be higher than the COG value.) An NFRC rating procedure provides a whole-window U-factor, which includes the effects of the framing. For double-glazed windows, typical whole-window U-factors are between 0.3 and 0.7 Btu/h-ft^2-°F.

Window frames are commonly available in metal, wood, vinyl, and fiberglass. Metal frames conduct the most heat and must have a thermal break for good performance. Insulated vinyl and fiberglass frames have the best energy performance.

Applicable Codes

The California Nonresidential Energy Efficiency Standards (Title 24) apply to schools, and these standards require that roofs, walls, and floors have a minimum level of insulation. The criteria are expressed both in terms of a minimum R-value and a maximum U-factor. The California 2005 Title 24 standards provide a set of pre-calculated U-factors for common construction assemblies. These are included in Joint Appendix IV of the standards, and must be used when using the envelope tradeoff or whole building performance methods to demonstrate code compliance. For unusual constructions not included in Joint Appendix IV, the U-factor may be calculated using acceptable methods shown in Table 22.

The requirements vary by climate region and are summarized in Table 21. Roofs must be insulated with at least R-11 insulation in the south coast region, while a minimum of R-19 is required in the other California climate regions. Walls require R-11 along the coast, but R-13 for the valley, desert, and mountains. R-19 floor insulation is required in the mountains and R-11 in the other climate regions. For relocatable classrooms, a construction that meets the most stringent requirements in Table 21 complies with the standard.

Table 21—Title 24 Standards for Building Envelope

		South Coast		**North Coast**		**Central Valley**		**Desert**		**Mountains**	
Roofs	R-value	11		19		19		19		19	
	U-value	0.076		0.051		0.051		0.051		0.051	
Walls	R-value	11		11		13		13		13	
	Wood frame	0.110		0.110		0.102		0.102		0.102	
	Metal frame	0.224		0.224		0.217		0.217		0.217	
	Metal Building	0.123		0.123		0.113		0.113		0.113	
	Mass (7 ≤ HC < 15)	0.430		0.430		0.430		0.430		0.330	
	Mass (15 ≤ HC)	0.690		0.650		0.650		0.410		0.360	
	Other	0.110		0.110		0.102		0.102		0.102	
Floors	R-value	11		11		11		11		19	
	Mass (7.0 ≤ HC)	0.139		0.139		0.090		0.139		0.090	
	Other	0.071		0.071		0.071		0.071		0.048	
Windows	U-value	0.77		0.77		0.47		0.47		0.47	
	Relative Solar Heat Gain	Non-North	North	Non-North	North	Non-North	North	Non-North	North	Non-North	North
	0%–10% WWR	0.61	0.61	0.61	0.61	0.47	0.61	0.46	0.61	0.49	0.72
	11%–20% WWR	0.61	0.61	0.55	0.61	0.36	0.51	0.36	0.51	0.43	0.49
	21%–30% WWR	0.39	0.61	0.41	0.61	0.36	0.57	0.36	0.47	0.43	0.47
	31%–40% WWR	0.34	0.61	0.41	0.61	0.31	0.57	0.31	0.40	0.43	0.47
Skylight U-factor	Glass w/ curb	1.18		1.42		1.18		1.18		1.18	
	Glass w/o curb	0.68		0.82		0.68		0.68		0.68	
	Plastic w/curb	1.32		1.56		1.32		1.32		1.04	
Skylight SHGC Glass	0%–2%	0.79		0.79		0.46		0.46		0.68	
	2.1%–5%	0.40		0.40		0.36		0.36		0.46	
Skylight SHGC Plastic	0%–2%	0.77		0.79		0.77		0.71		0.77	
	2.1%–5%	0.62		0.65		0.62		0.58		0.58	

Source: California 2005 Nonresidential Energy Efficiency Standards (Title 24)

Fenestration has a large impact on heating and cooling loads. The standards allow total fenestration area to be no more than 40% of the total exterior wall area. Most classroom buildings use less than this limit. The Fenestration Performance Guideline provides thermal performance requirements for windows and skylights. These products must be rated by National Fenestration Rating Council test procedures.

The 2005 Title 24 Nonresidential Standards now require cool roofs for low-sloped buildings. The cool roofs guideline provides information on cool roof applications that are compliant with the new standard.

Design Tools

The thermal performance of construction assemblies can be calculated in many ways. The appropriate method depends on the type and complexity of construction. The basic calculation methods include:

- *Series Calculation Method.* This is the easiest way of calculating U-factor, but its use is limited to constructions that have no framing and are made of homogenous materials.
- *Parallel Path Calculation Method.* This simple extension of the series calculation method can be used for wood-framed assemblies.
- *Effective R-value (Isothermal Planes).* This method uses principles similar to the series and parallel path calculation methods, and is appropriate for construction assemblies such as concrete masonry and metal-framed walls/roofs where highly conductive materials are used in conjunction with insulated or hollow cavities.
- *Two-Dimensional Calculation Method.* Two dimensional heat flow analysis may be used to accurately predict the U-factor of a complex construction assembly. Two dimensional heat flow analysis is also the best method for determining whole-window U-factors. Calculating two-dimensional heat flow involves advanced mathematics and is best performed with a computer.
- *Testing.* This is the most accurate way to determine the U-factor for all types of construction, except slabs-on-grade. But because a large variety of possible construction assemblies exist, it is costly and time consuming and impractical to test them all. Calculation methods are usually more cost-effective.

Table 22 provides guidelines on which method can be used with different types of construction assemblies. For California, these U-factor calculation methods only apply for construction assemblies not covered in Joint Appendix IV of the Title 24 standards.

Table 22—Procedures for Determining U-Factors for Opaque Assemblies

	Series Calculation Method	Parallel Path Calculation Method	Effective R-value (Isothermal Planes)	Two-dimensional Calculation Method	Testing
Roofs					
Insulation above Deck	✓			✓	✓
Attic (wood joists)		✓		✓	✓
Attic (steel joists)			✓	✓	✓
Other				✓	✓
Walls					
Mass			✓	✓	✓
Wood Framed		✓		✓	✓
Steel Framed			✓	✓	✓
Other				✓	✓
Below-Grade Walls					
Mass			✓	✓	✓
Other				✓	✓
Floors					
Mass	✓		✓	✓	✓
Steel Joist			✓	✓	✓
Wood Framed		✓	✓	✓	✓
Other				✓	✓

Computer Programs

The calculation methods described above are implemented in a number of design tools and computer programs.

- *The EZFrame program*, available from the California Energy Commission (CEC), can be used to calculate the U-factor of metal framed wall and roof constructions and accounts for many features such as the gauge of the steel used for framing members, the percent of knockouts in the web, and insulating tape between the framing members and the sheathing. The cost is $14. For more information, contact the CEC. Tel: (916) 654-5106 or (800) 772-3300. Web site: www.energy.ca.gov/efficiency/computer_prog_list.html. (The list of approved programs for the upcoming 2005 Title 24 standards is under development at the time of press.).
- *The Therm program*, available from Lawrence Berkeley National Laboratory is designed primarily to analyze window frames, but can be used for any type of two-dimensional heat transfer analysis. This program can be downloaded from windows.lbl.gov/software/therm/therm_getacopy.htm.
- *The WINDOW 5.2 program*, available from Lawrence Berkeley National Laboratory can be used to analyze thermal performance of window assemblies. It uses two-dimensional heat transfer calculation methods consistent with NFRC rating procedures. It has the flexibility to analyze combinations of glazing products, frames, spacers and gas fills, at different orientations (tilts). It also can provide surface temperature predictions for different environmental conditions, which is useful when considering thermal comfort. For more information, see windows.lbl.gov/software/window/window.html.

- General-purpose energy simulation programs such as DOE-2 and EnergyPlus can be used to calculate the energy savings of various construction assemblies. With these programs, the dynamics of heat transfer are modeled. In fact, EnergyPlus models the temperature gradient in constructions. DOE-2, on the other hand, uses a more simple response factor method.

Pre-Calculated Data

The U-factor of common constructions has been calculated and values are published in a number of sources.

- Joint Appendix IV of the 2005 California Nonresidential Manual has a wealth of useful data, including R-values of common materials, pre-calculated U-factors, and other data. The manual can be downloaded from www.energy.ca.gov/title24/nonresidential_manual/index.html.
- Appendix A of ANSI/ASHRAE/IESNA Standard 90.1-2001 has published values in both inch-pound and metric (SI) units. Constructions include walls, roofs, floors, slabs, and below-grade walls. These values are also contained in the EnvStd 4.0 computer program, which can be downloaded from www.archenergy.com/products.

Indoor Air Quality and Moisture

It is extremely important to provide an exterior weather barrier with drainage plane to prevent moisture from entering construction cavities. Wet or damp construction cavities, attics, and plenums are a major source of mold and can contribute significantly to indoor air quality (IAQ) problems. In addition, moisture can damage the structure and degrade the performance of insulation, increasing energy and operating costs. For example, the California Air Resources Board reports that most of the IAQ complaints that they receive with regard to schools are related to leaky roofs that have resulted in the growth of mold in a plenum or attic space.

Water vapor can also enter construction cavities through a process of moisture migration. Moisture migrates from the warm and humid side of the construction assembly to the cold dry side of the construction assembly. The vapor cools as it moves through the wall and may condense into water molecules that can accumulate to cause damage and create mold. To prevent water vapor migration, framed walls, floors, and roofs should have a vapor barrier on the warm moist side. For California climates, this means that the vapor barrier should be on the interior side. Vapor barriers also are available as part of most insulation products and consist of an asphalt-impregnated paper or metal foil. Care should be taken during construction to ensure that this vapor barrier is continuous, tightly secured at the framing members, and not damaged. Special care should be taken in lockers, showers, food preparation areas, and other spaces that are likely to have high humidity.

In addition to correctly installing a vapor retarder, it is important to provide adequate ventilation to dry spaces where moisture can build up. Most building codes require that attics and crawl spaces be ventilated, and some require a minimum 1-in. clear airspace above the insulation for ventilation of vaulted ceilings. Even the wall cavity may need to be ventilated in extreme climates. An infiltration barrier should be installed under slabs with ventilated gravel in areas with soil gas contaminants like radon or methane.

Insulation Protection

Insulation should be protected from sunlight, moisture, landscaping equipment, wind, and other physical damage. Rigid insulation used at the slab perimeter of the building should be covered to prevent damage from gardening or landscaping equipment. Rigid insulation used on the exterior of walls and roofs should be protected by a permanent waterproof membrane or exterior finish. In cold climates, mechanical or other equipment should not be installed in attics, since it can generate heat and cause uneven snow melting and ice dams. For moderate climes, access to equipment installed in attic spaces should be provided in a way that will not cause compression or damage to the insulation, which may mean using walking boards, access panels, and other techniques to prevent damage to the insulation.

In situations where insulation is left exposed (including return air plenums), fiberglass insulation products should be encapsulated in a manner that prevents fibers from becoming airborne. To maintain a continuous vapor barrier, all seams should be sealed with tape or mastic. In this application, simply stapling the insulation is not adequate.

Acoustic Performance

Acoustic design is a cross-cutting issue: the choice of interior surfaces and finishings, HVAC equipment location and selection, ductwork, diffuser selection and site layout are all important design considerations. The design of the building enclosure and choice of insulation also affect the acoustic performance of school facilities. The 2002 voluntary ANSI Standard S12.60 provides “best practice” recommendations for acoustic performance. Best practice design will yield a background noise level of 35 decibels (dBA) or lower. Decibels are a measure of the sound pressure level, measured on a logarithmic scale. By comparison, a whisper has a sound level of about 20 dBA, speech range of about 50–70 dBA, and a loud rock concert of 120 dBA. For a teacher to be intelligibly heard, the teacher’s voice must be at least 10 dB higher than the background noise level in the classroom.

For the building enclosure, one means of reducing noise levels in the classroom is to reduce the sound transmission from adjacent spaces and from outdoors. The ability of a wall assembly to limit sound transmission between spaces is known as the *sound transmission class* (STC). This is a measure of the noise reduction in decibels, weighted over frequencies common in human speech (125 Hz–4000 Hz). So this rating does not account for low-frequency noise such as that generated by HVAC equipment or musical instruments. Best practice for construction assemblies requires an STC of 50–60. The higher the rating is, the better the sound reduction. For example, an exterior noise source of 80 decibels will result in an interior sound level of 30 decibels, when transmitted through a wall with an STC rating of 50. Modern construction that uses lightweight materials for interior walls provides only limited sound reduction. Providing a layer of gypsum board on both sides of a stud wall, with staggered joints, will reduce sound transmission. Other options for reducing sound transmission are to use metal studs, to include an air space in the cavity or to increase the wall mass. A simple test is to turn on a television in a classroom at a level that can be easily heard, and to check if the sound can be heard or program content understood in adjacent classrooms. Make sure that partition walls extend up to the structural deck and do not terminate at suspended ceilings.

Design the exterior building enclosure to block external noise such as that generated from traffic or mechanical equipment. Adding mass to exterior walls, such as increasing the thickness of a concrete masonry unit wall, will reduce sound transmission from the outside. Using high performance windows and designing to minimize air infiltration will also help to minimize impacts of external noise.

Material Efficiency and Other Environmental Considerations

One of the most effective ways to achieve material efficiency in a building is to reuse all or part of an existing building enclosure. This reduces solid waste produced by a project and avoids the environmental burdens associated with production and delivery of materials for a new building enclosure. Saving the building enclosure, however, may not be appropriate if the existing structure is not energy efficient and cannot be adequately upgraded to meet high performance objectives.

When designing a new building enclosure, material efficiency can be achieved by:

- Using panelized, pre-cut, and engineered construction products.
- Designing with standard dimensions to reduce on-site waste.
- Designing a compact building (this also reduces impervious surface on the site, but may conflict with daylighting objectives).
- Planning for future adaptability to extend the life of the building.
- Choosing durable materials and systems.

In addition, building enclosure and insulation materials exist that are recyclable, include recycled or resource-efficient content, or have other environmentally preferred characteristics. The materials may, for example, avoid introducing toxins into the building or natural environment, or they may be produced using sustainable methods. In addition to the design strategies above, refer to the following Table 23 for some easily achievable strategies that will improve the sustainability of the building enclosure and insulation.

When weighing options for environmentally friendly insulation, it is important to specify products that have been independently tested or certified. Scientific Certification Systems (SCS) verifies claims of the recycled content of insulation products. CHPS maintains a list of insulation products that have met the Section 01350/DHS Standard Practice standard for low VOC emissions, as tested by independent agencies. More information is available at the CHPS Web site (www.chps.net).

For specific product recommendations, also see GreenSpec: The Environmental Building News Product Directory and Guideline Specifications, available at www.buildinggreen.com/, and OIKOS's Redi Guide

(Resources for Environmental Design Index), available from Iris Communications, (800) 346-0104, www.oikos.com/.

Table 23—Strategies for Constructing Resource-Efficient Building Enclosures

Building Component	Strategies	Environmental Benefits & Considerations
Foundation and Concrete Work	For concrete materials, specify fly ash as replacement, not addition. 10%–25% replacement is commonly specified, but higher percentages are possible, depending on application.	Formerly landfilled as industrial waste, fly ash is now used to replace energy-intensive Portland cement in concrete mix. Fly ash adds workability and strength. Consider using "high volume" fly ash concrete (with 50% fly ash).
	Use autoclaved and/or aerated concrete for appropriate concrete applications.	Aerated concrete is lighter and has better insulating properties than standard concrete.
	Prohibit dumping concrete waste anywhere intended to be pervious.	Prevents degradation of the site and permits infiltration.
	Use steel rather than wood forms.	Although energy intensive, steel is reusable, contains recycled content and can be recycled at the end of service life.
	If wood forms are used, reuse wood in framing and sheathing.	Reduces resources used. Reduces waste.
	Use low and non-toxic form releases. Bio-based products are available.	Prevents soil contamination, and reduces human health risk. Promotes worker safety. Water-based products should be protected from freezing during storage.
	Use expansion joint fillers with recycled content.	Appropriate use of recycled, relatively low-strength materials, such as waste cellulose from recycled newspapers.
	Use rebar supports with recycled content. DOT-approved products are available with 100% recycled content, including engineered plastics and fiberglass.	Rebar supports in concrete form-work have minimal structural requirements; appropriate use of recycled waste plastic.
	If using ICFs, use options with ozone-friendly foam ingredients. (ICFs are permanent forms with integral insulation that are not disassembled after the concrete is cured. Note: not all ICFs are alike; field R-values can differ significantly so rely on results from completed projects.)	ICFs can provide significant improvements in energy efficiency and can reduce the use of energy-intensive Portland cement. Using ozone-friendly options (with EPS foam) eliminates a source of global warming.
	Use sill sealers to limit infiltration at the foundation.	Increases energy efficiency.
	Use sub-slab ventilation in areas with radon or potential soil gas submissions.	Improves indoor air quality.
Masonry Walls	Use mortar dropping control product to prevent blocking of weep holes. Product available with 100% recycled polyethylene.	Maintains air flow and allows moisture migration from behind masonry veneer facades. Improves building durability.
	For CMUs: maximize recycled content. Typically available with 10% recycled content.	Reduces resources used to produce new CMU material. No difference in product performance or application. Products are high strength, high fire resistance, and highly durable.
	For CMUs: use CMUs containing fly ash.	Formerly landfilled as industrial waste, fly ash is now used to replace energy-intensive Portland cement in concrete mix. Fly ash adds workability and strength.
	For CMUs: consider using lightweight CMUs.	Reduces transportation-related impacts.
	For CMUs: pull watermark line down below window framing to eliminate finishing details.	Reduces maintenance over the life of the building.
	For CMUs: do not paint, order with color.	Avoids resources used to produce paint. Avoids use of VOC-emitting paints generally used to finish CMUs. The pigments typically used in colored CMU are nontoxic and contain none of the solvents associated with painting and re-painting. Products are low maintenance.
	Use fireproofing available with recycled EPS foam and recycled newsprint.	Traditionally, products contained fiberglass and asbestos for this use. More benign products that make efficient use of recycled materials are preferable.

Building Component	**Strategies**	**Environmental Benefits & Considerations**
Wood Framing	Use advanced or intermediate framing systems where applicable and accounting for seismic requirements for building site. Example framing elements include 24 in. on-center framing, insulated headers, two stud corners with drywall clips, ladder partitions. References: *Builder's Guide*—Building Science Corporation, and *Efficient Wood Use in Residential Construction*—Natural Resources Defense Council.	This both allows for more insulation, less "cold" spots, and increased wood efficiency, thus improving both energy and materials efficiency.
	Use engineered wood products in place of dimensional lumber such as floor joists and roof joists.	Engineered wood products are lighter weight and use fewer resources for the same function as dimensional timbers.
	Use wood certified with Forest Stewardship Council (FSC) or Scientific Certification Service (SCS). A variety of certified dimensional and engineered wood products are available.	Prevents degradation to forest and wildlife habitat.
Siding	Use fiber cement siding. Most available factory primed; suggest back priming. Proper painting is important for the siding's long-term durability.	Reduces virgin wood use and can be a durable option.
Roofing	Use metal roofing.	Includes recycled content, is durable, and can be recycled at the end of service life.
	Use non-PVC options for membrane roofing.	Avoids the environmental impacts of PVC manufacturing.
	Consider a green or vegetated roof system for low-slope roofs. These roofs contain plants in a lightweight soil to absorb and slow runoff that would otherwise pour from rooftops. These roof systems typically consist of drainage, soil, and vegetation layers. Be sure to use native plants and grasses in green roof systems.	Can absorb and slow rainwater runoff to reduce peak loads on sewer systems. Helps reduce building heat gain and prevents urban heat islands. Plantings also absorb carbon dioxide. Helps conserve energy in the winter by insulating rooftops. Green roofs, however, require structural steel to support their weight. Because steel has high-embodied energy, this may offset some of the environmental benefits of using green roofs.
Moisture and Waterproofing	Sealants and repellants: Limit use of sealants through proper detailing. Use least-toxic options. Avoid products containing methylene chloride, chlorinated hydrocarbons, aromatic and aliphatic solvents, styrene butadiene, or products containing bactericides and fungicides classified as phenol mercury acetates, phenol phenates, or phenol formaldehyde.	Combining good detailing and low toxicity will prevent air quality problems while promoting long service life of the building.
	Do not rely on caulking for waterproofing. Proper flashing will prevent water from entering the building.	In addition to adding durability to shell, proper flashing prevents mold and mildew build up, reducing health risk.
	If using a vapor retarder, select film available with up to 100% LDPE (plastic).	Utilizes plastic waste that would otherwise be landfilled. Reduces resources required to produce virgin-based material.
	Use cellulose insulation produced with 100% recycled newsprint.	Utilizes paper waste that would otherwise be put in landfills.
	If using rigid insulation with polyisocyanurate foam, use ozone-friendly option.	Prevents further degradation of the earth's atmosphere through global warming.
Exterior Doors *	Use doors produced with reclaimed lumber.	Reduces pressure on timber supply, as well as degradation of forest habitat.

** for window recommendations, see Daylighting chapter*

Source: Adapted from GreenSpec: The Environmental Building News Product Directory and Guideline Specifications

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Seep, Benjamin, et. al. 2000. "Classroom Acoustics II," *Classroom Acoustics Publications* Acoustical Society of America. This document links good acoustical design with learning and teacher performance.

Additional Information

Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747 Phone: 516.576.2360, Fax: 516.576.2377

United States Access Board, 1331 F Street N.W., Suite 1000, Washington, DC 20004-1111. 800 872-2253 (v) 800 993-2822 (TTY) fax: 202 272-0081. Information is available online at www.quietclassrooms.org.

Information on STC and typical performance of common construction assemblies can be found at: www.stcratings.com.

EnergyPlus is a building energy simulation program for modeling building heating, cooling, lighting, ventilating, and other energy flows. The program provides capabilities for modeling the performance of emerging HVAC technologies, and provides thermal comfort predictions. More information can be obtained from the U.S. Department of Energy's Building Technologies Program, or online at www.eere.energy.gov/buildings/energyplus/.

GUIDELINE IN1: WALL INSULATION

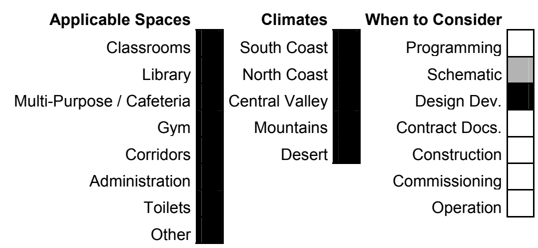
Recommendation

Insulate exterior walls at a level appropriate for each class of construction and climate.

Class of Wall	South Coast, North Coast Climates	Central Valley, Desert, Mountain
Wood-Framed Walls	Insulate 2x4 wood-framed walls with R-13 fiberglass batt insulation or use other insulating materials with a similar thermal resistance. When 2x6 wood framing is needed for structural (or other) reasons, insulate with at least R-19 fiberglass insulation.	Use 2x6 wood studs and advanced framing techniques to increase the percent of insulated cavity in walls. Insulate the cavities with R-19 batt insulation or other materials with a similar thermal resistance.
Steel-Framed Walls	Insulate 2x4 steel-framed walls with R-13 fiberglass batt insulation or other materials with a similar thermal resistance. When 2x6 framing is needed for structural (or other) reasons, insulate the cavities with at least R-19 fiberglass insulation.	Provide a continuous thermal barrier by installing a layer of continuous insulation on either the exterior or interior surface of the wall. Protect the insulation from physical damage and from moisture penetration.
Mass Walls	Shade mass walls from exposure to direct sun. Insulation is marginally cost effective in coastal climates.	Insulate mass walls either by furring on the interior surface, with an exterior insulation finish system (EIFS), or with an integral insulation system.

Figure 106—Insulation

Source: CertainTeed



Description

The construction of exterior walls affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood-framed, steel-framed, or mass) is usually determined by requirements for fire separation between spaces, durability, or other issues. The recommended insulation levels for these classes are based on life-cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates and less in more temperate climates.

Concepts of thermal heat transfer are presented in this chapter’s Overview and should be reviewed, since they apply to walls as well as other building enclosure components.

Applicability

These recommendations apply to all exterior walls in all spaces that are heated or cooled. Design decisions that affect wall thickness must be considered in the schematic design phase of the project.

Applicable Codes

For both metal-framed and wood-framed walls, the California Building Code requires R-11 insulation in the north and south coast climates, and R-13 insulation in the other climate zones. Criteria for framed walls are provided as both a minimum R-value and a maximum U-factor. Only U-factor criteria are provided for mass walls and less insulation is required than for framed walls. See the Overview to this chapter.

Fire protection codes (the California Building Code) require noncombustible construction for certain classes of schools, which prohibits wood framing. In some instances, walls must provide a 4-hour fire separation near property lines and in other applications, which generally requires mass walls.

Structural and seismic safety requirements often dictate the thickness and spacing of framing members. For masonry walls, they usually require at least partial grouting of all exterior walls.

Integrated Design Implications

Well-insulated and sealed walls can reduce drafts and thermal loads in buildings, which can result in smaller HVAC equipment and reduced costs.

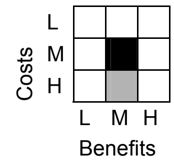
Insulation provides more than a barrier to heat flow: it can impede water vapor transmission or air infiltration, reduce noise transmission, and provide fire protection.

Figure 107—Rigid Insulation

Source: CertainTeed

Cost Effectiveness

The cost of insulating the cavity of wood- and steel-framed walls is low. Fiberglass batt cavity insulation is typically much cheaper than rigid insulation. Approximate installed costs of batt insulation are \$0.48/ft^2 for R-11 batts to \$1.20/ft^2 for R-38 batts. For rigid continuous insulation, expanded polystyrene (EPS) foam is less expensive than polyurethane or polyisocyanurate, at approximately \$2.00/ft^2 for EPS vs. \$3.75/ft^2 for urethane.



However, insulating mass walls is more difficult and expensive. Insulating the cavity of mass walls is not very effective because of thermal bridges across the concrete webs and seismic safety requires that most of the hollow cells be grouted and reinforced. The most effective way to insulate mass walls is to use an EIFS, which costs \$7/ft^2 for 1-in. insulation and \$8/ft^2 for 2-in. insulation. If budget permits, this is the preferred method, since the benefits of the thermal mass are maximized. As an alternative, steel or wood furring can be used on the interior of the wall, batt insulation can be placed in the cavities between the furring strips, and gypsum board can be used as the interior finish.

Benefits

Insulating walls has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Greater acoustic separation is provided from the outdoors.
- Masonry walls can be insulated on the interior, but the benefits of thermal mass are mostly lost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.

Design Tools

The Overview section of this chapter has a discussion of methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass walls, because of the time delays and dynamic effects inherent with this type of construction.

Design Details

For framed walls, provide a continuous vapor barrier on the inside surface of walls. If the vapor barrier that comes with batt insulation is used, then the paper or foil should be stapled to the face of the studs, not the inside. This will provide a more secure and continuous vapor barrier and will reduce compression of insulation.

For wood framing in the central valley, desert, and cold climates, use 2x6 framing. The studs should be spaced at 24-in. o.c., the headers over doors and windows should be insulated with rigid insulation, and minimum wood framing should be used at corners, wall intersections, and openings.

Concrete masonry unit (CMU) construction is high-strength, fire-resistant, durable, and economical. Improvements in manufacturing and quality control of colored concrete masonry ensure greater CMU uniformity and color consistency, reduced porosity, and reduced shrinkage. In addition, high-performance water repellents can be applied to walls or added to the concrete and mortar mixes so that it is unnecessary to paint or coat the units with block filler to avoid water penetration. EIFS systems used with mass walls should be installed according to manufacturers' instructions. Make sure that the exterior finish is durable and weather resistant.

Electrical and mechanical equipment should be minimized for exterior walls. Equipment such as electrical outlets and other recessed equipment can create thermal bridges and increase infiltration. Adding either an interior or exterior insulation layer will greatly reduce the heat transfer through the masonry wall. The Title 24 Joint Appendix IV Table IV.19 contains effective R values for insulation installed in furring spaces. For example, 2x4 framing with R-11 batt insulation has an effective R-value of 9.3. A 10-in. solid-grout medium weight concrete masonry unit has a U-factor of 0.59 (from Table IV.12 of Joint Appendix IV) or an R-value of 1.7. When the interior furring and insulation layer is added to the CMU, the combined assembly has an R value of 11.0, or a U-factor of 0.091. Thus, adding the interior furring and insulation reduces the rate of steady-state heat transfer by more than 80%. Refer to the Overview section for a review of fundamental concepts of heat transfer through building components.

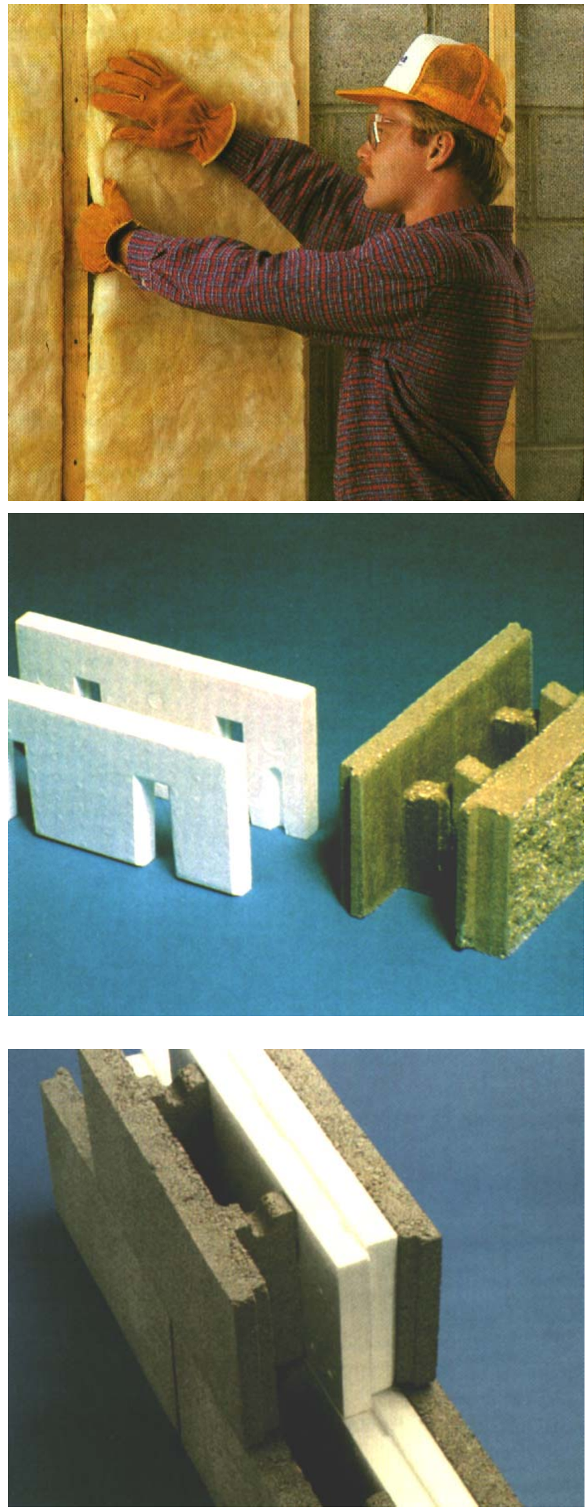


Figure 108—Integral Mass Wall Insulation Techniques
Source: Korfil CBIS

For wood framed walls, use wood products that are produced through sustainable forest practices. Require that framing members be certified by the Forrest Stewardship Council.

For metal-framed walls, specify that the steel used for manufacturing have 30% recycled content.

Insulation Choices

Installed cost, ease of installation, the use of recycled content, fire and safety issues, water permeability and performance degradation affect the choice of insulation.

Batts are installed between frame stud joists and beams of wood-framed and metal-framed walls. This type allows for easy installation, but gaps and compression may lower the effective R-value.

- Fiberglass batts are installed between frame stud joists and beams. They offer a low material and installed cost and good fire protection.
- Cotton batts have a good insulating value per inch and a high recycled content, and provide less exposure of harmful materials to installers. These are only offered as unfaced insulation and require a separate vapor retarder.
- Plastic fiber (PET) batts are environmentally friendly alternative, with less recycled content and reduced skin irritation for the installer. However, this product melts at a lower temperature than fiberglass and is more difficult to handle.
- Loose-fill (“blown-in”) insulation can be used for retrofits of existing walls and hard-to-reach places.
- Cellulose has a high R-value per in, and forms a good air barrier due to its high density. It is also made from a very high recycled content. Its weight may cause settling, lowering its insulation effectiveness over time. Special fire retardants are required with this type of insulation.
- Fiberglass loose-fill insulation is also available. This also provides a good air barrier and has less settling than cellulose. Installed costs are slightly higher than cellulose insulation.
- Mineral wool (rock or slag wool) is a non-combustible product that provides good sound attenuation. With this insulation there is potential for emissions of respirable particles.

Spray-in-place foams can be used with steel framing. This insulation type provides a good air barrier and good coverage near obstructions, at a higher cost than batt insulation. The insulating material can be polyurethane, wet-spray cellulose, spray-in fiberglass, or icynene foam. Approximate installed costs are $1-2/ft^2.

Rigid foam panels provide a continuous insulation barrier and air barrier. They are used with metal framed walls to provide a continuous insulation layer. Common materials are EPS, polyisocyanurate (“polyiso”) and polyurethane. EPS foam boards are the most common; they are relatively low cost, have good moisture resistance, and maintain their rated R-value. Polyiso panels have a higher R-value per inch and good structural strength, but tend to lose their insulating properties over time, and are more expensive. Extruded polystyrene foams are suitable for below-grade walls, and have excellent moisture resistance.

Structural panels, or structural insulated panels (SIPs) are prefabricated panels, typically consisting of a rigid foam insulation surrounded by an interior and exterior layer of oriented strand board for structural strength. These provide a continuous insulation barrier and allow for rapid construction. The insulating material may be EPS foam or polyisocyanurate. The R-value of the whole assembly varies from R-11 to R-38. More information can be found in Joint Appendix IV of the California 2005 Title 24 Nonresidential Standards.

Operation and Maintenance Issues

Exterior and interior wall finishes must be maintained. For interior finishes, maintenance is important for both aesthetic reasons and lighting reasons—light colors should be maintained to enhance the performance of the electric lighting and daylighting systems. Exterior surfaces should be maintained to be waterproof or water resistant, and secure. This is important to prevent water from entering construction cavities, which can cause the growth of mold, damage the structure, and deteriorate the performance of thermal insulation. Mold can be a major source of indoor air quality problems and needs to be avoided.

Thermographic measurement techniques can be used to assess the condition on insulation in walls. Cold spots in the wall indicate where insulation may be compressed or damaged from moisture penetration.

Commissioning

Verify that the specified levels of cavity and/or continuous insulation are installed. Check for gaps in insulation or compression near framing members or other penetrations.

The use of some insulation materials, such as cellulose or mineral fiber, phenolic or extruded polystyrene foams, polyurethane, and polyisocyanurate insulation must comply with the California Quality Standards for Insulating Materials (CCR, Title 24, Part 12). A list of compliant insulation products can be obtained from the Insulation Program of the Department of Consumer Affairs. Installations of insulation must also meet fire safety requirements.

References

Also see the Overview section of this chapter.

North American Insulation Manufacturer's Association (NAIMA). 2004. *Facts #35: An Insulation Comparison*. www.naima.org/pages/resources/library/html/BI475.HTML, or www.naima.org/pages/resources/library/pdf/BI475.PDF

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Additional Information

American Concrete Institute (ACI), PO Box 9094, Farmington Hills, MI 48333-9094. Tel: (248) 848-3800. Fax: (248) 848-3801. Web site: www.aci-int.org/.

National Concrete Masonry Association (NCMA). 2302 Horse Pen Road, Herndon, VA 20171-3499. Tel: (703) 713-1900. Fax: (703) 713-1910. Web site: www.ncma.org/. The Web site provides a list of certified masonry consultants.

Cellulose Insulation Manufacturers Association, www.cima.org.

GUIDELINE IN2: ROOF INSULATION

Recommendations

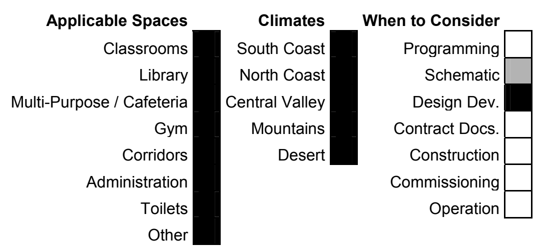
Insulate roofs at a level appropriate for each class of construction and climate. The recommended roof insulation depends on the class of construction and the climate. See also the guidelines for cool roofs and radiant barriers.

Roof Class	South Coast, North Coast	Central Valley, Desert, Mountain
Insulation above Deck Including Mass	Provide a continuous layer of R-13 rigid insulation over the structural deck and protect this with a durable weatherproof membrane.	Provide a continuous layer of R-19 rigid insulation over the structural deck and protect this with a durable weatherproof membrane.
Wood Framed, Attics and Other	Install R-30 blown in insulation in ventilated attics. Use R-30 batt insulation in other framed cavities.	Install R-38 blown-in insulation in ventilated attics. Use R-38 batt insulation in other framed cavities.

Figure 109—Blown-In Insulation

Source: CertainTeed

Description



The construction of roof assemblies affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood-framed, steel-framed, or mass) is usually determined by requirements for fire separation between spaces, durability, or other issues. The recommended insulation levels for these classes are based on life-cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates, with less in more temperate climates.

Concepts of thermal heat transfer are presented in the Overview to this chapter and should be reviewed, since they apply to roofs as well as other building enclosure components.

Applicability

This roof insulation guideline is applicable for all spaces in schools that are heated or cooled. The class of construction is usually determined in schematic design, but the insulation level can be set in design development or even contract documents.

Applicable Codes

The California Building Code requires R-11 in the south coast climates and R-19 insulation in the other climate zones. Criteria are provided as both a minimum R-value and a maximum U-factor. See the Overview to this chapter for a more comprehensive discussion of the codes applicable in California.

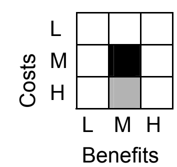
Fire protection codes (the California Building Code) require noncombustible construction for certain classes of schools, which may prohibit wood framing in roof assemblies.

Structural and seismic safety requirements often result in the roof being used as a structural diaphragm to resist twisting or buckling during earthquakes or extreme wind.

The North American Insulation Manufacturers Association (NAIMA) has published a standard for fiberglass insulation for metal buildings, NAIMA 202-96. Insulation for metal buildings must have higher tensile strength and better recovery after compression.

Integrated Design Implications

Well-insulated roofs and roof cavities can reduce drafts and thermal loads in buildings. HVAC ducts located in ceiling cavities can be leaky and can be a significant component of thermal loads. These losses are far less significant when ducts are located in sealed and insulated ceiling cavities. Reduced loads can result in smaller HVAC equipment and reduced costs.



Cost Effectiveness

The cost of roof insulation varies with the class of construction. Insulating attics and the cavity of wood- and steel-framed roof assemblies is low since labor is minimal and the roof cavity is readily accessible during construction. Rigid insulation installed over structural decks is more expensive due to construction details and added insulation cost.

Benefits

Insulating roofs and ceilings has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.

Design Tools

This chapter's Overview has a discussion of methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass roofs, because of the time delays and dynamic effects inherent with this type of construction.

Design Details

The construction of the roofing membrane is important in controlling water and moisture and ensuring durability. The roof itself must be designed to support loads from foot traffic, wind, and thermal cycles. The selection of a roofing type depends on the roof structure, height, wind load, and installation requirements. For low-sloped roof construction that is common with classrooms, there are three common roof types. Built-up roofing (BUR) consists of several layers of fiberglass embedded with asphalt, bound together with hot tar. The tar binds with the asphalt to create a continuous membrane. Modified bitumen roofs contain a polymer additive to the asphalt, for good resistance to thermal shock, punctures and tears. The additive also allows for an installation without the use of hot tar. Single-ply roofs reduce the dependence on the contractor for a quality installation. More information on design issues and installation details can be obtained from the National Roof Contractors Association (NRCA).

Insulation installed in exposed applications or in return air plenums should be either encapsulated or otherwise sealed from contact with moving air.

Make sure that insulation is dry before walls or other cavities are enclosed. Moisture in building cavities can be a source of mold, which can cause building damage and indoor air contamination.

Do not install insulation over suspended ceilings, because the insulation's continuity is likely to be disturbed by maintenance workers. Also, a suspended ceiling is a poor barrier to infiltration. If the insulation is located at the ceiling, many building codes will consider the space above the ceiling to be an attic and require that it be ventilated to the exterior. If vented to the exterior, air in the attic could be quite cold (or hot) and the impact of the leaky suspended ceiling would be worsened.

Use type IC light fixtures in insulated gypsum board ceilings.

Consider recycled insulation materials for attics and other places where loose-fill insulation is used. If cellulose (recycled paper) is used, make sure that the chemicals used as a fire retardant contain no VOCs and are not a possible source of pollution.

Operation and Maintenance Issues

The roof membrane must be maintained to prevent moisture from entering the roof cavity. Moisture in ceiling/roof constructions is a common source of mildew, which can cause serious IAQ problems. Insulation materials themselves require no maintenance.

Emissions from hot tar used for built-up roofs and modified bituminous roofs can be a problem when application is done for year-round schools. One method to manage emissions is to stage the kettle in a restricted area away from children and to use either a filter, an after-burner, low-fuming asphalt or some other odor control mechanism during application. Some fume recovery systems are able to pass gases through a thermal converter, where they are mixed with fresh air and superheated to avoid fumes and odors. The use of low-fuming asphalt also helps to eliminate some odor and fume at the point of application.

Commissioning

No commissioning is needed for roof insulation systems.

References

See the Overview section of this chapter.

National Roofing Contractors Association (NRCA). 2001. *Roofing and Waterproofing Manual*. 5th ed. Rosemont, Illinois: NRCA. Refer to the guideline on moisture control for information on how to design the roof to control moisture that has entered the roof assembly.

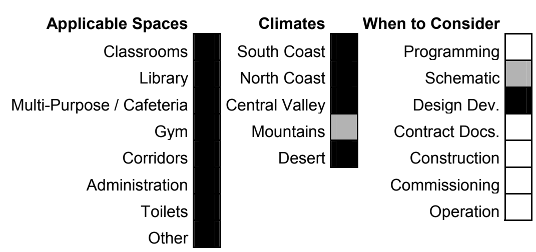
GUIDELINE IN3: COOL ROOFS

Recommendation

In air conditioned buildings, use a roof surface that is light in color (high reflectance), yet has a non-metallic finish (high emissivity). Asphalt roofs with a cap sheet and modified bitumen roofs should be coated with a material having an initial reflectance greater than 0.7 and an emittance[39] greater than 0.8. Single-ply roofing material should be selected with the same surface properties.

Figure 110—White Single Ply Membrane with Heat-Welded Seams

Source: BondCote Roofing Systems



Description

Solar gain on roofs is a significant component of heat gain and using materials that have a high reflectance and a high emittance can significantly reduce the load. The high reflectance keeps much of the sun's energy from being absorbed. The high emittance allows radiation to the sky. Cool roofs are typically white and have a smooth texture. Commercial roofing products that qualify as cool roofs fall in two categories: single-ply and liquid-applied. Examples of single-ply products include:

- White PVC (polyvinyl chloride).
- White CPE (chlorinated polyethylene).
- White CPSE (chlorosulfonated polyethylene, e.g., Hypalon).
- White TPO (thermoplastic polyolefin).

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39 Heat radiated from a roof surface is proportional to the 4th power of the absolute temperature and depends on emittance. Emittance is the ratio of radiant heat flux emitted by a specimen to that emitted by a black body at the same temperature and under the same conditions.

Liquid-applied products may be used to coat asphalt cap sheets, modified bitumen, and other substrates. Products include:

- White elastomeric coatings.
- White polyurethane coatings.
- White acrylic coatings.
- White paint (on metal or concrete).

Cool roofs are becoming available in different colors. Table 24 shows reflectance and emittance for some typical roofing products.

Table 24—Cool Roof Options

Roof Type		Reflectance	Emittance	Cost ($/ft²)
Built-up	With white gravel	0.30–0.50	0.80–0.90	1.2–2.15
	With gravel and cementitious coating	0.50–0.70	0.80–0.90	1.2–2.15
	Smooth surface with white roof coating	0.75–0.85	0.85–0.95	1.2–2.15
Single-Ply	White (EPDM, CPE, CSPE, PVC)	0.70–0.78	0.85–0.95	1.0–2.05
Modified Bitumen	white coating over a mineral surface	0.60–0.75	0.85–0.95	1.5–1.95
Metal Roof	white, painted	0.60–0.70	0.80–0.90	1.8–3.75
Asphalt Shingle	white	0.25–0.27	0.80–0.90	1.2–1.5
Liquid Applied Coating	Smooth white	0.70–0.85	0.85–0.95	0.60–0.80
	Smooth off-white	0.40–0.60	0.85–0.95	0.60–0.80
	Rough off-white	0.50–0.60	0.85–0.95	0.60–0.80
Concrete Tile	White	0.65–0.75	0.85–0.90	3–4
	Off-white coating	0.65–0.75	0.85–0.90	3–4
Cement Tile		0.70–0.75	0.85–0.90	3–4

Source: Akbari, H., et al., "Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements," Code Change Proposal, PG&E, 2002

A new single rating for the thermal performance of cool roofs is the Solar Reflectance Index (SRI). This incorporates the effects of both solar reflectance and emissivity on the thermal performance of a cool roof. (This rating is being considered for the upcoming LEED 2.2 criteria.) SRI indices for cool roofs can be calculated from the Cool Roof Rating Council's CRRC-1 test procedure results. Specify cool roofs with an SRI index of 79 or higher.

An alternative method of reducing roof heat gain is to plant natural vegetation on the roof, commonly known as green roofs. Green roofs provide multiple benefits: they reduce solar heat gain and prevent rain and moisture from penetrating the roof membrane. Their application in schools may be limited if mechanical equipment is located on the roof.

Applicability

Cool roofs are applicable to all spaces in schools and to all California climates. The benefits are less, however, in the cold regions. In order to take advantage of equipment downsizing, cool roofs should be considered in the schematic design phase.

Applicable Codes

The 2005 California Energy Efficiency Standards now require cool roofs on low-sloped roofs[40] of commercial buildings. The cool roof must be certified by the Cool Roof Rating Council with a minimum initial solar reflectance (□) of 0.70 and minimum initial thermal emittance (□) of 0.75. This organization has a rating procedure, CRRC-1, for certifying cool roofs. The standard allows for a tradeoff for cool roof products such as metallic surfaces that have an emittance less than 0.75 if their solar reflectance exceeds 0.70. Cool roofs are also considered in ANSI/ASHRAE/IESNA Standard 90.1-2001 and state energy codes in Georgia, Florida, and Hawaii. Credit may be realized for cool roof products that exceed minimum requirements if the whole building performance method of compliance is used.

The Leadership in Energy and Environmental Design (LEED) program administered by the U.S. Green Building Council (U.S. GBC) requires low-sloped cool roofs to have an initial solar reflectance of 0.65, and aged solar reflectance of 0.50, and a minimum thermal emittance of 0.9.

Integrated Design Implications

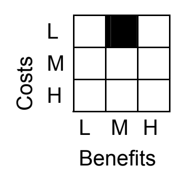
Cool roofs can significantly reduce cooling loads, allowing for the use of smaller air conditioning equipment or in some cases, eliminating air conditioning entirely in favor of natural ventilation. Like all roofing systems, skylights and other roof penetrations, as well as the rooftop equipment mounts, should be considered in the design of the roof. Equipment access should be provided in a manner that does not create undue wear or damage to the roof membrane.

The cooling load reduction from a cool roof is inversely proportional to the level of roof insulation. For insulation levels that meet minimum code requirements, cool roofs result in lower life-cycle costs.

Cool roofs reduce the need for plenum and attic ventilation.

Cool roofs will increase winter heating energy consumption since the heat transmission through the roof is reduced. This could result in increased gas-furnace emissions where natural gas is used for heating.

Cost Effectiveness



The additional cost for coating an asphalt cap sheet or modified bitumen roof is about $\$1/ft^2$ to $\$2/ft^2$. The cost premium for white coatings, cementitious coatings, or white gravel is very low, between $\$0.05$ and $0.20/ft^2$[41].

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[40] A low-sloped roof is defined as having a rise to run ratio of 2:12 or less.

[41] Akbari, H., et al. 2002. "Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements," Code Change Proposal, 2005 Title 25 Building Energy Efficiency Standards Update, PG&E,

California has implemented a rebate program for cool roofs. Qualifying roofs must be Energy Star certified. In addition, the roof must have an initial solar reflectance of 0.65 and thermal emittance of 0.80, or a solar reflectance index of 75%, calculated using ASTM E-1980.

Figure 112—Elastomeric Being Applied Roof

Source: Dow Corning

Benefits

Cool roofs can save demand charges and energy charges. They are highly cost effective, especially in the desert and central valley climates. However, there are other benefits as well. Since solar radiation (especially ultraviolet light) is a major cause of roof deterioration, cool roof coatings can significantly increase the life of the roof membrane. Smaller daily thermal cycles in surface temperature will reduce the wear on the roof membrane caused by material expansion and contraction. Cool roofs also can help make the whole community cooler by reducing the "heat island" effect.

Design Tools

Cool roofs are effective for a number of complex reasons. They reflect heat from the sun, and assessing this benefit requires a model that accounts for the position and intensity of the sun. Sun that is absorbed by the roof (that which is not reflected) increases the surface temperature of the roof and induces heat gain in addition to that driven by temperature differences. At night and at other times, hot roof surfaces radiate heat to the night cool sky. This is a valuable benefit that requires knowledge of the roof surface temperature and the sky temperature. Because of the complexity of heat transfer related to cool roofs, energy simulation programs are necessary to accurately assess their benefits.

Figure 111—Standing Seam Metal Roof with White Coating

Source: Snap-Clad Metal Roofing and Boarman Kroos Phister Rudin & Associates

Oak Ridge National Laboratory's Radiation Control Calculator can be used to estimate energy savings. See www.ornl.gov/roofs+walls.

Design Details

The performance of cool roofs is affected by the accumulation of dirt. Dirt accumulation can be reduced if roof surfaces slope at least 0.25 in./ft.

When liquid applied coatings are used, carefully select coatings that are compatible with the underlying substrate.

Liquid applied cool roof coatings should comply with ASTM Standard 6083-97 for durability and elongation and have a minimum thickness of 20 mils.

Operation and Maintenance Issues

To ensure continued performance of cool roofs, they need to be cleaned each year with a high-pressure water spray. (Verify that doing this does not void the product warranty.) Liquid-applied coatings may need to be refinished every 5 years or so.

Commissioning

No commissioning is needed.

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Additional Information

Berdahl, 2000. Cool Roofing Materials Database. Lawrence Berkeley National Laboratory, Berkeley, CA. http://eetd.lbl.gov/coolroof/

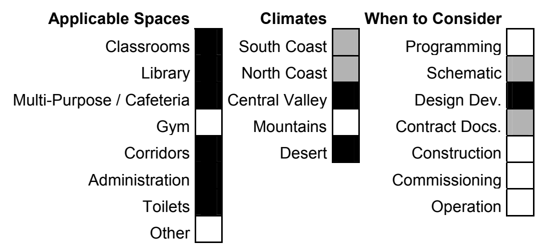
GUIDELINE IN4: RADIANT BARRIERS

Recommendation

Use a radiant barrier in conjunction with attic construction in schools in all climates.

Figure 113—Installing Radiant Barrier

Source: Toolbase (Permission not requested)



Description

A radiant barrier is a surface with a low emittance that is installed at the ceiling of attics. The radiant barrier surface is usually aluminum foil or another shiny metallic finish that has a low emittance. A couple of installation methods exist. The least costly method is to use plywood or composition board with a film that is pre-applied to the board. An alternate, and more effective method, is to drape foil over the rafters before the sheathing is installed.

Radiant barriers are effective because they reduce one of the major components of heat gain, which is radiation from the hot attic ceiling to the cooler attic floor. The amount of heat that is radiated from the attic ceiling to the floor is directly proportional to the emissivity of the surfaces. Uncoated plywood and most other conventional building materials have an emittance of about 0.8, while the surface of a radiant barrier has an emittance of around 0.1. The radiation component of heat transfer can, therefore, be as much as eight times lower than without a radiant barrier.

Radiant barriers are effective in reducing cooling loads, but not heating loads. Radiant barriers can also improve the system efficiency of HVAC air distribution ducts that are located in attics. Duct losses during cooling mode are proportional to the temperature difference between air inside the duct and the temperature of the attic. Radiant barriers reduce the temperature of the attic during cooling conditions, and therefore, duct system efficiency is improved.

Applicability

Radiant barriers are highly recommended in the central valley and desert climates of California. They can also be effective in coastal climates. They are recommended for attics over any spaces that are cooled by air conditioners or natural ventilation. Radiant barriers should be considered no later than the design development phase so that the HVAC equipment may be appropriately downsized.

Applicable Codes

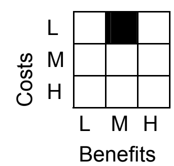
The California Building Code, which applies to schools, does not recognize radiant barriers. However, the California standards for low-rise residential buildings require radiant barriers in central valley and desert climates.

A radiant barrier must be rated Class A by the National Fire Protection Association or Class I by the Uniform Building Code (UBC). To meet the requirement, the material must have a Flame Spread Index of 25 or less and a Smoke Developed Index of 450 or less, as tested by ASTM E-84. Look for these ratings on material data sheets provided by the manufacturer.

Integrated Design Implications

Radiant barriers directly reduce cooling loads, which can result in smaller air conditioners. HVAC air duct efficiency is also improved when air distribution ducts are located in attics.

Cost Effectiveness



When applied to sheathing, the cost premium for radiant barriers is on the order of \$0.10/ft² to \$0.15/ft². Cost is a little higher for draped installation, mainly because additional labor is required.

Benefits

Radiant barriers reduce cooling loads and energy costs. They can also result in smaller air conditioners, which can more than compensate for the added cost of the radiant barrier. Attics where radiant barriers are installed have a lower temperature, which results in improved HVAC duct efficiency and other benefits.

In temperate California climates, the primary benefit is the reduction in load attributable to heat transmission through the roof. At peak cooling conditions, the radiant barrier blocks nearly 100% of roof heat gain. The primary benefit is the reduced peak demand, and lower cooling capacity for equipment. Because of the cool nights typical in most California climates, the net energy benefit is lower when averaged over the cooling season. The benefit will be much greater for schools with year-round operation.

As with cool roofs, the benefit of the radiant barrier is proportional to the heat gain through the roof. If the building already has a cool roof and good insulation levels, the energy savings specifically attributed to the radiant barrier will be much lower.

Design Tools

Estimating the benefits of radiant barriers can be approximated by making an adjustment to the U-factor of the ceiling/roof construction. The problem with this approach is that radiant barriers only have a benefit in reducing cooling loads. In fact, they can have a slightly negative effect on heating loads, since solar gains are reduced which might be useful when schools are in a heating mode. The most accurate way to evaluate radiant barriers in attics is to use an hourly simulation model where the attic itself is modeled as a separate, unconditioned thermal zone, and where radiation transfer can be explicitly modeled. The only models with these capabilities are for research purposes and are difficult for practitioners to use. However, the U.S. Department of Energy (DOE) released a tool called EnergyPlus, which has these capabilities. Version 1.2 was released in April 2004.

Design Details

Choose radiant barrier surfaces that have an emittance less than 0.1, when tested in accordance with ASTM E408. When comparing products, select a product with the lowest emittance. Some have an emittance as low as 0.05.

Install radiant barriers so that the shiny surface faces down to prevent dirt from accumulating on the surface. Dirt can depreciate performance.

When using radiant barriers that are pre-applied to sheathing, make sure that care is taken to not damage the surface during shipping and installation.

When using the draped method of installation, let the radiant barrier sag about an inch from the sheathing, creating an additional air gap. This accounts for the improved performance of the draped method of installation.

Use caution if installing radiant barriers on top of attic floor insulation. During colder weather, a radiant barrier could cause condensation to be trapped on the inside. If using radiant barriers over floor insulation, consider barriers that have high vapor permeability values, allowing moisture to escape.

Operation and Maintenance Issues

Radiant barriers rarely require any maintenance, unless they are damaged while other maintenance work is being performed in an attic.

Commissioning

No commissioning is necessary.

References

Oak Ridge National Laboratory. June 1991. *Radiant Barrier Fact Sheet*. U.S. Department of Energy. www.ornl.gov/sci/roofs+walls/radiant/rb_01.html

Medina, M. May/June 2003. Radiant Barriers: Depends on Where You Live. *Home Energy* 20 (3): 14–16.

California Energy Commission. 2001. *Residential Alternative Calculation Method Approval Manual* The California ACM Approval Manual for low-rise residential buildings has detailed installation requirements in Section 4.24. This document is available at www.energy.ca.gov/.

Additional Information

Ross Middle School, Ross, CA. Architect: Esherick Homsey Dodge & Davis.

The California Bureau of Home Furnishings (as part of insulation certification) certifies radiant barriers with an initial product emissivity of 0.05 or less.

Reflective Insulation Manufacturers Association (RIMA)
661 East Monterey
Pomona, CA 91767
Telephone: 714-620-8011

GUIDELINE IN5: REDUCE INFILTRATION

Recommendation

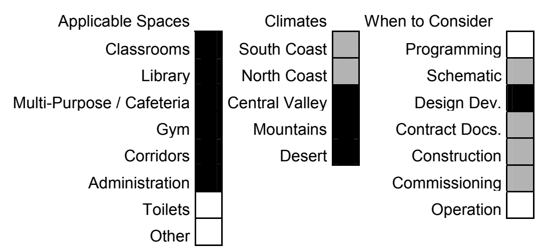
Design and construct the building envelope to limit the uncontrolled entry of outside air into the building. This is achieved through building envelope sealing (caulking and weatherstripping), specifying windows and doors that have been tested to have low rates of infiltration, and by using air lock entries in cold climates. Specify windows that have a low air leakage rate, less than 0.30 cfm/ft^2, as tested by NFRC rating procedures.

Figure 114—Performing a Blower Door Test for Testing Air Infiltration Rates

Source: Energy Conservatory (Permission not yet requested)

Description

Controlling infiltration is very important to achieving energy-efficient buildings. Air leakage introduces sensible heat into conditioned and semi-heated spaces. In climates with moist outdoor conditions, it is also a major source of latent heat. Latent heat must be removed by the air conditioning system at considerable expense. The ANSI/ASHRAE/IESNA 90.1-2001 Standard has requirements for the sealing of building envelope elements, infiltration through doors and windows, and vestibules to limit infiltration at main entrance doors to buildings.



Applicability

Schools in all climates should be sealed to reduce infiltration, but it is especially important in the more harsh climates such as the cold, central valley and desert climates. The recommendations apply to all spaces in schools. Sealing and infiltration control should be first considered in the design development phase, but details should be specified in the contract documents. Tight construction is mainly a matter of care during construction and should be verified during construction and verified in the commissioning phase.

Applicable Codes

The California Building Code specifies minimum infiltration rates for fenestration products and requires that the building envelope be sealed to reduce unwanted infiltration.

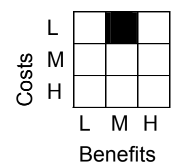
The 2005 Title 24 standard requires fenestration products and single doors to have air leakage rates not exceeding 0.3 cfm/ft², and double doors to have air leakage rates not exceeding 1.0 cfm/ft², as tested by NFRC 400 or ASTM E 283.

Integrated Design Implications

Poorly sealed buildings can cause problems for maintaining comfort conditions when additional infiltration loads exceed the HVAC design assumptions.

Infiltration of warm, moist outside air can cause condensation on surfaces within the building assembly. Materials that are air barriers also inhibit moisture migration. See the guideline on Moisture Control for more information.

Cost Effectiveness



The cost of controlling infiltration is minimal. Mainly it is a standard of care that must be exercised during the construction phase.

Benefits

Controlling infiltration makes it easier to balance and maintain HVAC systems. Energy costs are also reduced in a cost-effective manner. As warm, moist outside air moves through the building assembly, the air is cooled, which can result in condensation within the construction. Condensation can lead to mold growth, degradation of insulation performance, and structural damage, if not treated. Condensation will also accelerate corrosion of metal components in the building assembly.

Design Tools

All energy calculation methods are capable of accounting for infiltration in some manner. Some use an air-changes-per-hour method, while others are based on the concept of an effective leakage area. Many hourly simulation methods are capable of modeling infiltration using either calculation method. During construction, air leaks can be detected and repaired through pressurization tests, often called blower door tests. With this procedure, a building or space is pressurized with a large fan that is usually mounted in the door (thus, blower door). The space is pressurized to about 50 Pascals of pressure and leakage is measured. The location of leaks can be identified using smoke sticks.

Design Details

Exterior joints, cracks, and holes in the building envelope shall be caulked, gasketed, weather stripped, or otherwise sealed. The construction drawings and specifications should require the sealing, but special attention is needed in the construction administration phase to ensure proper workmanship. A tightly constructed building envelope is largely achieved through careful construction practices and attention to detail. Special attention should be paid to several areas of the building envelope including:

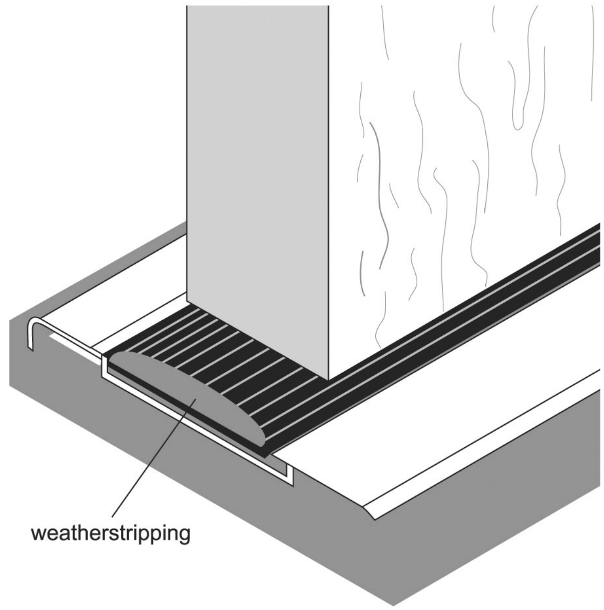


Figure 115—Door Weatherstripping

- Joints around fenestration and door frames.
- Junctions between walls and foundations, between walls at building corners, between walls and structural floors or roofs, and between walls and roof or wall panels.
- Openings at penetrations of utility services through roofs, walls, and floors.
- Site-built fenestration and doors.
- Building assemblies used as ducts or plenums.
- Joints, seams, and penetrations of vapor retarders.
- All other openings in the building envelope.

ANSI/ASHRAE/IESNA Standard 90.1 also has requirements for limiting infiltration through mechanical air intakes and exhausts. These requirements are addressed in the mechanical section (§ 6) of the standard, not in the building envelope section.

Fenestration and Doors

Fenestration products, including doors, can significantly contribute to infiltration. For glazed entrance doors that open with a swinging mechanism and for revolving doors, the infiltration should be limited to 1.0 cfm/ft². Infiltration rates should be verified with NFRC 400. A laboratory accredited by the NFRC or other nationally recognized accreditation organizations must perform the ratings.

Vestibules

In cold California climates, vestibules should be created at the main entrance to schools. All the doors entering and leaving the vestibule must be equipped with self-closing devices and the distance between the doors should be at least 7 ft. This distance allows for exterior doors to close before the interior doors are opened, and complies with the Americans with Disabilities Act (ADA). The vestibule helps to control air pressure differences between indoors and outdoors. It reduces infiltration in the summer and exfiltration in the winter.

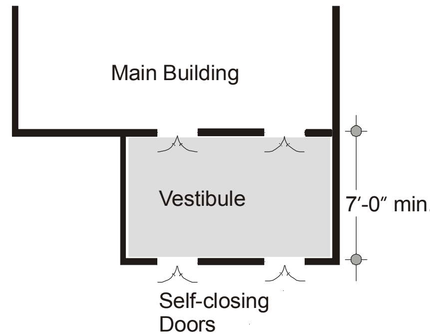


Figure *116*—Vestibule Diagram

Air Barriers

Materials are considered air barriers if they have a permeability rating less than 0.004 cfm/ft² at a pressure of 0.3-in. w.g., according to standard ASTM E 2178.

Bituminous roof membranes, extruded polystyrene, plywood sheathing (1/2-in. thickness), foil-backed gypsum, foil-faced urethane and phenolic insulation, and closed-cell urethane foam are common air barrier materials. An air barrier system must be designed for continuity, durability, air impermeability, and structural support. The air barrier should be designed to last the life of the structure. The load imposed by wind and stack effects must be properly transferred to the building structure.

Air barriers can be classified as:

- Combined air and vapor barrier systems—can be asphalt membranes, fluid-applied membranes, torch-applied membranes or spray-applied urethane foams. They provide both an air barrier and a high resistance to vapor diffusion. These are installed on the winter-warm side of an exterior wall system.
- Vapor permeable air barrier systems—fluid-applied barriers that intentionally allow water vapor to pass through the material. These are located away from the condensing plane of the structure.
- Multi-component systems—consist of several air barrier materials joined by sealants, tape or foams. Quality of construction and coordination between trades is crucial in ensuring the air barrier effectiveness.

More information and sample installation details can be obtained from the Air Barriers Association of America (see www.airbarriers.org).

Operation and Maintenance Issues

Weatherstripping around doors and other openings must be maintained and replaced every 5 to 10 years. Caulking in exposed locations will need to be replaced or touched up each time the exterior of the school is painted.

Commissioning

The commissioning agent should verify that weather stripping and caulking is properly installed. Fenestration products should be labeled by NFRC to enable easy field verification of the infiltration requirements. Commissioning air barrier systems involves both visual and qualitative evaluations and tests, as well as quantitative testing. The Air Barrier Association of America provides product certifications and recommended test procedures. A "Level 2" contractor (with 3,000 hours experience) should be on the job site continuously when an air-vapor barrier is installed. Verifying the installation of an air barrier involves visual inspection, an adhesion test, and testing air infiltration rates through building pressurization.

Testing of air infiltration rates can be performed using either a building pressurization, a "blower door" test, or the use of a tracer gas. The ASTM E779-99 test procedure involves pressurizing a single-zone (such as a classroom with a packaged unit) with the supply fan. The Brookhaven National Laboratory developed a technique that measures the concentration of a PerFluorocarbon tracer gas (PFT) over time. The technique uses a small emitter of the gas and a receiver, which measures the average concentration of the gas in the room. While this method does not pinpoint the source of air leaks, it can reveal long-term problems with infiltration.

References/Additional Information

Nonresidential Manual for Compliance with the 2005 Energy Efficiency Standards, California Energy Commission, available from www.energy.ca.gov/.

Installing Caulking and Weatherstripping, www.weservehomes.com/diy/ha_diy.html.

Weatherstripping to Reduce Heating and Cooling Bills, www.doityourself.com/energy/weatherstripping.htm.

Advanced Building Guideline, Reference Manual, New Building Institute, 2004.

Air Barrier Association of America 1600 Boston-Providence Highway Walpole, MA 02081 (866) 956-5888 Fax (866) 956-5819. The Air Barrier Association of America (ABAA) is a non-profit corporation organized to inform and educate the building construction industry of the values of including an air barrier system in building construction.

Commercial Air Barrier Systems—Professional Contractor Quality Assurance Manual, Air Barrier Association of America, 2001.

GUIDELINE IN6: SLAB ON GRADE INSULATION

Recommendation

Provide exterior insulation for slab-on-grade floors to prevent moisture condensation in cold, desert and mountain climates. Provide a vapor barrier to prevent moisture migration up through the slab.

Class of Wall	South Coast, North Coast Climates	Central Valley, Desert, Mountain
Slab-on-Grade	No requirement for unheated slabs. For heated slabs, use R-7 of continuous insulation for 12 in. and R-5 continuous insulation below the slab.	Use a minimum of R-10 continuous insulation for 24 in. around the perimeter for unheated slabs. For heated slabs, use continuous insulation below the slab.

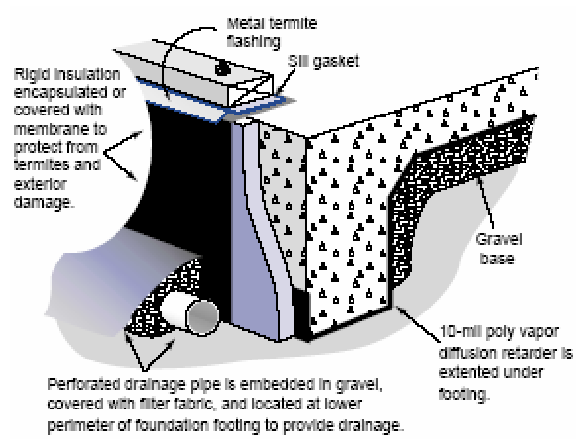
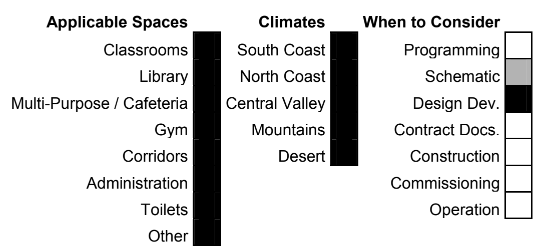


Figure 117—Slab Edge Insulation

Source: Technology Fact Sheet, Slab Insulation, Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department Of Energy



Description

Most school facilities in California use slab-on-grade construction. Slab-on-grade floors should be insulated around the perimeter to reduce heat loss to outdoors. Most of the winter heat loss occurs at the perimeter, through the foundation to the cold outside air. In some climates, continuous insulation should be placed beneath the slab. The requirement distinguishes two classes of slabs: heated and unheated. Heated slabs contain hot water piping or coils embedded within the slab or beneath the slab to provide for space heating. Since the heat losses are greater from the warmer heated slab, more insulation is required.

Applicability

These recommendations apply to all slab-on-grade floors in all spaces that are heated or cooled.

Applicable Codes

Insulation must meet Title 24 requirements and meet national fire protection codes.

Integrated Design Implications

A vapor barrier may be required underneath the slab to prevent moisture from migrating upwards through the slab. A thin layer of low-density polyethylene can be placed underneath the slab to prevent moisture migration. In cold climates, a layer of continuous insulation should be placed directly underneath the slab, to maintain the slab and floor above the dewpoint temperature. In cold climates, the frost line also acts as a vapor barrier.

Carpet will provide a small increase in the floor insulation level: typically carpet provides an R-2 to R-3 insulation level. The increase in surface temperature will improve thermal comfort.

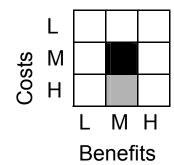
The use of insulation at the slab perimeter will reduce heat loss and eliminate cold drafts. This may reduce or eliminate the need for perimeter heating.

Cost Effectiveness

Installation costs for slab insulation are generally low. For instance, for residential construction, installation cost is \$0.15-0.35 / ft^2.[42] Costs can be higher in some instances because of issues related to coordinating insulation installation with other trades.

Benefits

The benefits of additional insulation are reduced heating and cooling requirements, due to reduced envelope loads. Insulation at the floor will also enhance comfort, by helping to maintain a floor temperature closer to room temperature.



Design Tools

Building energy simulation tools such as DOE-2 may be used in determining the impact of insulation on building cooling and heating loads, but modeling ground heat transfer is tricky and needs to be pursued with caution. It is important to both capture the thermal mass effects as well as the heat loss. Simulation tools allow exterior components to be coupled to exterior air or to ground temperature, which can be entered as a schedule. Coupling to ground temperature is more accurate and the ground temperatures should approach the monthly average dry-bulb temperature.

For most projects, it is best to use published values that are based on tested data or advanced calculation procedures. Calculation of F-factors for slab perimeter heat losses requires two-dimensional heat transfer models. Computer programs are available for calculating the thermal conductance (U-factor) of complex assemblies (Therm-LBNL, EZFrame). Computer programs are also available for

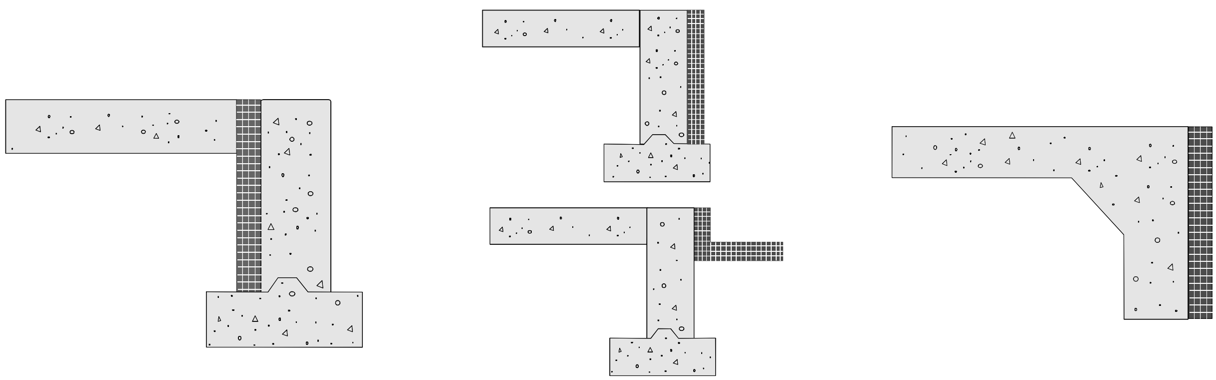
42 Southface Energy Institute, "Insulating Foundation and Floors," 2003. Southface Energy Institute, 241 Pine St., Atlanta, GA 30308, 404-872-3549, www.southface.org.

calculating two or three-dimensional heat transfer using finite difference or finite element methods (ANSYS).

The 2005 California Title 24 Energy Efficiency Standards has tables with F-factors for slab-on-grade floors. Information can be found in Joint Appendix IV of the standard, and can be accessed on the California Energy Commission's Web site: www.energy.ca.gov/title24/2005standards/index.html.

Design Details

The figure below shows acceptable methods of using perimeter insulation for slab-on-grade.



Permitted by Prescriptive and F-Factor Methods

(a) Insulation Inside—Permitted

Permitted by Prescriptive and F-Fact or Methods

(b) Insulation Outside—Permitted

Permitted by Prescriptive And F-Factor Methods

(c) Monolithic Slab -- Permitted

Figure 118—*Slab-On-Grade Acceptable Perimeter Insulation Types*

Source: ASHRAE 90.1-2001 User Manual

It is essential to use insulating materials that will not deteriorate when exposed to water. Extruded polystyrene is the preferred material because it has closed cells. Avoid using expanded polystyrene or polyisocyanurate, as the cells can fill with water and the insulation becomes ineffective.

Slab edge insulation is usually both above grade and below grade. The part that is above grade needs to be protected from ultraviolet (UV) exposure and from physical damage from landscaping and maintenance equipment.

In some areas, termite infestation can be a problem with slab insulation. The rigid insulation can provide a path for insects to enter the building. Refer to the CHPS Maintenance and Operations Manual (Volume IV) on integrated pest management recommendations.

Operation and Maintenance Issues

Foundations are susceptible to moisture infiltration and deterioration due to contact with earth. Keep all untreated wood materials away from the earth to avoid contact with the soil. In termite-prone areas, extra care should be taken to prevent termites from tunneling through insulation.

Provide an adequate drainage system to drain water away from the building. The earth should be sloped away from the building at a 5% grade to allow for adequate drainage.

Commissioning

No commissioning of slab-on-grade floors is needed other than normal construction administration.

References/Additional Information

Advanced Building Guidelines Reference Manual, New Buildings Institute, 2004.

Technology Fact Sheet, Slab Insulation, Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department Of Energy

ASHRAE 90.1 Users Manual

ASHRAE Handbook of Fundamentals

Southface Energy Institute, "Insulating Foundation and Floors," 2003. Southface Energy Institute, 241 Pine St., Atlanta, GA 30308, 404-872-3549, www.southface.org.

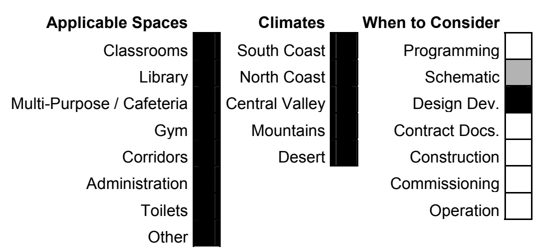
GUIDELINE IN7: FENESTRATION PERFORMANCE

Recommendation

Specify double-paned windows with low-emissivity coatings for energy performance. Such windows should be certified by the NFRC. If aluminum framing is used, specify a frame with a thermal break. Shade south-facing windows with exterior overhangs. When using skylights or windows for daylighting, specify products with a high visible light transmittance and low solar heat gain.

Figure 119—Skylight Used at Capistrano Unified with Dimming Controls

Source: Energy Design Resources



Description

Fenestration (windows and skylights) serves many purposes. It provides a connection to the outdoor environment, daylighting and in the case of operable windows, natural ventilation. This guideline focuses on the thermal performance of windows and skylights.

The thermal performance of fenestration can be measured by two properties: the U-factor and the SHGC, both described in the overview of this chapter. U-factor affects both heating and cooling requirements, while SHGC primarily affects cooling loads. For skylights, and windows intended for daylighting, a glazing should be selected that has a high VLT and a low solar heat gain.

Applicability

These recommendations apply to all spaces that are heated or cooled. Some window types are designed specifically for certain types of spaces—refer to the Lighting chapter for details.

Applicable Codes

The NFRC has procedures for determining the thermal performance of fenestration products. The NFRC has established a rating system to evaluate the whole window performance including the frame, spacer, and glazing. More information can be found at their Web site, www.nfrc.org. The whole-window U-factor, VLT, and SHGC are shown on a label attached to all rated windows. Site-built windows and skylights will not have these ratings available.

The American Architectural Manufacturers Association (AMMA) has a voluntary specification for skylights. This specification, AAMA 1600, provides rating procedures for measuring air infiltration and water penetration. Contact the AAMA for more information.

A maximum window to wall ratio (WWR) of 40% is allowed for commercial buildings, as specified in the 2005 Title 24 standards. Refer to the Overview for fenestration requirements for different climate regions.

Integrated Design Implications

Windows used for daylighting can reduce electric lighting requirements, which will reduce electricity use and lower peak cooling demand. High performance windows can prevent cold interior surface temperatures, reducing or eliminating the need for perimeter heating in many California climates.

The amount of glazing used has a large impact on the space heating and cooling loads. In California classrooms, window areas are typically well below the limits required by Title 24.

Interior shading devices are not required by code, but will reduce solar heat gain, lowering cooling loads. When used, Venetian blinds can reduce the radiant heat transmission through windows by 25%–30%. Tightly closed vertical blinds can reduce heat transmission by as much as 70%.

High performance windows will reduce heating and cooling loads and impact the sizing of HVAC equipment. Also, windows with low U-factors will improve thermal comfort, by keeping the window inner surface temperature closer to room temperature.

The benefits of high performance windows depend on the window area. Windows with low SHGC and U-factors are especially important for buildings with larger window areas.

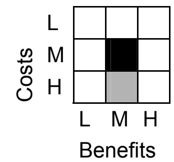
Good daylighting design will reduce lighting requirements for portions of the building. Refer to the Chapter on Daylighting Design for more information.

For skylights, the skylight area should be between 3%–12% of the daylit floor area. Double-glazed skylights are recommended for cold, mountain and some inland valley climates, while single-glazed skylights are sufficient for temperate coastal climates.

Cost Effectiveness

High performance glazing costs a little more, but is extremely cost effective. Double-paned glass has a cost premium of \$3–\$4 per ft^2 and low-e coatings have a premium of \$1–\$2 per ft^2. Often cooling and heating capacity can be reduced and heating and cooling energy will also be reduced. These first cost and operating cost savings usually more than offset any cost premium associated with high performance windows and skylights.

Benefits



High performance windows have several important benefits for high performance schools:

- Cooling and heating energy use is reduced.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.
- Well-insulated windows will be more resistant to condensation.

Design Tools

The Overview section of this chapter has a discussion of methods and procedures for calculating U-factors. Building energy simulation programs (DOE2, EnergyPlus, BLAST) are useful in determining the effect of window area and thermal performance on heating and cooling requirements.

SkyCalc is a free software tool that was developed for Southern California Edison as part of a California Public Interest Energy Research (PIER) research project. It enables the user to determine the best skylighting strategy to minimize lighting and electricity energy use. Refer to www.energydesignresources.com/resource/129/ for more information.

Design Details

The fenestration frame holds the glazing material in place and forms the structural link with the building envelope. The frame and the spacer between the glazing panes in multiple glazed units form a thermal short circuit in the insulating value of the fenestration. This degradation of the U-factor at the fenestration perimeter can be minimized with high performance frame and spacer technologies now available. This is important both for energy conservation and the potential for condensation on the frame.

Frames are available in metal, wood, vinyl, composite, and fiberglass. Metal frames conduct the most heat and must have a thermal break for good performance. Windows with insulated vinyl and fiberglass frames have the lowest U-factor. Vinyl and plastic frames are low maintenance and require no paint, but the use of PVC can contribute to pollution, and thermal expansion can lead to premature failure of the seal. Fiberglass frames are durable with good energy performance, but emissions can affect IAQ, and the manufacturing process causes pollution. Specify durable, factory-applied finishes for metal frames.

Exterior overhangs should be deep enough to minimize direct sunlight on the window during the hottest times of the year. For south-facing windows, a good rule-of-thumb is to design the overhang with a shading cutoff angle about equal to 90° minus the site latitude. This provides full shading between March 21 and September 21. Providing good exterior shading can dramatically reduce peak cooling loads and cooling energy use. Overhangs for windows facing east and west should be carefully designed for the specific site, climate and space. Deciduous trees located south of a window can also provide summertime shading.

The NFRC also includes optional test procedures for rating air leakage and condensation resistance. The air leakage test determines a leakage rate in cfm/ft^2 of window area; typical ratings are 0.1–0.3.

Window Performance

High performance windows have a high VLT relative to the solar gain: they let the light in but not the heat. High performance fenestration features include double and triple glazing, low-emissivity coatings, and blue/green tints. These have become a very important means of energy conservation in modern construction to reduce both thermal losses and solar gains, while providing natural daylight. Fenestration has three principal energy performance characteristics, which have been identified by the NFRC to be tested and labeled on manufactured windows: VLT, SHGC, and U-factor. (These properties are defined in the Overview to this chapter.) Site-built windows and skylights may or may not have such tested information available.

In general, the U-factor and SHGC should be as low as possible. However, there are some tradeoffs between SHGC and U-factor. A high performance window with a low SHGC will lower summer cooling loads, but will reduce solar heat gain during the winter, resulting in higher heating loads. For buildings in colder climates that have high heating loads, the U-factor becomes more important. In California, most of the heat gain through windows is solar heat gain, so SHGC has a greater effect than the U-factor on cooling requirements.

There are different ways that manufacturers achieve high performance windows. First, tints will reduce the solar heat gain (lower SHGC), but will also reduce the VLT. Tints will not affect the U-factor. A second strategy is to use a coating on top of the glazing. Reflective coatings reduce heat gain and glare, but do not let light pass through. This has led to the development of “low e” coatings. “Low-e” coatings are spectrally selective: they reduce heat transmission while letting visible light pass through.

To reduce the U-factor, multiple layers of glazing are used, with air or inert gases used to fill the gaps between layers. Multiple glazings are applicable to cold climates with significant heating loads. The space between panes affects the performance: the thicker the air space, the better the insulation. However, if the space becomes too wide, convection occurs between glazing layers. Performance is not improved beyond an air gap of about 1 in. Combinations of these strategies are often used. With low-e coatings, multiple glazings and the use of gas fills, windows can achieve SHGC values as low as 0.2 and U-factors as low as 0.25.

The table below provides standard practice (Title 24-compliant) fenestration products and best practice fenestration for different climate regions. Values are representative thermal performance characteristics of high performance windows. When specifying a fenestration product, NFRC rating data should be used. For coastal and mountain climates, the recommendation significantly reduces both the SHGC and U-factor. For valley and desert climates, high performance fenestration will provide a large reduction in SHGC and modest reduction in U-factor. Other fenestration options may provide even better thermal performance.

Table 25—Standard and High Performance Fenestration

	Standard Practice				High Performance					
Climate	**Glazing**	**Frame**	**SHGC**	**U-factor**	**Glazing**	**Frame**	**SHGC**	**Diff.**	**U-factor**	**Diff.**
Mountains	Tinted double low-e	Metal	0.39	0.57	High perf. tint double low-e	Metal with thermal break	0.31	21%	0.42	26%
North Coast	Tinted double low-e	Metal	0.39	0.57	High perf. tint double low-e	Metal with thermal break	0.31	21%	0.42	26%
South Coast	Tinted double low-e	Metal	0.39	0.57	High perf. tint double low-e	Metal with thermal break	0.31	21%	0.42	26%
Valley	High perf. tint double low-e	Metal with thermal break	0.36	0.49	Reflective high perf. tint double low-e	Metal with thermal break	0.19	47%	0.42	14%
Desert	High perf. tint double low-e	Metal with thermal break	0.36	0.49	Reflective high perf. tint double low-e	Metal with thermal break	0.19	47%	0.42	14%

Source: Small HVAC System Design Guide, California Energy Commission, 2003. Standard practice meets current Title 24 envelope requirements. Best practice glazing fenestration uses insulated spacers.

Skylight Performance Characteristics

Skylights are an effective method of providing natural daylight to school classrooms. High performance glazings are designed to transmit visible light while blocking solar radiation. As with windows used for daylighting, skylights should have a high VLT and low SHGC. A measure of the glazing effectiveness is the light to solar gain (LSG) ratio, the ratio of the visible light transmittance to solar heat gain (VLT/SHGC). For skylights this ratio should exceed 1.1.

Some skylights have automatic or manual louvers to block direct sunlight, useful when lower light levels are desired (such as during video presentations).

Skylight glazings can be glass, acrylic, polycarbonate or fiberglass. Some examples of high performance skylight glazings are shown in the table below.

Table 26—Representative Properties of Skylight Glazings

Type	Glazing	Color	VLT	SHGC	LSG
Acrylic/fiberglass	Single	Clear	0.92	0.77	1.19
		Med White	0.42	0.33	1.27
	Double	Clear	0.86	0.77	1.10
		Med White	0.39	0.30	1.28
Fiberglass	Insulated translucent	Crystal	0.30	0.30	1.01
Glass	Single	Clear	0.89	0.82	1.09
		Green	0.74	0.59	1.25
	Double	Clear	0.78	0.70	1.11
		Green	0.66	0.47	1.40
	Double, low-e	Clear	0.72	0.57	1.25
		Bronze	0.45	0.39	1.15
		Green	0.61	0.39	1.56
	Triple, low-e	Clear	0.70	0.53	1.32
		Bronze	0.42	0.37	1.14
		Green	0.61	0.38	1.61

Source: Energy Design Resources, www.energydesignresources.com/docs/sg-3-specs.pdf. For specific products, consult NFRC ratings.

In addition to the skylight itself, the effectiveness of the skylight at distributing light depends on the skylight well. A portion of the light that is transmitted through the skylight glazing will strike the skylight well. Some of this light will reflect off the well and be transmitted back out of the skylight. The skylight efficacy is a measure of the light that is transmitted through skylight glazing and skylight well to the space relative to the heat gain through the skylight. Using highly reflective surfaces for the skylight well will maximize the amount of light transmitted to the room. This is especially important for skylights with deep wells.

Diffusing properties of skylights should also be considered. A highly diffuse material will scatter the light and provide a more even light distribution. The ability of glazing to diffuse light is a distinct property from the VLT. A highly diffuse material that is not transparent can still have a high VLT. Unfortunately, specifications on diffusion properties are rarely available for fenestration products. A simple diffusion test is to place a sample of the product in the sun and see if it allows your hand to cast a shadow. A fully diffusing material will blur the shadow beyond recognition and will not concentrate the sunlight into local hot spots.

As with windows, heat transmission through the skylight is characterized by the U-factor. The U-factor primarily impacts winter heating loads. In the summer most of the heat gain through skylights is via solar radiation. Flush-mounted frames that are assembled on site will have less framing area exposed to the outdoors, and consequently, lower U-factors than integral frames.

Operation and Maintenance Issues

UV degradation and other aging effects may occur with some glazings. Durability characteristics, such as structural strength, scratch resistance, breaking and fire resistance, should be considered when selecting a glazing. Cleaning of windows will ensure proper VLT of daylight windows. Windows should be inspected and recaulked according to manufacturer's recommendations.

UV degradation and other aging effects may occur with some glazing materials. Durability characteristics, such as structural strength, scratch resistance, breaking, and fire resistance, should be considered when selecting a glazing. The VLT will change over time. Some skylight glazing materials, such as fiberglass, are particularly susceptible to UV degradation. Consult with manufacturer's specifications for long-term performance.

Commissioning

The commissioning process begins at the design phase. The design intent document should include a specification of energy performance goals and how those goals will be met.

Whole building commissioning involves inspection of the quality of the construction and checking details such as window flashing. The quality of construction ensures that performance meets design expectations and helps prevent problems with air infiltration and moisture.

References/Additional Information

The American Architectural Manufacturers Association has developed industry standards for doors, windows and skylights. For more information, see www.aamanet.org.

Advanced Building Guidelines, New Buildings Institute, 2004.

ASHRAE Handbook of Fundamentals, ASHRAE, 2001.

National Fenestration Rating Council, 8484 Georgia Avenue, Suite 320, Silver Spring, MD 20910. Voice: (301) 589-1776, Fax: (301) 589-3884, Email: info@nfrc.org

Efficient Windows Collaborative. University of Minnesota, Twin Cities. 1998-2003.

Jacobs, Pete, "Small HVAC System Design Guide," California Energy Commission, 2003.

Southern California Edison, "Design Brief: Glazing," E Source, Energy Design Resources, 2000.

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GUIDELINE IN8: MOISTURE CONTROL

Recommendation

Building envelope assemblies should be designed to prevent accumulation of moisture due to leakage, condensation of water vapor, or infiltration of warm humid air. Design building envelopes to maintain the relative humidity of surfaces below 80% to inhibit mold growth. Provide air and vapor retarder for all building envelope components.

Provide a means for low-slope roof assemblies to dry out if moisture accumulates during the winter rainy season.

Provide a grade for the first 10 ft around the building perimeter to direct rain and groundwater away from the foundation.

Figure 120—Smart Vapor Barrier

Source: New Buildings Institute

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	▒
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	■	Mountains	■	Contract Docs.	□
Corridors	■	Desert	■	Construction	□
Administration	■			Commissioning	□
Toilets	■			Operation	□
Other	■				

Description

Moisture accumulation in building envelopes affects the building's thermal performance and durability. If not properly addressed, moisture buildup can lead to mold growth and impact the health of the occupants. Building design to control both moisture and air infiltration is an integrated design practice that requires attention at the design phase and execution in the construction phase.

Moisture control is accomplished by preventing water entry, by designing the building envelope to prevent condensation of moist air, by minimizing air infiltration and by removing any accumulated moisture by draining, venting, or diffusion.

Applicability

These recommendations apply to all spaces in California climates. Buildings in warm, humid climates require vapor retarders to be installed on the exterior warm, humid side of the building structure.

Applicable Codes

Per Title 24, liquid-applied roof coatings must have a maximum permeance of 50 perms, tested by ASTM D1653.

Vapor retarders should be selected according to the procedure ASTM C755, “Standard Practice for Selection of Vapor Retarders for Thermal Insulation.”

Integrated Design Implications

Vapor retarders are often used to control moisture migration. Materials that prevent moisture migration will tend to inhibit air infiltration and vice versa.

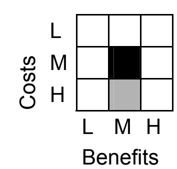
The major source of condensation in building assemblies is air leakage; an air barrier system to control air leakage is critical. Consider the airtightness requirements of the air barrier system and its location in the assembly so that building components affected by condensation have a chance to dry. The properties of air barrier materials should be selected carefully from a permeance standpoint, relative to their location in the assembly. The envelope designer needs to understand clearly the design conditions indoors and reconcile the owner’s and program’s needs with the HVAC designer.

Cost Effectiveness

Careful design to control air infiltration and moisture may increase costs at the design stage, but should not increase construction costs. The benefits of extended roof life and improved indoor air quality justify costs at the design stage.

Benefits

Moisture control will prevent the growth of mold and ensure proper IAQ. Insulation performance is maintained. Preventing moisture accumulation in roofing materials will extend the life of the roof.



Design Tools

There are several software packages that model heat and moisture transfer across building envelope assemblies; a commonly used (free) software accessible to design professionals is WUFI-ORNL/IBP. This software, which originated at the Fraunhofer Institute of Building Physics in Holzkirchen, Germany, (Kuenzel 1996) was further developed at DOE’s Oak Ridge National Laboratory (Karagiozes 2001) in a collaboration that resulted in a user-friendly package suitable for North America. It has hourly weather files for 50 U.S. cities and numerous Canadian ones as well.

The software calculates heat and moisture increase and loss in the materials of the building assembly due to rain wetting, solar radiation, wind, cloud cover, temperature, and relative humidity. It considers the orientation effects on a wall relative to all of these. Inputs and outputs are either in inch-pound (IP) or metric (SI) units. The intent of a successful analysis is to maintain the relative humidity (equivalent moisture content) of all materials inboard of the drainage plane below 80% relative humidity. This ensures that the air in the construction assembly stays below the thresholds determined to be a trigger for rot, corrosion, chemical deterioration, and mold growth. Although this program provides a simplified model of heat transfer, it is one of the best tools available to model diffusion and include the effects of rain wetting, wind, orientation, solar radiant heating, and radiant cooling.

Design Details

Moisture Control Terminology

There are several terms describing materials and strategies for moisture control. It is important to differentiate vapor barriers from vapor retarders. A vapor barrier is virtually impermeable to water vapor. Examples of such materials are rubber membranes, glass, and plastic films. A vapor retarder is a material that inhibits transmission of water vapor but is not prevent its migration. Examples include plywood or oriented strand board (OSB) and some types of insulation. For mild California climates, vapor retarders are installed on the interior (“winter warm”) side of the building assembly. Building Science Inc. has identified three classes of vapor barriers and retarders based on the permeability of the material (see Table 27). Class I materials have a permeability of 0.1 or less. Class II materials have a permeability of 1.0 or less. Both are considered impermeable and are considered vapor barriers. Class III materials have a permeability of 10.0 or less and are considered vapor retarders, rather than vapor barriers.

Table 27—Types and Classifications of Vapor Barriers

Type	Description	Class	Perms	Examples
Vapor Barrier	Impermeable	I	0.1 or less	Rubber membranes, polyethylene film, glass, aluminum foil, sheet metal, oil-based paints, vinyl wall coverings, and foil-faced insulating sheathings
		II	1.0 or less	
Vapor Retarder	Semi-Permeable	III	10.0 or less	Plywood, oriented strand board, unfaced expanded polystyrene, fiberfaced isocyanurate, heavy asphalt impregnated building papers, the paper and bitumen facing on most fiberglass batt insulation and most latex based paints
Breathable	Permeable		more than 10.0	Unpainted gypsum board and plaster, unfaced fiberglass insulation, cellulose insulation, unpainted stucco, lightweight asphalt impregnated building papers, asphalt impregnated fiberboard, exterior gypsum sheathings, cement sheathings, and “housewraps.”

Source: Joseph Lstiburek. Understanding the Terms Barrier and Retarder for Vapor and Air, February 2002.

Controlling and Managing Liquid Water Entry

The building envelope (above and below grade) should be designed to resist water intrusion, and to effectively drain water that passes through the cladding. Manage water intrusion by providing a drainage plane behind the cladding. Manage liquid water intrusion by using waterproofing, damp proofing and dewatering techniques. Wall assemblies should be designed with flashings and drainage planes and should not depend on a single sealant layer as the primary means of water intrusion prevention. All windows should be flashed. Roofs should be pitched to drains.

Controlling Condensation

Controlling moisture accumulation by condensation is achieved by ensuring that the building surfaces remain above the indoor air dewpoint. To prevent the growth of mold, interior surfaces should be kept at a relative humidity of 80% or less. Reducing air infiltration will also minimize the potential for condensation in the envelope structure.

Control of Moisture Migration

Moisture migration is controlled through the use of vapor retarders, which inhibit moisture migration but do not completely block the diffusion of moisture through the building assembly. This limits the movement of moisture to colder areas of the building assembly, reducing the potential for condensation, which can cause deterioration and mold growth. The performance of these materials is classified by a permeance rating. A material is considered a vapor retarder if it has a permeance of between 1 and 10 perms (1 perm = 1 grain H_2O/h-ft^2). Many materials can serve the dual purpose of limiting air infiltration and limiting vapor transmission. Such materials include asphalt-impregnated building papers, liquid-applied films, polymer-based wraps and insulation. Polymer-based films and wraps have a constant resistance to vapor diffusion that is independent of humidity level. Materials such as kraft paper that are wood-based behave very differently. These materials have low permeance at low relative humidity levels, which inhibits moisture migration outwards from the warm interior in the winter, while allowing for moisture migration when the reverse pattern occurs in the summer. Synthetic materials that are specifically designed to take advantage of the natural vapor diffusion processes that occur over the seasons are referred to as “smart vapor retarders.” The higher permeance during high relative humidity conditions promotes summer drying.

Roofs

Low-sloped roofs offer a special challenge in controlling moisture. The entry of water vapor through the roof membrane is inevitable. Installing an impermeable water vapor retarder below the insulation will prevent the construction assembly from drying out if moisture does enter. This problem is exacerbated as daily temperature swings cause moisture migration cycles through the assembly, degrading the roof structure. One strategy to control moisture in low-sloped roofs is to design a self-drying roof assembly. Any moisture that accumulates during the winter rainy season must be allowed to permeate through the structure. Desjarlais (1995) provides a straightforward design procedure for determining the desired vapor resistance of the vapor retarder. The moisture that accumulates in the roof structure in the winter is determined by the difference in vapor pressure between outdoors and indoors and the vapor resistance of the material, integrated over the winter season. This total moisture gain must be moved by summertime drying. One potential solution is to perforate insulation with very small diameter holes (1-3 mm) that allow moisture to pass through but block convective heat transfer.

Slabs on Grade

Concrete in slabs should be dried to an equivalent relative humidity content of 75%, as measured by ASTM Standard F-2170-02. Vapor retarders under slabs have to be placed in intimate contact with the underside of the slab, never with a layer of sand or fill on top (that can store capillary moisture for months or years). Wet curing is better than applying a curing agent, because curing agents trap moisture.

Operation and Maintenance Issues

Roofs should be inspected twice a year, and after significant storms, to check for potential problem areas.

Thermographic testing can be used to detect spots where moisture has affected the building envelope. Moisture will degrade the performance of insulation, resulting in warm and cold spots in problem areas.

Commissioning

Success of the building enclosure in preventing moisture depends on the quality of construction. A whole building commissioning process that begins at the design phase provides a systematic means of designing for moisture control.

References/Additional Information

ASHRAE Handbook of Fundamentals. ASHRAE, 2001.

Advanced Buildings Reference Guide. 2004. New Buildings Institute.

Desjarlais, Andre and David Kyle. 1995. “Assessment of Technologies for Constructing Self-Drying Low-Sloped Roofs.” Oak Ridge National Laborartory for DOE.

National Roofing Contractors Association, 10255 W. Higgins Road, Suite 600, Rosemont, IL 60018, www.nrca.net. NRCA is a trade association that provides information for designers and building owners on products and best practice.

GUIDELINE IN9: ACOUSTIC DESIGN

Recommendation

Design the building envelope to provide acoustical performance that meets the 2002 voluntary American National Standards Institute (ANSI) Standard S12.60. This specifies a background noise level of 35 decibels on the A scale (dBA) or lower. To achieve this, design walls separating classrooms with a minimum sound transmission class (STC) of 50, bathroom walls with an STC rating of 53, and walls isolating noise from music spaces, cafeterias and mechanical equipment rooms with STC ratings of 60.

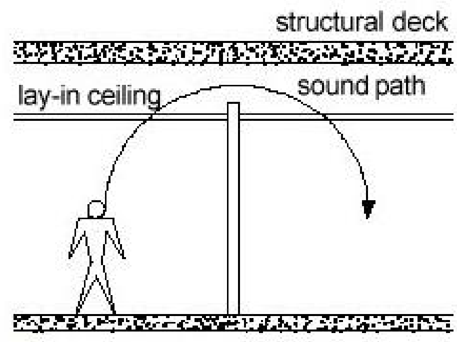
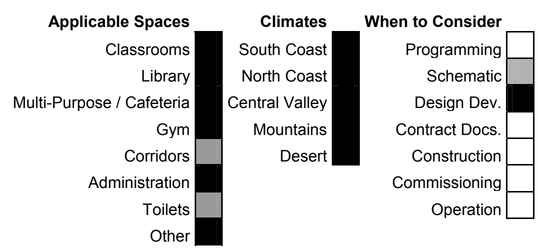


Figure 121—Example of Poor Acoustic Design

Interior partitions should extend up to the structural deck to limit sound transmission between classrooms. Source: Acoustical Society of America



Description

Good acoustic performance is a result of integrated design of both building envelope components and HVAC equipment selection and location. For the building envelope, acoustics is affected by reverberation, sound transmission between classrooms, and exterior noise sources. ANSI Standard S12.60 specifies a maximum background noise level of 35 dBA. A low STC rating for wall assemblies will ensure that sounds are not transmitted between classrooms. Classroom sound levels are especially critical in elementary schools, as children do not develop contextual listening skills at such a young age.

Applicability

These recommendations apply to all occupied spaces. Larger spaces such as auditoriums and gymnasiums have special considerations that are described below.

Applicable Codes

State energy codes do not provide requirements for indoor acoustic levels.

Structural and seismic safety requirements often dictate the thickness and spacing of framing members. For masonry walls, they usually require at least partial grouting of all exterior walls.

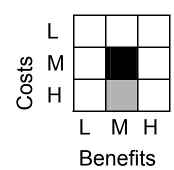
Integrated Design Implications

Classroom acoustics is also affected by sound reverberation from interior surfaces, and noise generated from HVAC equipment and exterior sources. HVAC equipment selection and location and duct design play a large role in classroom acoustics. Refer to chapters on Interior Surfaces and HVAC for more information. Design the site layout to eliminate or mitigate exterior noise sources. Acoustics is a criterion for selection of insulation materials. Heavyweight batts such as recycled cotton fibers provide good sound attenuation. Spray-in foams also provide good sound attenuation.

Cost Effectiveness

Designing the building envelope for good acoustic performance may require: higher NRC acoustic ceiling tiles, good quality drop seals and gaskets on doors, and an extra drywall layer to reduce sound transmission. HVAC design may require longer duct runs, larger duct cross-sectional area and a higher number of diffuser grilles. Costs average around $4.50/ft^2 for new classrooms but can be as low as $1.50/ft^2. Designing new construction for good acoustic performance is much less costly than retrofitting a bad design.

Benefits



Proper classroom acoustics will ensure an environment conducive to learning. It will prevent the teacher from having to strain his or her voice to be heard. Studies have shown that in many classrooms only 75% of spoken words can intelligibly be heard.[43]

Design Tools

There are a variety of acoustic software packages that can be used to analyze acoustics in buildings (more information is available at www.acoustics.org). Estimated STC ratings for common constructions can be found at www.stcratings.com. For music halls, special design considerations may be required that require assistance from an acoustics professional.

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[43] Seep, Benjamin, et al. 2000. “Classroom Acoustics I—a resource for creating learning environments with desirable listening conditions.” rev. 2002. Acoustical Society of America.

Design Details

Sound Transmission Class

Design interior walls to minimize sound transmission between rooms. The ability of a wall assembly to limit sound transmission between spaces is known as the STC. This is a measure of the noise reduction in decibels, weighted over frequencies common in human speech (125 Hz–4000 Hz). A change in STC of 3 dB is noticeable; an increase in STC of 10 dB provides twice the sound reduction. STC ratings do not address noise that occurs at other frequencies, such as that generated from HVAC equipment, musical instruments and some exterior noise sources. Modern construction that uses lightweight materials for interior walls provides only limited sound reduction. Providing a layer of gypsum board on both sides of a stud wall, with staggered joints, will reduce sound transmission. Other options for reducing sound transmission are to use metal studs, to include an air space in the cavity, or to increase the wall mass.

STC Requirements

The ANSI requirement for STC depends on the space. Interior walls separating classrooms, and exterior walls, should have an STC rating of 50 or higher. Walls separating music spaces or isolating noise from a mechanical equipment room should have a minimum STC of 60, while bathroom walls should have a minimum of 53. Metals studs provide better sound isolation than wood studs. Adding mass to a wall or increasing the air space will also improve performance. Staggering studs or using dual studs can provide a significant increase in acoustic performance. Typical STC ratings for wall constructions are shown below. Ratings are usually based on laboratory tests of a construction assembly. Actual performance will depend on the quality of construction, as air leakage paths will reduce the effective STC rating.

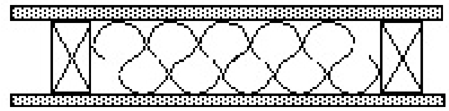
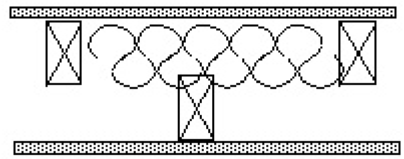
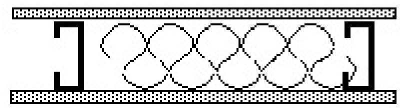
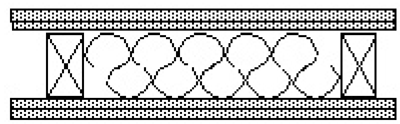
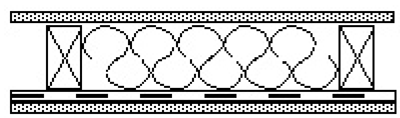
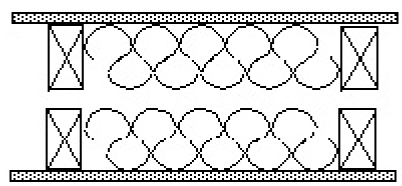
Concrete walls have relatively high STC ratings due to their thermal mass. Representative values are shown in Table 28.

Table 28—Estimated STC Ratings for CMU Walls

	Hollow Units		Grout Filled		Sand Filled	
Wall Thickness, in.	Weight	STC	Weight	STC	Weight	STC
4	20	44	38	47	32	46
6	32	46	63	51	50	49
8	42	48	86	55	68	52
10	53	50	109	60	86	55

Source: STCRatings.com. Values have a margin of error of +/- 4dB.

Table 29—Typical STC Ratings of Wall Constructions

Description	Estimated STC Rating	Wall Assembly
2x4 stud, ⅝-in. gyp (2 layers total), Batt insulation	34–39	
Staggered studs, ⅝-in. gyp (2 layers total), Batt insulation	46–47	
5/8" metal studs, ⅝-in. gyp (2 layers total), Batt insulation	43–44	
2x4 stud, ⅝-in. gyp (4 layers total), Batt insulation	43–45	
2x4 stud, ⅝-in. gyp (2 layers total), Resilient Channel, Batt insulation	45–52	
2x4 studs, ⅝-in. gyp (2 layers total), Batt insulation	56–59	

Source: STCratings.com

For exterior windows, double paned windows will have a higher STC rating (typically around 30) than single paned windows, with an STC rating near 27. Soundproofed windows that use laminated glass and spring-loaded seals can have STC ratings of 41–51. Larger windows will vibrate more than small windows of the same construction type when exposed to exterior noise, lowering their STC rating.

Impact Insulation Class

For multi-story facilities, another important design criterion is Impact Insulation Class (IIC). This rating is a measure of the ability of a floor-ceiling assembly to block transmission of structure-borne noise to the space below. IIC is measured using a tapping machine and a sound level meter. A minimum of IIC 50 is recommended for floors above learning spaces (measured without carpet). Carpet will significantly increase the ability of the assembly to block sound transmission. To increase the sound isolation from wood joist or concrete floors, special sound mats can be installed, as well as a layer of gypcrete that is spray-applied or mopped in place.

Make sure that partition walls extend up to the structural deck and do not terminate at suspended ceilings.

Consider location of classroom equipment. Classroom computers are often left running throughout the day. The CPU fans generate noise, which can be amplified when reflected off of hard surfaces. Television monitors are often located in classroom corners. This highlights the importance of reducing sound transmission between classrooms.

Manage exterior noise with good site planning and high performance windows. Locate classrooms away from playgrounds, busy roads, mechanical equipment, and other noise sources. Use double-paned glass to minimize sound transmission. For exterior walls, continuous insulation and designs that control air infiltration will also provide good sound attenuation. Exterior doors of adjacent classrooms should not be located side-by-side. Increasing the distance between exterior doors will help to reduce sound transmission.

Retrofit options to the building envelope include window replacement with double-paned insulating windows, installing drop seals and gaskets on doors, and adding carpet to classrooms (particularly to reduce noise sources from elementary grades).

The design of music education classrooms is complex and is best done with guidance from acoustic professionals.

Seal drywall at the top and bottom of the walls to ensure a continuous air barrier.

Operation and Maintenance Issues

No special maintenance is required for building envelope components with good acoustic properties.

Commissioning

Testing the sound levels of an empty classroom requires the use of a Type II sound meter. Typical meters only measure down to 40 dBA, so you should not get a reading in an empty classroom. This type of meter calculates a 1-hour average sound level that is required by the ANSI standard. For a low cost alternative, sound meters are available for as low as $79 that can provide an instantaneous reading to detect problem areas.

Measuring reverberation levels requires an acoustics consultant, but it can be estimated from the surface area and sound absorptance properties of the classroom interior surfaces.

No commissioning of exterior walls is needed other than normal construction administration.

References/Additional Information

The content of this guideline is largely based on recommendations from the Acoustical Society of America.

Seep, Benjamin, et al. 2000. "Classroom Acoustics I—a resource for creating learning environments with desirable listening conditions." rev. 2002. Acoustical Society of America.

The United States Access Board. 2003. "Listening for Learning: Counting the Costs of Noisy vs. Quiet Classrooms." www.quietclassrooms.org.

Nixon, Mike. 2003. "A Crash Course in Classroom Acoustics." Acoustical Surfaces, Inc., Chaska, MN.

Lubman, D. and L.C.Sutherland. 2001. "Good Classroom Acoustics is a Good Investment." Presented at the 17th Meeting of the International Commission for Acoustics, Rome, Italy, Sep. 2001. www.nonoise.org/quietnet/qc/ica22001.htm

Masonry Advisory Council. (library of typical STC ratings for masonry wall assemblies) www.maconline.org

The CHPS prerequisite is to design the classrooms and other core learning spaces to have background noise level less than 45 dBA. Credit is given for reducing the background noise level to 40 dBA or 35 dBA, the level recommended by the ANSI standard.

HVAC

OVERVIEW

This chapter presents guidelines for natural ventilation as well as mechanical heating and cooling systems. Presented together in one chapter, the organization emphasizes the interrelationship between these systems. Guidelines are provided for the following technologies and design strategies:

- Guideline TC1: HVAC Acoustics
- Guideline TC2: Displacement Ventilation System
- Guideline TC3: Single-Zone Unitary System
- Guideline TC4: Variable Air Volume System
- Guideline TC5: Fan-Coil System
- Guideline TC6: Water Source Heat Pump System
- Guideline TC7: Dedicated Outside Air System
- Guideline TC8: Economizers
- Guideline TC9: EMS/DDC
- Guideline TC10: Demand Controlled Ventilation
- Guideline TC11: Adjustable Thermostats
- Guideline TC12: CO Sensors for Garage Exhaust Fans
- Guideline TC13: Cross Ventilation
- Guideline TC14: Stack Ventilation
- Guideline TC15: Ceiling Fans

- Guideline TC16: Air Distribution Design
- Guideline TC17: Duct Sealing and Insulation
- Guideline TC18: Hydronic Distribution
- Guideline TC19: Hot Water Supply
- Guideline TC20: Radiant Slab System
- Guideline TC21: Baseboard Heating System
- Guideline TC22: Radiant Cooling
- Guideline TC23: Gas-Fired Radiant Heating System
- Guideline TC24: Chilled Water Plants
- Guideline TC25: Evaporative Cooling System

The main purposes of heating, ventilation and air conditioning (HVAC) systems are to provide thermal comfort and to maintain good indoor air quality (IAQ). These conditions are essential in a high performance learning environment. HVAC systems are also one of the largest energy consumers in schools, and relatively small improvements in design or equipment selection can mean large long-term savings in energy expenditures over the life cycle of the system.

The choice and design of HVAC systems can affect many other high performance goals as well. The acoustic environment of classrooms, libraries, and other school spaces can be adversely affected by noise created by the movement of air through ducts and air diffusers and from the operation of HVAC equipment. Water-cooled air conditioning equipment is generally more efficient than air-cooled equipment, but increases water consumption and maintenance.

There is no single HVAC solution that works best for all schools. Factors such as climate, local air quality, building size, construction budget, and maintenance resources all affect the optimal choice. To help in making that choice, this chapter provides some background information on thermal comfort, ventilation, and acoustics.

Integrated Design

To achieve a high-performance design, it is very important to integrate the mechanical systems with the building envelope, lighting system, and other equipment. Integrated design creates opportunities for greater comfort, lower first costs, easier equipment maintenance, and lower operating costs. It is sometimes difficult to recognize integrated design opportunities—with the typical design process, electrical, mechanical, and envelope systems are designed and specified by different disciplines and communications between the disciplines is limited. It is critically important to understand and define the project goals during pre-design and to establish a process of effective communication between design disciplines. It is equally important that the mechanical system designer participate in making early architectural design decisions. An extra investment in up-front design can easily pay for itself in improved efficiency and may also lead to reduced construction cost.

The interactions between systems may be obvious or they may be subtle. Some of the ways in which high performance can be achieved through integrated design are:

- Careful attention to shading, the locations of windows and glazing types, roof colors, building thermal mass, and enhanced natural ventilation may eliminate the need for cooling or at least shorten the cooling season.
- Natural ventilation can eliminate the need for ductwork, allowing higher ceilings and more opportunities for daylighting savings.
- Under-floor air distribution allows access for future power and communication needs.
- Attention to the radiant temperature of surfaces through careful envelope design reduces heating and cooling energy requirements. This is especially true of windows.
- Providing extra space for air handlers can offer many benefits. Larger face area for coils and filters reduces pressure loss. Adequate space at the fan outlet improves efficiency and may allow the use of housed fans, which are usually more efficient than plenum fans.
- Using a central heating and chilled water plant can allow for future installation of a thermal solar or geo-exchange source for heating or cooling energy, or for the use of a thermal energy storage system or other peak electric demand reducing measures.
- Integration of HVAC, multiple light switches, and lighting occupancy sensor controls can reduce operating costs for both systems.
- Selection of light colored finishes for systems furniture can reduce the lighting power required to achieve a certain illuminance level by as much as 25%, resulting in reduced cooling load and downsized air systems.
- Supply air temperature affects the airflow required for cooling or heating which, in turn, affects duct size and the space required for ducts. Advantages to lower supply air temperature are smaller ducts, potentially higher ceilings or reduced floor-to-floor height, and better moisture control. Disadvantages are a need for more duct insulation, less efficient cooling, and reduced economizer use.
- Better building envelope thermal performance reduces the hot spots and cold spots and enables the mechanical system to provide more uniform space conditions. A mechanical system maintains comfort by offsetting heat losses and gains from the building envelope, occupants, lights, and equipment. Most mechanical systems are unable to provide heating and cooling to the exact local sources of the losses and gains, so local temperatures in the space can become too hot or too cold and comfort issues arise.

- Comfort can be further improved by separating sedentary spaces from the building perimeter by "buffer" spaces such as circulation zones, which have less stringent comfort requirements. A buffer space strategy is an excellent example of an integrated design challenge because its implementation requires creative space planning to maintain efficient use of floor space and to capture daylighting benefits. By reducing building envelope loads and locating spaces near the building perimeter that have less stringent comfort requirements, the mechanical system can be downsized and also significantly simplified, resulting in cost savings that might not be achievable without attention to space planning and envelope design.

Thermal Comfort

Thermal comfort is affected by air temperature, humidity, air velocity, and mean radiant temperature (MRT).[44] Non-environmental factors such as clothing, gender,[45] age,[46] and metabolic activity also affect thermal comfort.

- Air temperature is measured with a normal thermometer, and most people are comfortable between 70ºF–76ºF. However, an individual's preferred temperature is higher in the summer and lower in the winter, mostly because of differences between summer and winter wardrobes.
- The relative humidity range for human comfort is about 20%–60%. The moisture content of air can also be expressed as the wetbulb temperature, humidity ratio, or dew point temperature.
- Ceiling fans, circulation fans, or operable windows can provide air movement, and such air movement increases the upper temperature limit of comfort by about 2º.
- The temperature of the surfaces surrounding a person (walls, ceiling, floor, and windows) affects the MRT, especially during hot and cold days. Caves have a low MRT, which makes them comfortable even when the air temperature is high. Likewise, rooms with heated floors are comfortable, although the air temperature may be cooler.

The traditional definition of thermal comfort found in ASHRAE Standard 55 defines comfort in terms of operative temperature and humidity and represents the range of thermal conditions when 80% of sedentary, or slightly active, people find the environment thermally acceptable (see Figure 122). Operative temperature is the average of the mean radiant and ambient air temperatures weighted by their respective heat transfer coefficients. The Standard 55 definition of comfort does not consider air movement or velocity. Most occupants do not feel comfortable when it is drafty and cold.

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[44] MRT is the temperature of an imaginary enclosure where the radiant heat transfer from a human body equals the radiant heat transfer to the actual non-uniform temperature surfaces of an enclosure.

[45] Women generally prefer temperatures about 1° warmer.

[46] Persons over 40 generally prefer temperatures about 1° warmer.

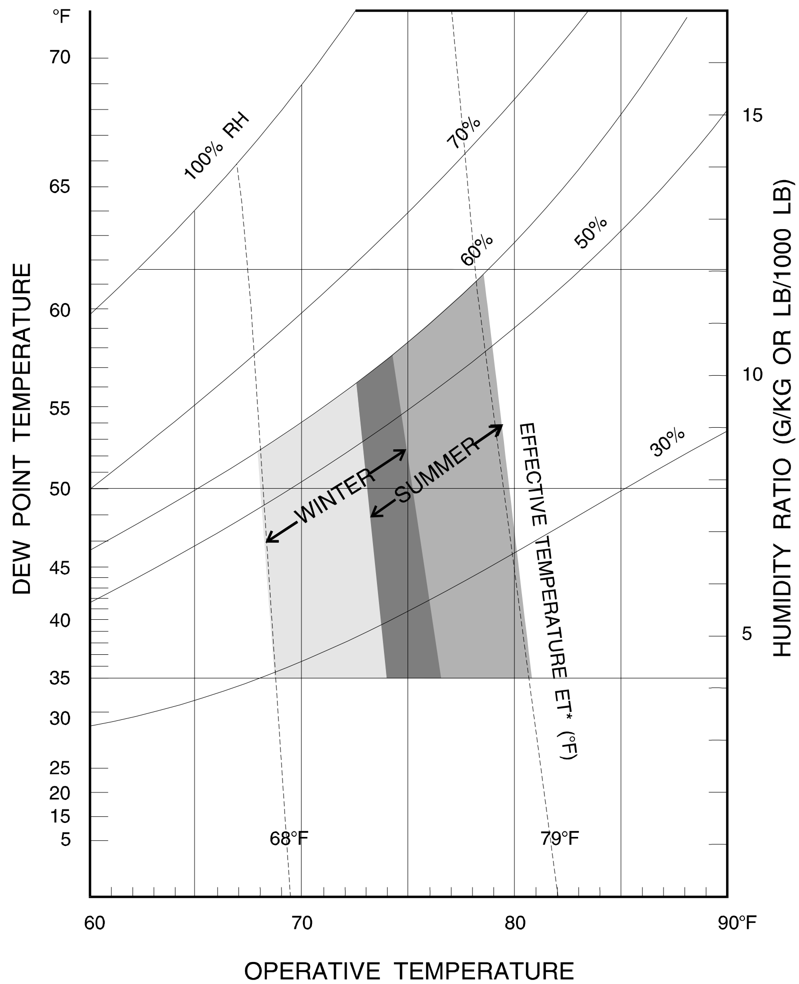

Figure 122—ASHRAE Standard 55 Comfort Envelope

Source: 2001 ASHRAE Handbook—Fundamentals*. This figure shows the temperature and humidity ranges within which about 80% of the population will be comfortable while wearing typical summer and winter clothing and being in a sedentary or slightly active state.*

Much of the research on thermal comfort is based on asking people if they are hot or cold and then correlating their response to measurements of air temperature, humidity, air velocity, and MRT. The ASHRAE thermal sensation scale is commonly used for such surveys (see Table 30). Some of this research has been conducted in test environments where temperature and humidity can be tightly controlled. Other research has been conducted in workplaces.

Table 30—ASHRAE Thermal Sensation Scale

Cold	**Cool**	**Slightly cool**	**Neutral**	**Slightly warm**	**Warm**	**Hot**
-3	-2	-1	0	+1	+2	+3

Since thermal comfort is not an absolute condition but varies with each individual, statistical measures of thermal comfort are sometimes used. One statistical measure is the predicted mean vote (PMV). PMV predicts the mean response of a large population on the ASHRAE thermal sensation scale (see Table 30). A PMV of +1 means that, on average, people are slightly warm. PMV can be calculated if information is known about the metabolic rate, typical clothing, and environmental conditions such as temperature and humidity. Once PMV is known, it can be translated to another statistical factor called percent of population dissatisfied (PPD).

Air movement also affects comfort. Operable windows, ceiling fans or circulation fans create or enable air movement. Too much air movement is uncomfortable, especially when it is cold. When it is hot, air velocities up to about 200 ft/minute are pleasant and enable most occupants to be equally comfortable at 2ºF higher temperatures. Air speeds higher than about 200 ft/minute should be avoided because they can create drafts and be annoying (see Table 31).

Table 31—Effect of Air Movement on Occupants

Air Velocity	Probably Impact
Up to 50 ft/minute	Unnoticed.
50 to 100 ft/minute	Pleasant.
100 to 200 ft/minute	Generally pleasant, but causes a constant awareness of air movement.
200 to 300 ft/minute	From slightly drafty to annoyingly drafty.
Above 300 ft/minute	Requires corrective measures if work and health are to be kept in high efficiency.

Source: Victor Olgyay, Design with Climate, Princeton University Press, 1963

An adaptive comfort model has been added to *Standard 55-2004* based on research by Gail Brager and others at the University of California, Berkeley. That research shows that occupants in naturally ventilated buildings are comfortable for a wider range of thermal conditions than in buildings that have continuous mechanical cooling. Occupants of air-conditioned schools develop high expectations for even and cool temperatures, and are quickly critical if thermal conditions drift from these expectations. Occupants in naturally ventilated schools adapt to seasonal changes in mean outdoor temperature and are comfortable for a wider range of conditions. They even prefer a broader range of thermal conditions.

Research shows that part of the difference in comfort expectations is due to behavioral adaptations: occupants in naturally ventilated schools wear appropriate clothing and open windows to adjust air speeds. However, some of the difference is due to physiological factors. The human body's thermal expectations actually change through the course of a year, possibly because of a combination of higher levels of perceived control (occupants can open and close windows) and a greater diversity of thermal experiences in the building.

Using the adaptive model of thermal comfort from of ASHRAE *Standard 55-2004* allows schools to be designed and operated to both optimize thermal comfort and reduce energy use. In many climates, maintaining a narrowly defined, constant temperature range is unnecessary and expensive. Figure 123 illustrates the adaptive comfort model, showing the range of indoor comfort temperature based on the mean monthly outdoor temperature.

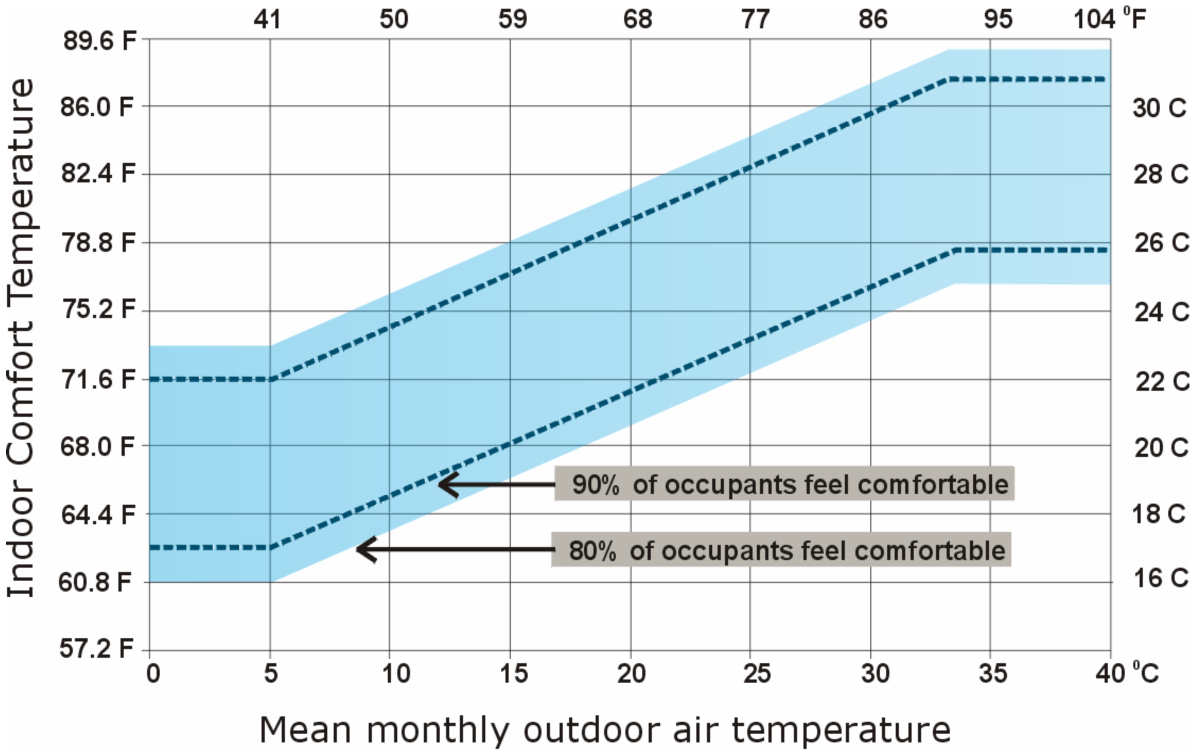

Figure 123—Adaptive Comfort Model from ASHRAE Standard 55-2004

Figure 124 applies the adaptive comfort model to Sacramento based on typical year climate data and shows how the indoor comfort temperature range varies over the year. The graph also shows the average daily maximum temperature for each month, which gives a rough indication of the season where natural ventilation might be able to meet comfort needs. Figure 125 shows the same information for San Francisco, Figure 126 covers Riverside, and Figure 127 shows Long Beach data. These graphs show that outdoor conditions in California's coastal areas typically fall within comfort boundaries, while the inland climates exceed the upper boundaries from late spring through early fall.

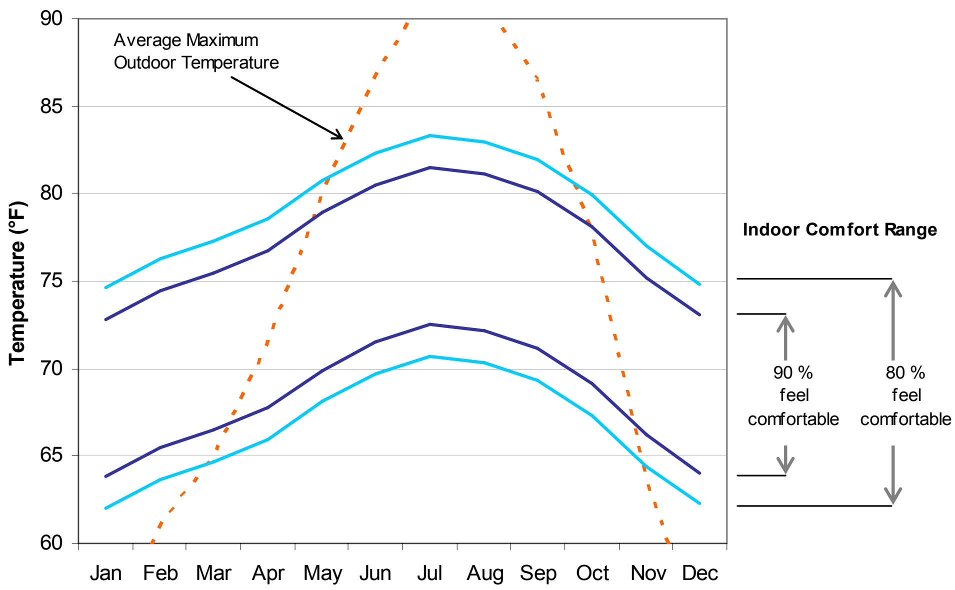

Figure 124—Adaptive Comfort Model Results for Sacramento

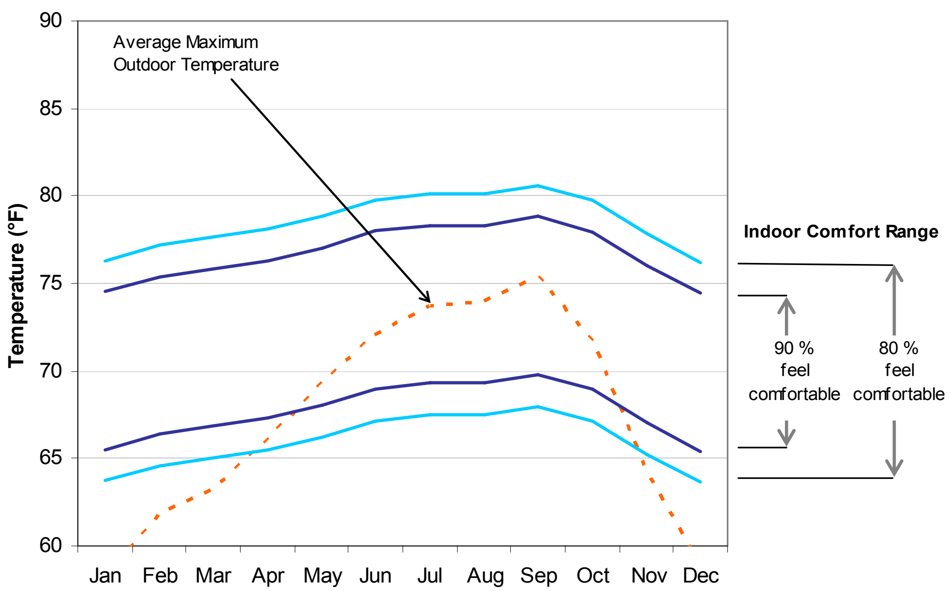

Figure 125—Adaptive Comfort Model Results for San Francisco

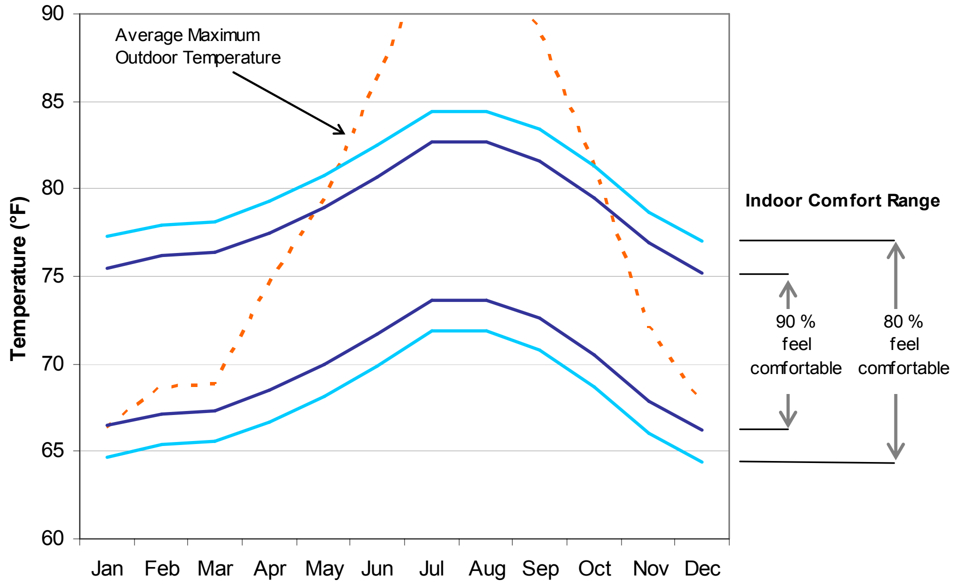

Figure 126—Adaptive Comfort Model Results for Riverside

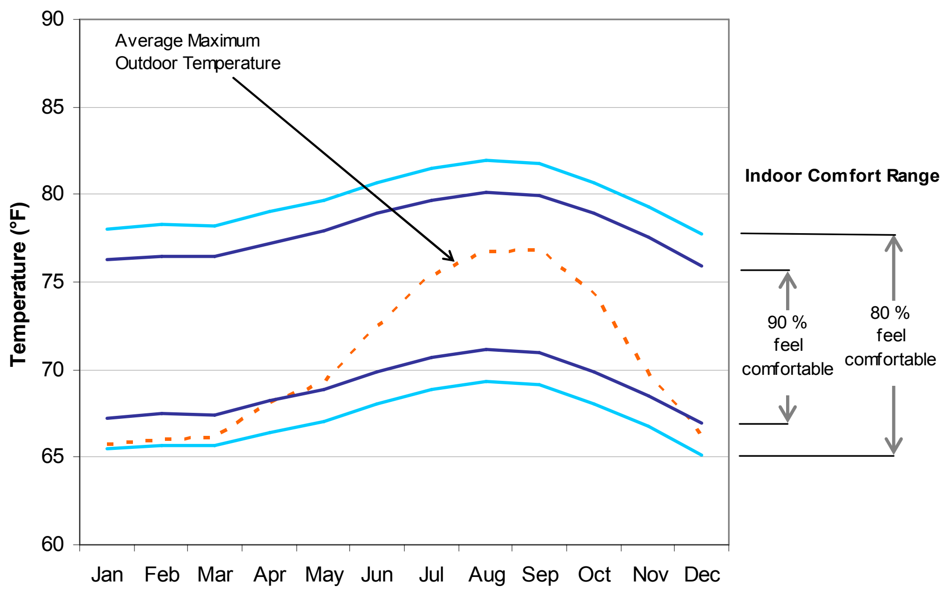

Figure 127—Adaptive Comfort Model Results for Long Beach

Potential for Natural Ventilation

Natural ventilation is an effective and energy efficient way to provide outside air for ventilation and to provide cooling in many California schools. Historically, most schools in California have not been air conditioned and natural ventilation has been the only means of cooling. The classic classroom has high windows to provide both natural ventilation and daylighting. In most California climates, natural ventilation is still a solid strategy, but windows must be designed to maintain a safe and secure facility while allowing air to enter and escape, even at night and on weekends.

The potential for natural ventilation varies with climate. Figure 124 through Figure 127 provide a rough idea of the potential for maintaining thermal comfort in classrooms for four California climate regions. These tables indicate the number of hours during the year that outdoor conditions fall within the comfort range. The hours listed in these charts cover 7AM–5PM. They show, for example, that outdoor conditions match indoor comfort requirements for 363 hours in Riverside, while the total is only 236 hours in Long Beach. Another value listed on these charts is the total number of hours when outdoor temperature exceeds the upper comfort limit, indicating roughly how many hours that air conditioning would be necessary. The charts show these values to range from 914 hours in Riverside to 126 hours in Long Beach. These totals correspond to 35% and 5% of school hours respectively (assuming a year-round schedule).

The potential for natural ventilation depends on a number of other factors in addition to outdoor temperature and humidity, and there can be cases where natural ventilation is not feasible even if the climate is mild. Noise and outdoor air quality are two significant issues. Some conditions that reduce the potential for using natural ventilation include the following.

- Outdoor air contaminants at the site make the use of unfiltered ventilation air a health hazard to occupants.
- Odors due to external sources cannot be mitigated.
- External noise is excessive at the windows or other potential natural ventilation openings, and the external noise sources cannot be mitigated with reasonable measures such as installing sound barriers along roadways or relocating equipment or other noise sources. For new campuses, it may be possible through careful site planning to keep noise sources such as playgrounds and circulation areas away from natural ventilation openings.

In even the mildest climates there may be some hours during the year when natural ventilation will not be able to keep the indoor conditions comfortable. In those cases a decision needs to be made whether some number of hours of “discomfort” are acceptable or whether a cooling system needs to be provided. Some school districts set a policy to guide this decision. San Diego, for example, permits air conditioning if indoor temperatures would otherwise exceed 78°F for more than 10% of school hours.

Where cooling is unavoidable, a “mixed mode” approach should be considered. In this approach the cooling system can be shut off and natural ventilation can be employed to maintain comfort and air quality when outdoor conditions are mild.

For modernization of existing naturally ventilated school buildings, it is important to note that there are measures that can improve the comfort of an existing building without resorting to air conditioning. Solar control measures such as window shading, roof insulation, and a cool roof surface can improve thermal comfort significantly. Lighting retrofits that reduce lighting power will also help a bit. These measures, together with repair or replacement of operable windows can help avoid the need for air conditioning as well as the significant long-term costs required to maintain and operate an air conditioning system.

	Relative Humidity											
Drybulb Temperature (°F)	<10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	100%	Total Hours
103-107		3	1									4
98-102		26	20									46
93-97		14	54	3								71
88-92		2	89	53								144
83-87		6	49	118	33							206
78-82		6	19	73	101	1						200
73-77		3	30	45	82	72						232
68-72			13	31	66	89	40	5				244
63-67			14	22	64	73	87	44	2			306
58-62			10	27	29	73	87	73	20			319
53-57			7	17	22	51	52	67	92	17		325
48-52				10	21	18	36	35	73	45	6	244
43-47				2	11	13	4	34	33	44	11	152
38-42					4	3	8	9	8	18	13	63
33-37					1	2	1	1	9	8		22
28-32							1	1				2
Total Hours	0	60	306	401	434	395	316	269	237	132	30	2580

Figure 128—Natural Ventilation Potential, Sacramento

385 Hours in Comfort Zone, 671 Hours above 78°F

	Relative Humidity											
Drybulb Temperature (°F)	<10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	100%	Total Hours
103-107	3	3										6
98-102	5	30	4									39
93-97	21	56	42	13								132
88-92	9	61	92	63	5							230
83-87	4	31	70	114	21	2						242
78-82		47	59	74	67	17	1					265
73-77	1	50	69	52	81	54	7	1				315
68-72	1	54	56	56	55	65	35	7	2			331
63-67		27	61	69	59	52	52	36	8			364
58-62		18	31	32	57	59	53	36	25	10	5	326
53-57		12	13	20	24	22	33	36	23	14	3	200
48-52		1	4	9	9	13	6	5	15	12	2	76
43-47			1	1	4	4	6	10	6	4	1	37
38-42					1	6	1		3	4		15
33-37							2					2
28-32												0
Total Hours	44	390	502	503	383	294	196	131	82	44	11	2580

Figure 129—Natural Ventilation Potential, Riverside
363 Hours in Comfort Zone, 914 Hours above 78°F

Drybulb Temperature (°F)	Relative Humidity <10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	100%	Total Hours
103-107												0
98-102												0
93-97												0
88-92			1		1							2
83-87		2	3	2	4	5	1					17
78-82	4	7	2	7	17	38	32					107
73-77	1	24	23	16	17	118	208	24				431
68-72	3	17	33	34	27	51	229	172	17			583
63-67		14	28	22	57	72	168	211	67			639
58-62	2	8	19	15	22	63	115	182	109	9	1	545
53-57	1	7	9	7	5	19	15	47	79	14		203
48-52		2		2	3	4	8	4	11	7	1	42
43-47			1	2		1		2	1	1	2	10
38-42										1		1
33-37												2
28-32												0
Total Hours	11	81	119	107	153	371	776	642	284	32	4	2580

Figure 130—Natural Ventilation Potential, Long Beach
236 Hours in Comfort Zone, 126 Hours above 78°F

Drybulb Temperature (°F)	Relative Humidity <10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	100%	Total Hours
103-107												0
98-102												0
93-97												0
88-92			1	3								4
83-87		8	1	8	10	8						35
78-82		2	9	2	29	31	14					87
73-77			3	3	7	72	70	5	1			161
68-72			5	3	13	55	218	46	3			343
63-67			3	6	12	61	154	230	21	6		493
58-62				7	22	54	158	283	124	10	2	660
53-57			2	2	8	30	57	158	181	36	3	477
48-52			1	1	5	10	34	48	119	19	2	239
43-47				2	2	3	7	24	21	10		69
38-42				1			2	1	3	4	1	12
33-37												0
28-32												0
Total Hours	0	10	25	38	108	324	714	795	473	85	8	2580

Figure 131—Natural Ventilation Potential, San Francisco
153 Hours in Comfort Zone, 126 Hours above 78°F

Outside Air Ventilation

Classrooms and other school spaces must be ventilated to remove carbon dioxide and other pollutants from exhaled breathing air, body odors, cleaning chemical odors, and other pollutants that are generated inside the building by occupant activities. The national consensus standard for outside air ventilation is ASHRAE *Standard 62.1*. This standard is the basis of requirements in Title 24 of the California Building

Code. Title 24 requires that outside air ventilation be provided through either natural ventilation or mechanical means.

If outside air is provided through natural ventilation, then all spaces within the room must be within 20 ft of a window, door, or other ventilation opening, and the total area of ventilation openings must be greater than 5% of the floor area. For a typical 960-ft² (30 ft x 32 ft) classroom, the minimum free ventilation area must be at least 48 ft². The 20-ft rule would also require that ventilation openings be provided on two sides of the room; otherwise some portions of the classroom would be further than 20 ft from a window. See Figure 132.

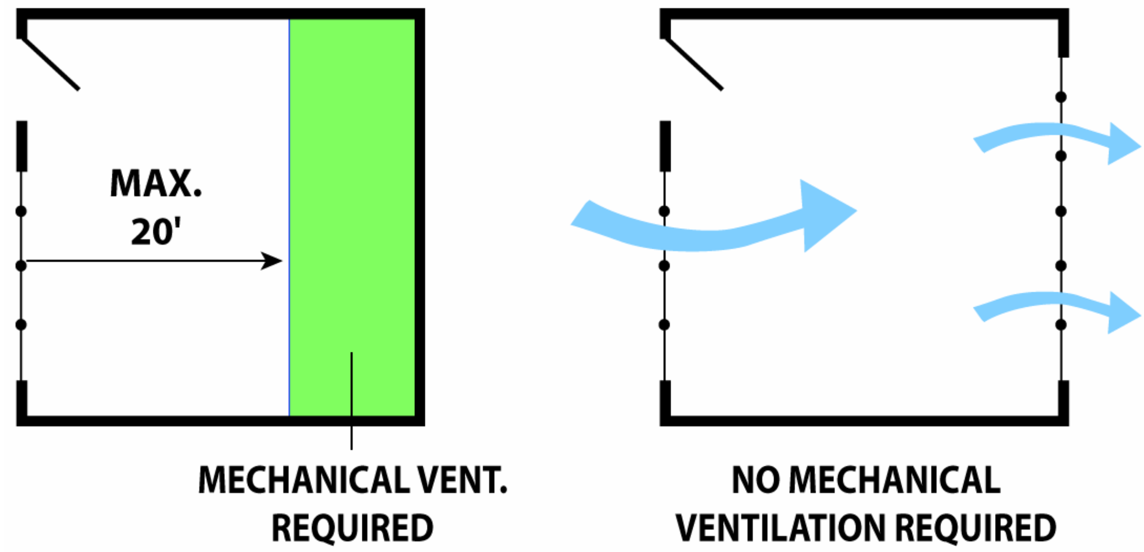

Figure 132—Mechanical Ventilation Requirement for Typical Classroom Space

If outside air is provided through a mechanical system, then at least 15 cubic feet per minute (cfm) of outside air must be provided for each occupant. A typical classroom with 30 people requires a minimum of 15 x 30 or 450 cfm per occupant. However, the actual code minimum ventilation rate for a typical classroom is 360 cfm.[47] Other spaces in schools require differing levels of outside air ventilation, based on the expected occupant density of the space and the recommended ventilation rate of 15 cfm/occupant. See Figure 133.

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[47] Title 24 specifies 15 cfm per person and sets the occupant density at one half the code-specified occupant density for fire egress, which is 20 ft²/occupant. This works out to 24 occupants for a typical 960 ft² classroom [(960 ft² / 20 ft²/occupant)/2], and 24 occupants times 15 cfm per occupant is 360 cfm of outside air ventilation per classroom.

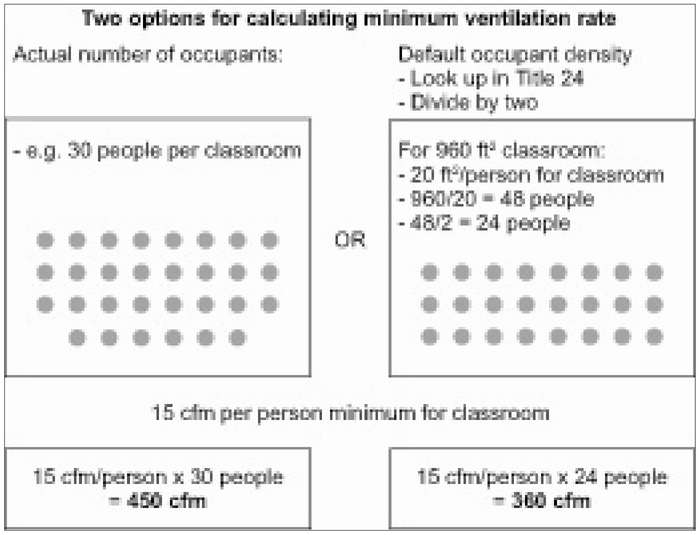

Figure 133–Mechanical Ventilation Rate Requirement for Typical Classroom Space

The number of occupants is highly variable in some school spaces such as gyms, auditoriums, and multi-purpose rooms. Title 24 requires systems to vary the quantity of outside air ventilation in these spaces based on the number of occupants. One technique for addressing this issue is to install carbon dioxide (CO_2) sensors that measure concentrations and vary the volume of outside air accordingly. If an auditorium fills up for a school assembly, CO_2 concentrations will increase, the HVAC system will be signaled, and outside air volumes will be increased accordingly. This type of control can both save energy and significantly improve IAQ. This type of technique combined with variable rate fans can significantly reduce electrical energy consumptions in large volume areas.

Title 24 not only specifies the minimum volume of outside air that needs to be provided to spaces, but also requires that this amount of air be provided during all hours when the spaces are normally occupied. Systems must also be designed to provide at least three air changes per hour, or the required ventilation rate indicated above for the hour prior to normal occupancy of the building. This requirement ensures the clearing of building-related contaminants that may have built up overnight while the system was shut down.

The location of ventilation air intakes and exhausts is a critical aspect of integrated building design and sometimes difficult to coordinate or optimize. Outside air intake dampers must be carefully located to avoid pollution from sources such as parking lots, loading docks, adjacent roadways, sewer vents, or boiler exhaust fumes. Patterns of air movement around buildings can be quite complex and dynamic. Designers are advised to consult ASHRAE *Handbook—Fundamentals* Chapter 15 airflow analysis models for exhaust stack reentrainment modeling. If major sources of industrial pollution exist nearby, more sophisticated models are often used for predicting down wind concentrations of pollutants. In the extreme case of urban settings with multiple building heights, designers should consider building scale models for testing in wind tunnels.

IAQ is also affected by the selection of interior finishes and materials. These issues are discussed in the Interior Surfaces and Furnishings chapter. The design of air distribution ducts and fan systems can also have a significant effect on IAQ. Exposed fiberglass and other porous or flaking materials should never be used on the interior of ducts, unless they are encapsulated with a surface finish that is robust, will not break down from atmospheric ozone exposure (smog), and can be cleaned with a mechanical brush without releasing particles.

Load Calculations

Load calculations form the basis of mechanical system design and must be performed properly for systems to function as intended, especially with respect to energy-efficient operation. The compressors in oversized packaged air conditioners or heat pumps cycle frequently and overall efficiency drops with each cycle. Frequent cycling also reduces the efficiency of boilers, furnaces, and many other types of equipment. Properly sized equipment, with multiple firing rates and stages of cooling, reduces cycling and helps maintain efficient operation, but smaller, properly sized equipment that is matched to the building load is also often less expensive and can reduce initial construction costs.

Many computer programs and calculation methodologies can be used for load calculations. However, the results are only as accurate as the inputs. The assumptions used about infiltration rates, lighting levels, equipment, and occupant loads are often more important than the actual software that is used in the calculations. Engineers should take care to make assumptions that are consistent with the energy-efficient recommendations made in other chapters of this manual. An efficient building shell and lighting system should result in significant mechanical equipment size reductions and reduce cost. Recommendations for good load calculation procedures include the following.

- Thoroughly and clearly document assumptions and load calculation inputs and include a summary of this information in any "design intent documentation." These assumptions should include indoor and outdoor design conditions. Include all input parameters that strongly affect load calculation results.
- For the lighting internal gains, verify the lighting loads based on fixture counts for spaces and actual lamp and ballast power demands rather than on simply Watt/ft^2 assumptions. For internal heat gain from the equipment (plug loads) load internal gains, base inputs on field verified measurements or field-based research rather than rule-of-thumb programming assumptions. For all internal gains, employ realistic schedules for varying power densities over the course of your design day.
- For envelope gains, confirm window performance based on basis-of-design glazing and frame effects and make sure to account for thermal bridging in wall elements. When defining zones in the load calculation tool, make sure to incorporate room mass effects as appropriate. Also, consider how the building systems control schemes might affect load calculations; e.g., if you plan on using supply temperature reset then interior zones where loads do not vary significantly should be designed with higher supply air temperatures than perimeters where loads do vary.
- Another recommendation is to develop and circulate a "load calculations standard" document within an engineering office to gather input and recommendations from a wide variety of engineers who will have experiences to contribute.

- Work in a manner that allows load calculations to be updated at appropriate periods as the design progresses. The use of “templates” within load calculation software tools can facilitate this process.
- Confirm load calculation results with “reality checks” to make sure results are correct. These can include quick hand calculations to roughly confirm results, comparison to typical “rule of thumb” metrics, and review by other experienced engineers.
- See Guideline TC2: Displacement Ventilation System for information about load calculations for displacement ventilation systems, which require different load assumptions than a typical mixing air delivery system.

It is critical that the mechanical designer also consider typical operating conditions and the efficiency and comfort performance over the range of likely conditions rather than just on the design day. Some of the recommended considerations for calculating loads under typical conditions are listed here.

Many buildings are rarely fully occupied; assume a reasonable partial occupancy level.

- Modern lighting systems often have occupancy sensor controls and seldom are all lights on at the same time. Assume some diversity in lighting load.
- Use a moderate assumption for plug loads.
- Use average weather conditions. Ideally, use an annual hourly simulation with typical climate data to evaluate the range of conditions.
- If the building has interior window shades, then assume that some fraction of the shades are deployed when sun strikes the window.
- Account for external shading from overhangs, sidefins or other external shading devices.

Figure 134 illustrates the sources of cooling load in a typical classroom. This example would be typical of a single-story “finger-plan” school, where the classroom has two walls exposed to outdoor conditions, each with a window and small overhang. An interesting point to note here is that the envelope loads – walls, windows, and roof – account for only about 20% of the total cooling peak load. Internal heat sources add up to 34%, and outdoor air for ventilation accounts for 46% of the load.

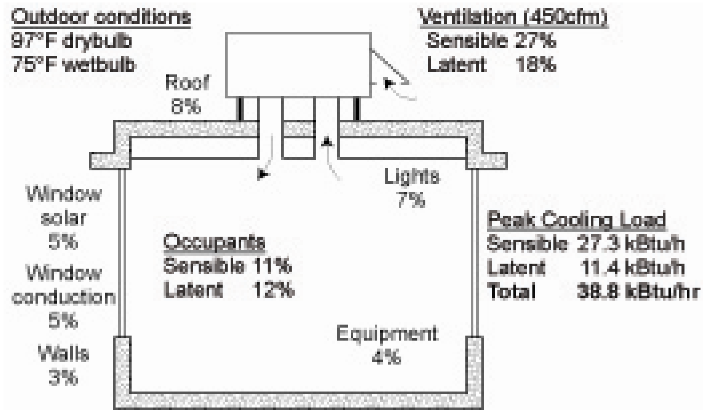

Figure 134— Peak Cooling Load Components for Typical Classroom, Sacramento Climate

Equipment Selections

When using the results of the load calculations to select equipment, keep in mind the energy use of this equipment at all times. One important factor in determining equipment energy use is the full-load efficiency of the piece of equipment. Although full-load efficiency is important, equipment only runs at full load for a small number of hours each year and spends the vast majority of operating hours at part-load conditions. As such, part-load efficiency typically is much more important to overall energy use than full-load efficiency.

When selecting equipment, take part-load operation and part-load efficiency into account. A good approach to selecting equipment on this basis is to use building simulation to thoroughly test different pieces of equipment against the predicted part-load operation profile and compare energy costs. Some manufacturers also offer software tools to evaluate equipment performance across a range of conditions.

Clearly, sizing mechanical systems properly is critical to both energy efficiency and cost effectiveness. However, designers might oversize mechanical systems for a variety of reasons:

- Uncertainty in earlier stages of design about real values for envelope or loads.
- Expense of rerunning load calculations and redesigning later in design.
- Late changes in design due to budget issues that cut into tighter sizing.
- Liability if the design cuts too close or occupancy conditions shift and mechanical systems are not adequate to maintain comfort for all occupants.

The best answer to these challenges is to focus on selecting a system that will operate effectively over a wide range of loads. It is still important to sharpen the pencil as much as possible and minimize equipment cost, but some margin of oversizing will not create a performance liability when attention is paid to designing for effective part-load operation.

Applicable Codes

The requirements of Title 24 related to outside air ventilation are described in the section above. In addition, Title 24 has many other requirements that affect the selection and design of school's HVAC systems. Some of the requirements are highlighted here:

- Equipment sizing is limited to the smallest unit that meets the design heating and cooling loads (with some exceptions).
- Rules are included for load calculation methods and assumptions.
- Most equipment must meet minimum energy-efficiency requirements. Air conditioner efficiency is expressed as a minimum energy-efficiency ratio (EER), while gas-fired heating equipment efficiency is expressed as an annual fuel utilization efficiency (AFUE). Water heater efficiency is communicated as an energy factor (EF).
- Systems that reheat or re-cool air are prohibited, including constant volume reheat systems and most multi-zone systems. (Triple deck multi-zone systems do not mix heated and cooled air, but rather mix heated and outside air, or cooled and outside air.) Variable air volume (VAV) systems with reheat are permitted as long as air volume is reduced to the minimum before reheating occurs.
- Pipes and ducts must be insulated and sealed.
- Ducts in single-zone systems such as packaged rooftop units must be either sealed and tested or be located within conditioned space. An exception is provided for high efficiency units in some cases.
- Appropriate HVAC controls must be installed. Every classroom or other thermal zone must have its own thermostat to control the supply of heating and cooling to the space. Systems must also have a means to automatically shut down during off hours. A time clock would be needed with programmable schedules, one for a school day and one for a non-school day, as well as a timed override for system operation after hours.
- Large systems (more than approximately 6 tons and more than 2,500 cfm) require that economizers be installed. Economizers are available and recommended for smaller systems as well, provided they are maintained and operated correctly.
- Large fan systems (25 hp or larger) have a maximum fan power limit of 0.8 W/cfm for constant volume systems and 1.25 W/cfm for variable volume systems.
- Individual VAV fans of 10 hp and larger must have a variable speed drive.
- For VAV systems with direct digital control to the zones, static pressure reset controls are required.
- Central plants with 300 tons capacity or greater are limited to a maximum of 100 tons of air-cooled chillers, and the remainder must be water or evaporatively cooled.

- Restrictions exist on the use of electric resistance heating systems when other alternatives are available.

Environmental Considerations

In terms of environmental performance, the HVAC system primarily affects energy usage, acoustic comfort, the life of building materials, and indoor environmental quality. Proper HVAC performance will enhance the learning environment and the health of the occupants. However, poor design or installation will detract from the learning environment and could contribute to illness. Other environmental considerations are relevant, such as efficient use of materials, employing energy recovery devices for heating or cooling, conservation of water, use of materials that can be readily recycled, and avoidance of ozone-depleting refrigerants. The following specific measures can be used to reduce the environmental impact of HVAC systems.

- Select environmentally preferable equipment and materials.[48]
- Specify low-toxic (water-based) mastic to seal ducts, or in cases where round ducts are utilized, specify internal gasketed duct joint systems so that duct sealants are not needed.
- Select durable long-life equipment with hinged access doors that allow for equipment service and that can be easily refurbished.
- Eliminate equipment that uses chlorofluorocarbon (CFC) refrigerants and carefully considering equipment that use hydrochlorofluorocarbons (HCFC) refrigerants.[49]
- Evaluate the environmental trade-offs between energy-efficient evaporative heat rejection and water consumption. Alternatives to potable water usage for evaporative heat rejection include ground and groundwater heat sinks, surface water heat sinks, and alternative sources of evaporative make-up water. The environmental impact of each alternative should be carefully weighed.
- Select metal components of HVAC systems that can be recycled. Suggest recycling equipment at the end of its life cycle. In addition, metal components of HVAC equipment typically include recycled content, although data are not readily available as to the amount.
- Consider energy recovery equipment for the ventilation system since heating and cooling the ventilation air accounts for the majority of the load that is placed on the systems in a well-designed facility. Payback periods for energy recovery are often 10 years; however, the school systems are designed to last 30–50 years.

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[48] For specific product recommendations, see GreenSpec: The Environmental Building News Product Directory and Guideline Specifications, www.buildinggreen.com/, and OIKOS's Redi Guide (Resources for Environmental Design Index), available from Iris Communications, (800) 346-0104, www.oikos.com/.

[49] Given the high efficiency purge systems and rigorous refrigerant management protocols currently in place, the inherent energy efficiency of R-123 over R-134 may represent a significant environmental benefit.

- Select environmentally friendly materials that can be installed with benign materials (i.e., fasteners instead of solvent glues).
- Consider renewable energy sources such as solar hot water systems.

Commissioning

Commissioning is the process of ensuring that the intent of the project program is properly reflected in the design and that the design intent is properly executed during construction and operation. Commissioning tasks start at the very beginning and continue throughout the project, even into the occupancy period. Experience has shown that most energy efficient designs do not achieve intended savings without the oversight and performance acceptance testing provided by a commissioning process.

For larger facilities, the project manager should consider including an independent commissioning agent in the early planning process. A commissioning plan should be developed during schematic design and updated at each project phase. Typical elements of a commissioning process include:

- Commissioning plan development.
- Documentation of design intent.
- Design review.
- Submittals review.
- Inspections and system functional performance testing.
- Enhanced operating and maintenance documentation, including hands-on training of the staff operating and maintaining the equipment.
- Post-occupancy testing and operation evaluation.

For small schools with relatively simple mechanical systems, a detailed commissioning process may not be feasible. However, some form of a performance acceptance testing of the equipment and controls is essential to ensure that systems are operating properly and at peak efficiency before, or soon after, occupancy.

Specific commissioning issues are discussed in each of the guidelines below. Also, the CHPS Best Practices Manual Volume V: Commissioning has more information. A number of sample commissioning plans and guidelines are also available. A good source is the Portland Energy Conservation Inc. at www.peci.org/. Other resources include the U.S. Department of Energy (DOE) at www.energy.gov/, the American Society of Heating, Refrigerating and Air-Conditioning Engineers at www.ashrae.org/, and the Sheet Metal and Air Conditioning Contractors' National Association at www.smacna.org/.

Design Tools

Software load calculation tools can greatly assist engineers in developing well-documented, clear load calculations, which form the basis of good mechanical system design. The following are some of the more commonly used programs.

- Trane Trace Load 700 (www.trane.com/commercial/software/trace/).
- Carrier E-20 II Hourly Analysis Program (www.carrier-commercial.com/software/).
- Elite CHVAC (www.elitesoft.com/).
- Wrightsoft Right-Suite Commercial (www.wrightsoft.com).

Psychrometric analysis programs facilitate the calculation of psychrometric states of room air for various loading conditions, infiltration and air supply rates.

Additional simulation programs are valuable tools for evaluating the part load performance of mechanical systems and the likely variations in loads. Examples include:

- DOE-2.1E (gundog.lbl.gov/)
- Equest (www.energydesignresources.com).
- EnergyPlus (www.energyplus.gov).

Computational fluid dynamics (CFD) software can help in studies of natural and mechanical ventilation and is very useful in creative integration of mechanical and architectural design. Historically, this type of analysis is expensive. Many manufacturers of air distribution equipment can now provide CFD graphic representation of the air distribution delivered by their products.

Other programs integrate with CAD software and aid the design of piping and duct systems. Many of these tools also have cost estimating capabilities, which are very helpful in design optimization and budget review.

DOE has a comprehensive listing of energy design tools at www.eere.energy.gov/buildings/tools_directory/.

Controls

HVAC, lighting, water heating, signal/communication wiring, and other systems need to be operated and controlled efficiently and effectively. With integrated design, the effective control of one system may depend on how another system is being operated. Building management systems offer integrated control of HVAC, lighting, outside air ventilation, natural ventilation, building security, and water heating systems. Energy can be saved through efficient control that turns off or slows down systems when they are not needed. In general, slowing down most fans by 25% cuts the electric energy the fan uses by 50%. Building management systems can also provide information for students and faculty to understand how the building is working and how much energy it is using. Building management systems should always be equipped with easy-to-use graphic interfaces to facilitate their proper use.

For more details, see the following guidelines in this chapter:

Guideline TC9: EMS/DDC

- Guideline TC10: Demand Controlled Ventilation
- Guideline TC11: Adjustable Thermostats
- Guideline TC12: CO Sensors for Garage Exhaust Fans

System Selection

There are at least two ways to look at the process of selecting an HVAC system type. One perspective is that system type has a significant impact on comfort, air quality, and operating cost. That perspective leads us to carefully consider which system type is optimal for our project. A second perspective is that any of the standard system types used for schools can perform well and be energy efficient if attention is paid to design and construction details. This second perspective leads us to focus our efforts on system design rather than system type selection. Both of these perspectives have merit, and fortunately they are not mutually exclusive. The recommendation in this section of the manual is that a reasonable amount of attention be paid to evaluating alternative system types. Then other portions of the manual can be referenced for guidance on high performance design for the selected system.

A fundamental decision in selecting an HVAC system is determining whether or not mechanical cooling is required. If natural ventilation can meet the cooling needs, then one of several heating-only system types can be selected. On the other hand, if mechanical cooling is necessary, then a different list of system options is appropriate. The decision whether air conditioning is necessary can often be made based on experience with other schools or buildings in the area. A climate analysis, as described earlier in the section titled Potential for Natural Ventilation, can also help determine whether natural ventilation is likely to be adequate.

If mechanical cooling is found to be unnecessary, then a choice from the following list of heating-only systems is likely to be appropriate. The first three are hydronic systems without a fan. The furnace and fan coil options use a fan, which can also be used to provide ventilation (see the topic Ventilation for Heating Only Systems for more details).

- Baseboard. Typically consists of a hot water tube with fins that runs along a portion of the perimeter wall within a metal housing. Air is heated primarily by convection as warm air rises out of the top and room air is drawn in at the bottom of the housing. No fan is necessary.
- Wall panel. Similar to a traditional radiator, hot water passes through tubes in a metal panel mounted on the wall. Heat is transferred to the space through a combination of convection and radiation. No fan is necessary.

- Heated floor. Hot water circulates through tubes in the floor, typically within a concrete slab. No fan is necessary.
- Furnace. Heated air produced by a furnace is delivered to the space via ducts and supply fan.
- Fan coil. Similar to a furnace except that air is heated by a hot water coil.

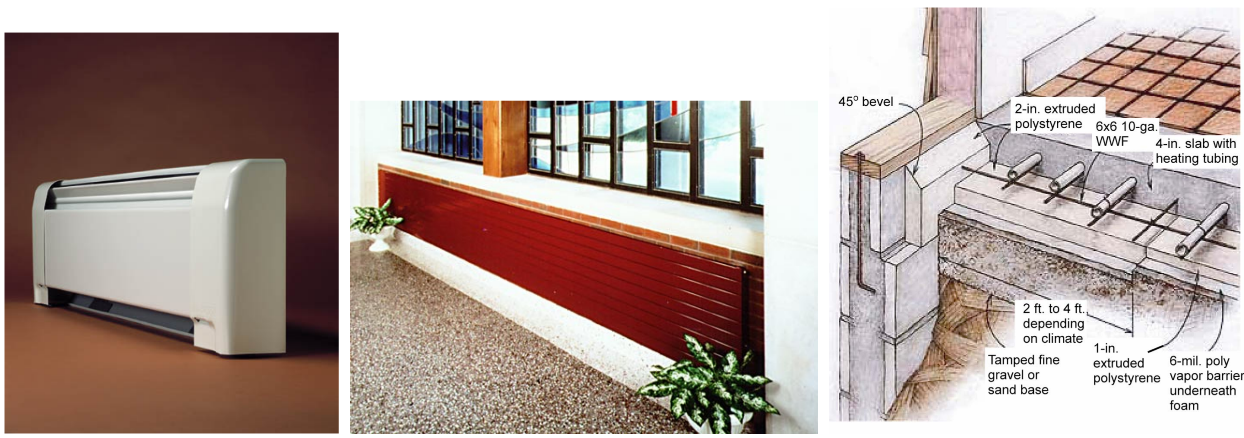


Figure 135—Examples of Hydronic Heating-Only System Options

Source: Embassy Industries Incorporated, Runtal

If mechanical cooling is necessary, then there are several HVAC system types to choose from.

- Single-zone packaged rooftop (see Table 34).
- Single-zone split system (see Table 35).
- Single-zone fan coil (see Table 36).
- Multiple-zone VAV reheat, with either packaged direct expansion (DX) or chilled hot water (CHW) cooling (see Table 37).
- Multiple-zone VAV dual-fan dual-duct, with either packaged DX or CHW cooling (see Table 38).
- Water loop heat pump, optionally with ground heat exchanger (see Table 39).
- Dedicated outside air system (DOAS) with radiant heating and cooling (see Table 40).

Regardless of whether or not cooling is required, the system type should be selected in a deliberate process that considers at least two system options and weighs these options against a variety of factors. A method to evaluate HVAC system options is presented in Table 33. This method provides a way to rank the performance of two or more HVAC system types in terms of a wide range of characteristics. The following process is recommended.

- Review the criteria in Table 33 in a discussion between the district and the design team, adding or deleting criteria as appropriate for the project.
- Set weightings that represent the relative importance of each of the criteria. These weightings can be given any value, but constraining the weightings to a total of 100 helps to focus discussion on the relative importance of the criteria.
- Identify a short list of two or more of the most promising HVAC system alternatives.
- Fill in a table for each HVAC system option, with a brief description at the top of the table and some comments on how each system performs in terms of each of the criteria.
- For each system, assign a score of 0 (worst) to 10 (best) for each of the criteria.
- Calculate the total score for each system by multiplying the weight times the score for each criteria and summing the total. The maximum total score will be 1000, which is achieved if a system is given a score of 10 on all criteria.
- Discuss the results between the district and the design team.

Ventilation for Heating-Only Systems

With a heating-only system, it is usually necessary to provide either special passive ventilation features or supplementary mechanical ventilation for air quality purposes. Continuous (or at least frequent) ventilation is necessary to meet modern air quality standards. Even if the room is designed with adequate operable openings so that code does not require a mechanical ventilation system (see Figure 11), a strategy should be in place to provide adequate ventilation whenever the windows are closed.

Passive ventilation with a heating-only system is feasible, but designing a system that provides good air quality, thermal comfort, and energy efficiency can be a challenge. The general goals are to avoid cold drafts and ensure adequate ventilation while avoiding excessive airflow that causes unnecessary heating load. The most likely approach to meeting these goals is to use a stack-effect ventilation strategy that includes a heat source at the air inlet to temper the outdoor air. More details on designing for stack ventilation are included in Guideline TC4: Variable Air Volume System but the general approach is to provide low inlets and high outlets. Whenever the indoor temperature is warmer than the outdoor temperature, then the “lighter” indoor air will tend to rise and exit through the upper vents. Cooler (“heavy”) outdoor air will be drawn in through the lower vents. The air flow increases as it gets colder outside. The air flow also depends on the size of the vents and the vertical distance between the inlets and outlets; greater size and greater distance provide greater air flow. Some of the issues that should be addressed with a passive ventilation design include the following:

- *Adequate airflow even when occupant-operable openings have been closed*
- *After-hours control to minimize unnecessary heating load*
- *Adequate airflow over the range of likely outdoor conditions*
- *Security of ventilation openings*
- *Removal of particulates from outdoor air*
- *Noise transmission through ventilation openings*
- *Drafts*
- *Distribution of ventilation air within the space (ventilation effectiveness).*

If passive ventilation is not practical, there are a number of options for providing supplementary mechanical ventilation in a heating-only system, In each case, the ventilation fans should either be run continuously when windows are closed or they should be controlled using a CO2 sensor so that they activate when occupants are present.

- *Furnace*
- *Fan coil*
- *Exhaust fan (central or space-by-space)*
- *Supply fan with barometric relief (central or space-by-space)*
- *Heat recovery ventilator (central or space-by-space).*

There are a number of advantages to using this HVAC system evaluation method.

- The design team and owner are forced to focus and agree on what system features are most important for the project. The relative importance is embodied in the weights that are applied to each attribute and in the selection of the attributes to consider.
- Both soft and hard factors can be compared in an objective manner. Scores can reflect relatively precise factors, such as simulated energy performance and first costs, as well as hard to measure factors such as perception of comfort.
- The method inherently documents the design intent. It also communicates the design intent to the other design team members.
- The method has more rigor than simply choosing a system based on "experience."

Air Delivery Type Selection

The air delivery method is an integral part of an HVAC system selection, but the options are presented separately in this manual because it is generally possible to use any of the three air delivery methods presented here with any of the HVAC system types listed above. That does not mean that air delivery method and system type should or can be independent decisions. When using the HVAC system evaluation matrix in Table 33, it is recommended that combinations of air delivery method and system type be compared to each other. For example, two options might include VAV reheat with overhead air distribution and VAV reheat with displacement ventilation.

It is important to evaluate the air delivery alternatives as early in the design as possible because air delivery methods have a significant impact on architectural design.

The three air delivery alternatives described here—overhead mixing, lower wall displacement, and raised-floor mixing/displacement—each offers advantages and disadvantages. Table 32 lists a number of issues to be considered when making a selection.

Table 32—Air Delivery Method Selection Factors

Description	Overhead (Mixing)	Lower Wall (Displacement)	Raised Floor (Mixing/Displacement)
	Diffusers located in the ceiling deliver 55°F air at velocity of 400 to 700 ft per minute.	**Diffusers mounted near the floor level deliver 65°F air at less than 100 fpm velocity.**	**Diffusers mounted in the floor deliver 65°F air at about 200 to 400 fpm velocity.**
Ventilation effectiveness	○ Supply air mixes with room air to dilute contaminants.	● Supply air travels directly to occupants rather than mixing.	◎ Generally better than an overhead system, but sensitive to air flow. Can work like a mixing system if air flow is too high.
Thermal comfort performance	● Even temperatures throughout the space in cooling mode (with proper design).	◎ Some potential for cooler air at floor level	◎ Some potential for drafts if occupants are too close to diffusers.
Acoustic performance	◎ Diffusers can be a source of noise is air velocity is high. Depends on the selection of diffusers.	● Quieter due to low air velocity at diffusers.	● Also quieter due to lower air velocity.
Heating mode performance	◎ Some potential for stratification if supply temperature is too high, leading to reduced ventilation effectiveness and comfort.	○ Reduced ventilation effectiveness and comfort when supply air temperature is higher than room air temperature due to low velocity of supply air leaving the diffuser.	◎ Depends on the amount of mixing that occurs in the occupied zone.
Humidity control	● Generally provides more dehumidification in cooling mode due to lower supply air temperature.	○ Requires special measures if dehumidification is necessary because supply air temperature is higher.	○ Requires special measures if dehumidification is necessary because supply air temperature is higher.
Energy efficiency	◎ Higher cooling energy consumption due to lower supply air temperature.	● Lower cooling energy due to higher supply air temperature, allowing outside air to provide cooling for a greater number of hours. Also less cooling load in occupied zone due to displacement effect (see Guideline Guideline TC3: Single-Zone Unitary System). Potentially lower fan energy due to low pressure loss through diffusers.	● Also lower cooling energy due to greater number of economizer hours. Potentially lower cooling load in occupied zone if air flow is sized properly.
First cost	● Typically lowest first cost.	◎ Typically higher diffuser cost	○ Typically highest due to cost of raised floor tiles and supports.
Floor area required	● None.	◎ Diffusers may take up some floor space if they are not mounted within the walls or casework. A clear area is required within a few feet of the diffuser(s).	○ Some floor space taken up by in-floor diffusers and area immediately adjacent to the diffusers may be subject to drafts.
Ceiling space required	○ Typically four 2 ft x 2 ft diffusers per classroom, with adjacent flat ceiling necessary to provide good air distribution.	● Return air grille typically needed either in the ceiling or the upper portion of the wall. Flat ceiling is not necessary.	● Return air grille typically needed either in the ceiling or the upper portion of the wall. Flat ceiling is not necessary.
HVAC system type constraints	● Wide range of equipment available.	◎ Selection of single-zone packaged HVAC equipment is limited because units are not traditionally designed for 65°F supply air temperature.	◎ Selection of single-zone packaged HVAC equipment is limited because units are not traditionally designed for 65°F supply air temperature.

Table 32—Air Delivery Method Selection Factors (continued)

Maintenance	●	Diffusers are less likely to be subject to tampering or vandalism.	◉	Diffusers are located within the occupied zone and could be subject to vandalism.	○	Diffusers in the floor can collect dirt and trash and should be cleaned periodically. Potentially subject to vandalism.
Flexibility	◉	Possible to move or add diffusers.	○	More difficult to change diffuser locations or add additional diffusers.	●	Can be the most flexible option for changing space layout.
Integrated design opportunities				Can eliminate suspended ceiling. Open ceilings or higher ceilings can improve daylight distribution. Diffusers can be integrated with casework.		Can run electrical distribution and communications system under the floor. Can eliminate suspended ceiling. Open ceilings or higher ceilings can improve daylight distribution.

Legend: ● Better than average (better performance or lower cost) ◉ Average ○ Worse than average (lower performance or higher cost)

Table 33—Evaluation Criteria for HVAC System Selection

SYSTEM DESCRIPTION—Describe the system characteristics here.

(central / room-by-room)
(chilled water / packaged)
(variable air volume / constant volume)
(dual-path / single-path)
(water-cooled / air-cooled)
(overhead air distribution / displacement ventilation / underfloor air distribution)
(ducted return / plenum return)
(special controls)
(other special characteristics)

Criteria*	**Criteria Weight† (Totals to 100)**	**Comments‡**	**Score (0 to 10) 0 = poor 10 = excellent**
Mechanical System First Costs	10	First cost ranked relative to other system options.	
Impact on Other Trades: General Contractor	4	Impact on construction requirements such as mechanical rooms, duct enclosures, shafts, equipment screens, gas service.	
Impact on Other Trades: Electrical Contractor	4	Impact on electrical system cost and complexity.	
Floor Space Requirements	4	Impact on usable floor area, e.g., for air shafts, equipment rooms, or displacement ventilation diffusers.	
Ceiling Space Requirements	3	Amount of space required for ducts, fan coils or other system components.	
Energy Efficiency: Normal Operation	10	Energy performance during normal school hours relative to the other system options, including consideration of part-load performance.	
Energy Efficiency: Off-hour Operation	4	Energy performance after normal school hours if only portions of the school are occupied.	
Flexibility for After-School-Hours Operation	4	The ability to air condition only portions of the school for after-hour activities.	
Acoustical Impact	8	Relative impact on noise in the classrooms and other spaces.	
Indoor Air Quality	8	Ability to provide adequate level of clean outdoor air to the occupied zone. Ability to provide 100% outside air during mild conditions.	
Comfort	8	Ability to maintain stable comfort and humidity	
Maintenance Cost	6	Maintenance cost relative to the other system options.	
Ease of Maintenance During School Hours	4	Ability to be accessed for routine or emergency maintenance tasks without disrupting classes.	
Compatibility with Maintenance Staff Resources	4	Level of training required to perform maintenance tasks, and frequency of maintenance required.	
Use of Standardized Parts	3	Commonly replaced components are standard items that can be stocked by the school district.	
Reliability	4	Likelihood of interruptions to service.	
Longevity	6	Length of expected useful life. Resistance to vandalism and weathering.	
Compatibility with Natural Ventilation	4	Potential for using interlock switches to disable mechanical ventilation and conditioning when windows are open.	
Flexibility for Future Occupancy Changes	2	Ease of rezoning, adding capacity, or adapting to change in occupancy.	
	100	*Total Score (Sum of Weight × Score, maximum is 1000)*	

* *Additional criteria may be added or substituted as appropriate.*

† *The criteria weightings in this table are included as examples. The weightings should be reevaluated for each project.*

‡ *The comments in this table are provided as guidance to the designer. When this table is filled out by the designer, these comments should be replaced with a brief discussion of the relative merits or drawbacks for each system option*

The following tables illustrate the evalution process for several basic system options:

- Single-zone packaged rooftop (see Table 34).
- Single-zone split system (see Table 35).
- Single-zone fan coil (see Table 36).
- Multiple-zone VAV reheat, with either packaged DX or CHW cooling (see Table 37).
- Multiple-zone VAV dual-fan dual-duct, with either packaged DX or CHW cooling (see Table 38).
- Water loop heat pump, optionally with ground heat exchanger (see Table 39).
- DOAS with radiant heating and cooling (see Table 40).

Table 34—Example Evaluation, Single-Zone Packaged Rooftop System

SYSTEM DESCRIPTION

Single-zone packaged rooftop system. Typically DX cooling with air-cooled condenser and constant-volume supply fan. Can have gas furnace heating or heat pump heating. Typically overhead air distribution. Options include economizer, multiple stage compressors and supply fans, demand control ventilation, high efficiency cooling, interlocks with doors and windows for mixed-mode operation.

Criteria	**Criteria Weight* (Totals to 100)**	**Comments†**	**Score* (0 to 10) 0 = poor 10 = excellent**
Mechanical System First Costs	10	Typically one of the lowest first cost HVAC options.	8
Impact on Other Trades: General Contractor	4	Structural considerations to support the unit and its roof penetrations. Additional roofing details required around curbs and penetrations.	5
Impact on Other Trades: Electrical Contractor	4	Generally requires 480V electrical service to each unit	3
Floor Space Requirements	4	No impact on floor space in single-story buildings, but space for air shafts required in upper floors of multi-story buildings.	10
Ceiling Space Requirements	3	Space above the ceiling typically required for ducts.	5
Energy Efficiency: Normal Operation	10	Typically less efficient due to constant volume fan operation and air-cooled condenser. However, cooling energy can be partially offset with an economizer. Part-load efficiency may be improved using multi-stage or variable capacity compressors and supply fans.	5
Energy Efficiency: Off-hour Operation	4	Off-hour efficiency is the same as normal operation efficiency.	5
Flexibility for After-School-Hours Operation	4	Good for off-hour operation because individual units can be run separately.	8
Acoustical Impact	8	Moderate acoustic performance depending on location of equipment, duct design, and diffuser selection.	5
Indoor Air Quality	8	Can provide good indoor air quality when operated to provide continuous ventilation, but the selection of high efficiency filters is limited due to typical space constraints within the units. Often available with CO_2 controlled ventilation as an option. Condensate drain pans can be a source of fungal or bacterial growth, and possibly will be cleaned less frequently than central air handlers.	5
Comfort	8	Reasonable comfort performance, but delivers varying supply air temperature as the compressor or furnace cycles on and off to meet thermostat setpoints.	5
Maintenance Cost	6	Relatively high due to the large number of units, each with its own compressor and controls.	3
Ease of Maintenance During School Hours	4	Routine maintenance can be performed without significant disruptions.	7
Compatibility with Maintenance Staff Resources	4	Staff should have air conditioner technician training.	5
Use of Standardized Parts	3	Replacement parts usually must come from the manufacturer.	4
Reliability	4	Typically moderate reliability, but if a unit fails then only one room is affected.	5
Longevity	6	Moderate longevity. Unit life is roughly 15 years.	3
Compatibility with Natural Ventilation	4	Relatively simple to use an interlock switch to disable unit when windows are open.	7
Flexibility for Future Occupancy Changes	2	Moderate rezoning flexibility because ducts and diffusers can be moved, but limited flexibility to modify capacity or unit location.	3
	100	*Total Score (Sum of Weight × Score, maximum is 1000)*	*539*

Critera Weights and Scores are provided as examples. Appropriate values will vary depending on project characteristics.

† *The comments in this table are provided as examples and do not necessarily apply to all projects.*

Table 35—Example Evaluation, Single-Zone Split System

SYSTEM DESCRIPTION
Single-zone split system. One indoor fan unit and outdoor condensing unit per classroom. Can have gas furnace heating or heat pump heating. Fan unit typically located above the ceiling or in a closet. Usually constant volume supply air, but variable speed and multi-speed fans are available. Typically overhead air distribution. Options include economizer, multiple stage compressors and supply fans, demand control ventilation, high efficiency cooling, interlocks with doors and windows for mixed-mode operation.

Criteria	Criteria Weight*	Comments†	Score* (0–10)
Mechanical System First Costs	10	Typically more expensive that a packaged rooftop system. Usually more labor required for installation.	6
Impact on Other Trades: General Contractor	4	Exterior curb or pad for the outdoor condensing unit required. May require closet or mechanical room for housing the indoor fan unit.	5
Impact on Other Trades: Electrical Contractor	4	Requires electrical service to both the indoor and outdoor components.	3
Floor Space Requirements	4	No impact on floor space unless indoor unit is housed in a closet.	7
Ceiling Space Requirements	3	Space above the ceiling typically required for ducts.	5
Energy Efficiency: Normal Operation	10	Split systems are typically available with higher efficiencies than packaged rooftop units. Otherwise usually not as efficient as a variable air volume system due to constant volume fan operation and air-cooled condenser. However, cooling energy can be partially offset with an aftermarket economizer. Part-load efficiency may be improved using multi-stage or variable capacity compressors and supply fans.	7
Off-hour Efficiency	4	Off-hour efficiency is the same as normal operation efficiency.	7
Flexibility for After-School-Hours Operation	4	Good for off-hour operation because individual units can be run separately.	8
Acoustical Impact	8	Reasonable acoustic performance depending on location of equipment, duct design, and diffuser selection. The outdoor condensing unit should not be located near windows, and measures may be necessary to mitigate noise from the indoor fan unit.	3
Indoor Air Quality	8	Can provide good indoor air quality when operated to provide continuous ventilation, but the selection of high efficiency filters is limited due to typical space constraints within the units. Condensate drain pans can be a source of fungal or bacterial growth, and possibly will be cleaned less frequently than central air handlers.	5
Comfort	8	Reasonable comfort performance, but delivers varying supply air temperature as the compressor or furnace cycles on and off to meet thermostat setpoints. Comfort can be improved with variable capacity cooling and heating.	5
Maintenance Cost	6	Relatively high due to the large number of units, each with its own compressor and controls.	3
Ease of Maintenance During School Hours	4	Routine maintenance may require access within the room if indoor unit is above the ceiling or in a closet (it is possible to design external access to mechanical closets).	4
Compatibility with Maintenance Staff Resources	4	Staff should have air conditioner technician training.	5
Use of Standardized Parts	3	Replacement parts usually must come from the manufacturer.	4
Reliability	4	Typically moderate reliability, but if a unit fails then only one room is affected.	5
Longevity	6	Moderate longevity. Unit life is roughly 15 years. The indoor unit should last somewhat longer than a rooftop system. Therefore, it is possible that only the outdoor unit needs to be replaced after 15 years.	5
Compatibility with Natural Ventilation	4	Relatively simple to use an interlock switch to disable unit when windows are open.	7
Flexibility for Future Occupancy Changes	2	Moderate rezoning flexibility because ducts and diffusers can be moved, but limited flexibility to modify capacity or unit location. Slightly more flexibility than a packaged rooftop unit.	5
	100	*Total Score* *(Sum of Weight × Score, maximum is 1000)*	*523*

* Criteria Weights and Scores are provided as examples. Appropriate values will vary depending on project characteristics.
† The comments in this table are provided as examples and do not necessarily apply to all projects.

Table 36—Example Evaluation, Single-Zone Fan Coil

SYSTEM DESCRIPTION

Fan coils provide heating and cooling for each room. Central air-cooled or water-cooled chiller provides chilled water to fan coils. Central boiler provides hot water. Fan coils typically provide constant-volume air supply, and space temperature is controlled by varying the supply air temperature. Fan coils are located above the ceiling, console style under the window, or in a separate mechanical closet. Outside air for ventilation may be ducted directly from outdoors to each fan coil, or may be supplied by a central ventilation air handler and ducted to each fan coil. Two-pipe fan coil systems are limited to providing either heating or cooling at one time to all spaces. Four-pipe systems can simultaneously heat some spaces while cooling others, but they have higher initial cost.

Criteria	**Criteria Weight***	**Comments†**	**Score* (0–10)**
Mechanical System First Costs	10	Moderate to high first cost.	4
Impact on Other Trades: General Contractor	4	Potentially lower floor-to-floor height due to less space required for central air distribution ducts.	7
Impact on Other Trades: Electrical Contractor	4	Requires power to each zone, but less than for packaged units.	5
Floor Space Requirements	4	Depends on fan coil location. Floor space may be required for console units or mechanical closets.	5
Ceiling Space Requirements	3	Depends on fan coil location.	3
Energy Efficiency: Normal Operation	10	Cooling efficiency can be high with water-cooled chiller. Air distribution efficiency is moderate and similar to single-zone packaged units. Compared to a VAV system, the air path is typically shorter and lower pressure drop, but fan is typically constant speed and less efficient than larger central VAV fans. Outside air economizer is typically a more expensive option for fan coils than for packaged rooftop units.	6
Energy Efficiency: Off-hour Operation	4	Individual fan coils can be activated for single-zone after-hours operation. However, central plant may need to operate to supply heating or cooling.	4
Flexibility for After-School-Hours Operation	4	Good flexibility, though efficiency may suffer.	4
Acoustical Impact	8	Fan coils can be noisy and require careful attention to placement. Console units may not be appropriate for classrooms.	3
Indoor Air Quality	8	Typically do not have 100% outdoor air capability, and availability of high efficiency filters will be limited. Condensate drain pans can be a source of fungal or bacterial growth, and possibly will be cleaned less frequently than central air handlers.	3
Comfort	8	Good comfort performance possible due to stable space temperature control (no compressor cycling).	8
Maintenance Cost	6	Lower cost to maintain central heating and cooling equipment compared to single-zone packaged system. But higher cost for filter replacements and cleaning than for central air handlers.	5
Ease of Maintenance During School Hours	4	Depends on location of fan coils. Central plant maintenance may need to take place after-hours.	3
Compatibility with Maintenance Staff Resources	4	Central plant maintenance may require outside service contractors.	4
Use of Standardized Parts	3	Some parts may be standard such as valves on fan coils.	7
Reliability	4	Generally more reliable than outdoor packaged equipment, but a central plant failure can affect the whole school rather than just a single room. Central plant design can include redundancy to minimize the impact of equipment failure.	6
Longevity	6	Good. Typically 20 to 30 years.	8
Compatibility with Natural Ventilation	4	Individual fan coils can be interlocked with window switches so that they shut off if windows are left open.	6
Flexibility for Future Occupancy Changes	2	Moderate flexibility because additional fan coils can be added, but relatively high cost for plumbing.	5
	100	*Total Score (Sum of Weight × Score, maximum is 1000)*	*506*

* Critera Weights and Scores are provided as examples. Appropriate values will vary depending on project characteristics.

† The comments in this table are provided as examples and do not necessarily apply to all projects.

Table 37—Example Evaluation, VAV Reheat System

SYSTEM DESCRIPTION

Central cooling fan systems supply 55°F–60°F air in ceiling-mounted ducts to VAV reheat boxes in perimeter zones, cooling-only or reheat boxes in interior zones. Return air path is either by ceiling plenum or via ducts above the ceiling. The air handler is typically located either on the roof or in a mechanical room. Cooling may be provided with a chilled water coil, or it may be a self contained packaged direct expansion unit. May have a return fan or a relief fan to provide space pressure control. Typically have 100% outdoor air economizers. In cool climates, heating at the air handler is provided via hot water coil or gas furnace. Reheat can be provided by hot water coils or electric resistance.

Criteria	**Criteria Weight**	**Comments†**	**Score* (0–10)**
Mechanical System First Costs	10	Moderate to high first cost, partly a function of the number of zones (i.e., VAV boxes with associated controls and hot water piping).	4
Impact on Other Trades: General Contractor	4	Air shafts may be required. Air handler is typically located on the roof or housed in an equipment room.	4
Impact on Other Trades: Electrical Contractor	4	Low voltage power to each VAV box for controls. Much smaller electrical demand to each zone than for individual fan coils or packaged systems,	7
Floor Space Requirements	4	Rooftop units require large supply and return shafts. Floor-by-floor units require fan rooms per floor	5
Ceiling Space Requirements	3	Significant duct space required above ceiling.	4
Energy Efficiency: Normal Operation	10	Potentially high efficiency if controlled properly. Low fan energy due to higher efficiency of larger central fan and lower airflow at low load. Cooling efficiency depends on type of equipment: chilled water cooling or evaporatively cooled DX units are typically most efficient. Supply air pressure reset controls are important to achieve maximum efficiency.	8
Energy Efficiency: Off-hour Operation	4	VAV boxes may be used to isolate unoccupied areas to minimize off-hour usage. Requires operation of central fan for after hours heating.	5
Flexibility for After-School-Hours Operation	4	Reasonable flexibility with properly programmed controls.	4
Acoustical Impact	8	Noise problems may occur near fan rooms and shafts. Slight VAV box noise and hiss from diffusers. Compressor noise near fan room for water-cooled units	7
Indoor Air Quality	8	Outside air economizer allows increased operation at 100 percent outside air. Efficient filters are widely available and more likely to be maintained. More cost effective to monitor ventilation air flow at a central air handler than at individual packaged units. Easier to keep cooling coils and condensate drain pans clean at central units. On the other hand, special attention to controls is necessary to ensure that each zone get adequate ventilation as air flow varies.	8
Comfort	8	Good cooling performance. Fair heating performance due to stratification.	7
Maintenance Cost	6	Rooftop equipment requires frequent maintenance. VAV boxes require occasional maintenance. Risk of water damage due to piping above the ceiling.	5
Ease of Maintenance During School Hours	4	Central air handlers can usually be accessed during school hours, though shut down will disrupt service to all zones. Access to individual VAV boxes depends on whether they are located above classroom ceilings or, for example, above the ceiling in a corridor outside the classroom.	5
Compatibility with Maintenance Staff Resources	4	Generally requires a higher level of training in HVAC controls.	3
Use of Standardized Parts	3	Some components, such as VAV damper actuators and reheat control valves, can be district standards.	5
Reliability	4	Generally good reliability if properly commissioned at beginning. However, a failure at the central air handler affects all zones rather than just a single room.	7
Longevity	6	Good. Typically 20–30 years.	7
Compatibility with Natural Ventilation	4	Moderate, but somewhat more complicated than with individual packaged units. Possible to set up controls that shut the VAV box damper when windows are open.	5
Flexibility for Future Occupancy Changes	2	Any number of zones may be used, but at a high cost per zone.	8
	100	*Total Score (Sum of Weight × Score, maximum is 1000)*	*591*

* Critera Weights and Scores are provided as examples. Appropriate values will vary depending on project characteristics.

† The comments in this table are provided as examples and do not necessarily apply to all projects.

Table 38—Example Evaluation, VAV Dual-Fan, Dual-Duct System

SYSTEM DESCRIPTION

Separate VAV supply fans for cool duct and warm duct. Typically the warm duct fan draws air from the return duct, reducing the need for heating. Then ventilation air is delivered via the cool duct. As an alternative, dampers can be arranged so that the ventilation air can be switched over from the cool duct to the warm duct during hot weather. Cooling-only VAV boxes in interior zones and dual-duct VAV boxes for perimeter zones. Dual-duct VAV boxes in perimeter zones operate in heating only mode for early morning warm up. During normal building operation, the boxes operate in cooling mode, modulating the supply of cool air to meet the cooling load. If the VAV box is at the minimum position required for ventilation, and the space is still overcooled, then the cool air is mixed with warm air in the dual duct VAV box.

Criteria	Criteria Weight* (Totals to 100)	Comments†	Score* (0–10) 0=poor 10=excellent
Mechanical System First Costs	10	Additional sheet metal ducts are required in the perimeter zones compared to a VAV reheat system, but these can be smaller, since their purpose is not ventilation, but just heating. Reheat coils and hot water piping eliminated.	5
Impact on Other Trades: General Contractor	4	Plumbing is eliminated in the plenum space. Additional floor-to-floor height may be necessary to accommodate additional ducts. Air shafts may be required. Air handler is typically located on the roof or housed in an equipment room.	4
Impact on Other Trades: Electrical Contractor	4	Same as standard VAV.	7
Floor Space Requirements	4	Roughly same as standard VAV.	5
Ceiling Space Requirements	3	Additional space may be required.	3
Energy Efficiency: Normal Operation	10	Efficiency similar to other VAV systems when system is operating in cooling mode. Reheat energy is significantly reduced.	9
Energy Efficiency: Off-hour Operation	4	Heating fan can cycle with loads to maintain temperature during off hours.	5
Flexibility for After-School-Hours Operation	4	Similar to standard VAV.	4
Acoustical Impact	8	Similar to standard VAV.	7
Indoor Air Quality	8	Similar to standard VAV.	8
Comfort	8	Same cooling performance as standard VAV. Potentially better heating performance and less stratification due to higher air flow in heating mode.	8
Maintenance Cost	6	Dual duct VAV boxes have similar maintenance costs as conventional boxes. Avoids potential problems due to hot water piping above the ceiling.	6
Ease of Maintenance During School Hours	4	Similar to standard VAV.	5
Compatibility with Maintenance Staff Resources	4	Similar to standard VAV.	3
Use of Standardized Parts	3	Similar to standard VAV.	4
Reliability	4	Similar to standard VAV.	7
Longevity	6	Similar to standard VAV.	7
Compatibility with Natural Ventilation	4	Similar to standard VAV.	5
Flexibility for Future Occupancy Changes	2	Similar to standard VAV.	8
	100	*Total Score (Sum of Weight × Score, maximum is 1000)*	*619*

* Critera Weights and Scores are provided as examples. Appropriate values will vary depending on project characteristics.

† The comments in this table are provided as examples and do not necessarily apply to all projects.

Table 39—Example Evaluation, Water Loop Heat Pump System

SYSTEM DESCRIPTION

Central outside air ventilation system with air handling unit on roof (or in mechanical room) provides ventilation to each floor or to each major space. A VAV terminal may be used on each floor or on each major space to control air volume to meet ventilation requirements. Water source heat pump typically located either above the ceiling or console style under the window. Two-pipe tempered water circulating loop provides heat sink for heat pumps in cooling mode and heat source in heating model. Excess heat removed from loop by cooling tower; heat deficits in circulating loop made up by central boiler. As an alternative or supplement to the cooling tower and boiler, the tempered water may be directed through a ground heat exchanger that cools the water in summer and warms the water in winter.

Criteria	**Criteria Weight***	**Comments†**	**Score* (0–10)**
Mechanical System First Costs	10	Moderate to high. Individual unit costs are higher than fan coils. Extensive distribution piping for tempered water loop and condensate drains; Dedicated outside air system for ventilation; Adjustable or controllable VAV terminals for control of outside air to each floor.	5
Impact on Other Trades: General Contractor	4	Little accommodation required on each floor; No mechanical rooms each floor. Small shafts.	7
Impact on Other Trades: Electrical Contractor	4	Each heat pump requires sizable electrical connection. Assume above 1 kW per ton of cooling capacity.	2
Floor Space Requirements	4	If perimeter units are above ceiling, no floor space is required.	7
Ceiling Space Requirements	3	Heat pumps, tempered water piping and condensate drain piping require extensive space above the ceiling.	3
Energy Efficiency: Normal Operation	10	Total air pressure drop through heat pump low, but fan motors inefficient. Typically no airside economizer. In certain climates simultaneous heating and cooling in different zones permits heat recovery through tempered water loop. A ground-coupled water loop system minimizes cooling tower and boiler energy, but may require fairly significant pumping energy.	5
Energy Efficiency: Off-hour Operation	4	Individual heat pumps can operate as necessary to provide heating and cooling to separate zones, but the tempered water loop must operate. Similar provision of night setback heating. Ventilation system modulated on floor-by-floor basis for after hours operation.	4
Flexibility for After-School-Hours Operation	4	Requires operation of central water loop for any of the heat pumps to operate.	4
Acoustical Impact	8	Heat pumps are noisy and low frequency compressor noise difficult to attenuate.	3
Indoor Air Quality	8	Typically no 100% outside air capability. Fan coil filtration is typically minimal. Condensate drain pans in heat pumps can plug, allowing microbial growth.	3
Comfort	8	System is comparable in comfort to overhead VAV. Temperature control zones may be larger than some other systems.	5
Maintenance Cost	6	Filters on individual heat pumps must be changed on a regular basis. Compressors and fractional horsepower fan motors must be replaced periodically. Condensate drains must be kept clear. All of the above activities require ceiling access.	5
Ease of Maintenance During School Hours	4	Depends on location of heat pumps.	3
Compatibility with Maintenance Staff Resources	4	Moderate maintenance training required. More complicated than individual packaged units.	4
Use of Standardized Parts	3	Possible to stock replacement parts for heat pumps.	7
Reliability	4	Moderate. Failure of a single heat pump affects only a single zone. Failure of tempered water loop distribution affects all zones.	5
Longevity	6	Moderate. Roughly 15 years for individual heat pump compressors.	5
Compatibility with Natural Ventilation	4	Moderate. Individual heat pumps can be interlocked with windows.	5
Flexibility for Future Occupancy Changes	2	Addition of new zones is expensive. Heat pumps can be moved or added, but plumbing is required.	3
	100	*Total Score (Sum of Weight × Score, maximum is 1000)*	*448*

* Critera Weights and Scores are provided as examples. Appropriate values will vary depending on project characteristics.

† The comments in this table are provided as examples and do not necessarily apply to all projects.

Table 40—Example Evaluation, Dedicated Outside Air System with Radiant Heating and Cooling

SYSTEM DESCRIPTION

Central outside air ventilation system with heating, cooling and dehumidification capability provides ventilation and dehumidification. Outside air delivered to each space, either constant volume or demand controlled ventilation using carbon dioxide concentration differential. Sensible heating and cooling provided by individual radiant devices in each space. Devices include radiant floors, radiant ceilings, radiant panels and valance units. Central air-cooled or water-cooled chiller provides chilled water to fan coils. Central boiler provides hot water.

Criteria	Criteria Weight*	Comments†	Score* (0–10)
Mechanical System First Costs	10	Radiant ceilings very expensive, radiant floors less so, but less cooling capacity; dedicated outside air system delivers 20%–25% of volume of VAV system but has same components.	2
Impact on Other Trades: General Contractor	4	Very small shafts and rooftop units for ventilation and dehumidification only. Furred columns required for hot water/chilled water piping for radiant ceiling.	8
Impact on Other Trades: Electrical Contractor	4	Single rooftop unit for ventilation; control terminals each floor; modulating valves for radiant zones.	8
Floor Space Requirements	4	Smallest shafts required.	8
Ceiling Space Requirements	3	Smallest ducts required. Smallest on-floor mechanical room.	7
Energy Efficiency: Normal Operation	10	Low cooling transport energy offsets loss of airside economizer. High chilled water temperature for radiant cooling panels extends waterside economizer range.	6
Energy Efficiency: Off-hour Operation	4	Ventilation system can shut down after-hours; Individual floors can be ventilated on a selective basis. After hours heating and cooling provided to individual radiant zones according to schedules, programmed requests and thermostat operation.	5
Flexibility for After-School-Hours Operation	4	Moderate. Requires operation of chilled water or hot water system to serve a single zone. Depends on part load efficiency of the central plant.	4
Acoustical Impact	8	Quietest system.	8
Indoor Air Quality	8	No 100% outside air capacity. Low turnover rate for particulate filtration. Central ventilation air handler allows better selection of filters.	7
Comfort	8	Control of mean radiant temperature improves comfort maintenance. Temperature control zones may be larger than with some systems.	6
Maintenance Cost	6	Only rooftop equipment requires frequent maintenance; Reduced number of VAV terminals each floor. Corresponding to ventilation zones. Control valves on radiant panels or floors may require service.	5
Ease of Maintenance During School Hours	4	Some maintenance will require access to classrooms.	5
Compatibility with Maintenance Staff Resources	4	Training required in operation of system that is not common in U.S.	2
Use of Standardized Parts	3	Control valves can be standardized.	5
Reliability	4	Good reliability.	7
Longevity	6	Should have at least 20 to 30 year lifetime.	7
Compatibility with Natural Ventilation	4	Attention necessary to humidity control due to the potential for condensation on radiant cooling panels, therefore natural ventilation can create a problem in humid climates.	3
Flexibility for Future Occupancy Changes	2	Some radiant ceiling systems allow flexible re-piping of ceiling to reconfigure temperature control zones.	4
	100	*Total Score (Sum of Weight × Score, maximum is 1000)*	*564*

* Critera Weights and Scores are provided as examples. Appropriate values will vary depending on project characteristics.

† The comments in this table are provided as examples and do not necessarily apply to all projects.

GUIDELINE TC1: HVAC ACOUSTICS

Recommendation

Design the HVAC system to provide acoustical performance that meets the 2002 voluntary American National Standards Institute (ANSI) Standard S12.60. A combination of measures is usually required to meet these criteria. For an overhead air distribution system serving a classroom, a typical set of measures includes the following:

- Use four supply diffusers, each selected for an NC rating of no greater than 18.
- Size ducts adequately to avoid excessive air velocity.
- Avoid abrupt duct transitions that cause pressure loss and create noise.
- Avoid use of dampers or other obstructions within the ducts.
- Avoid locating equipment within or directly above the classroom.
- Lay out ducts to minimize sound transmission, including strategic use of plenums, acoustic duct liner, duct turns, and branch takeoff locations.

Figure 136—Exterior Ducts

Adding exterior ductwork avoids downflow of turbulent supply air. Source: Trane.

Applicable Spaces	Climates	When to Consider
Classrooms	South Coast	Programming
Library	North Coast	Schematic
Multi-Purpose / Cafeteria	Central Valley	Design Dev.
Gym	Mountains	Contract Docs.
Corridors	Desert	Construction
Administration		Commissioning
Toilets		Operation
Other		

As an alternative to overhead air distribution, consider a displacement ventilation system, which uses lower air velocities and can be quieter.

Description

Good acoustic performance is a result of integrated design of building envelope components, HVAC equipment selection and location, ductwork design, and specification of interior surfaces. ANSI Standard S12.60-2002 recommends limiting the noise level to 35 decibels (dBA). In order to meet that target, HVAC acoustic design requires proper equipment selection and location to address the sound source, careful ductwork design to address sound transmission paths, and diffuser selection to address the noise transmitted to the students.

Other sections of this manual also address acoustic design issues.

Applicability

These guidelines apply to "core learning spaces." The acoustic environment in larger spaces such as auditoriums and gymnasiums is primarily affected by reverberation time.

Applicable Codes

There are no mandatory requirements for indoor sound levels. Sound levels from unitary equipment should be tested according to industry standard ARI 270.

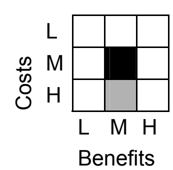
Integrated Design Implications

Classroom acoustic performance is also affected by reverberation and noise transmission between classrooms. The design of the building enclosure and interior partitions to minimize noise transmission between classrooms is covered in the Building Enclosure chapter. The specification of interior surfaces to reduce reverberation is covered in the Interior Surfaces chapter.

Refer to the Air Distribution guidelines for more information on duct design.

Acoustic design decisions can affect the energy efficiency of the HVAC system. Some measures, such as larger ducts, low-pressure-loss duct transitions, and reduced fan speed can improve the HVAC system efficiency. Other measures such as the use of longer duct runs or use of additional turns in the duct path can increase energy consumption. Therefore, measures that improve both acoustic performance and energy efficiency should be given priority.

Cost Effectiveness



HVAC design for acoustic performance may require longer duct runs, larger duct cross-sectional area and a higher number of diffuser grilles, acoustic duct liners or the addition of a duct silencer at the fan discharge. Incremental costs of measures to address HVAC noise vary from 0.3% to 6% of total new construction costs.[50] Incremental costs of high performance acoustic design will be lowest with central systems. In some instances, good acoustic design will result in lower operating costs, offsetting incremental first costs.

[50] Lubman, David and Louis C. Sutherland, presentation at the CHPS Acoustics Technology Charrette, Sacramento, CA, August 2003.

Benefits

Proper classroom acoustics will ensure an environment conducive to learning. It will prevent the teacher from having to strain his or her voice to be heard. Studies have shown (ASA 2000) that in many classrooms only 75% of spoken words can intelligibly be heard. Even if recommended background noise levels are met, improper attention to HVAC acoustic design can result in low-frequency noises that distract students. Addressing the sound paths from HVAC equipment ensures that both the background noise level (dBA) and sound quality provide an environment conducive to learning.

Design Tools

There are a variety of acoustic software packages that can be used to analyze acoustics in buildings (more information is available at www.acoustics.org). Trane has an acoustics software program, TAP, which is used to analyze acoustic performance of HVAC systems. It uses ASHRAE-approved algorithms to analyze sound transmission through all paths, and the resulting indoor noise level.

Design Details

The first step in HVAC acoustic design is to establish a design goal for the interior space. Acoustic performance is addressed by a source-path-receiver model. Strategies to reduce background sound levels in school facilities include reducing or isolating the noise source, designing the paths to block noise transmission or increase sound attenuation, and situating the receivers to reduce noise levels where the students are located.

Noise Sources

Unducted systems should be avoided when possible, since they typically cannot meet the requirements of the ANSI 2002 S12.60 Standard. Systems to avoid include mini-splits, packaged terminal air-conditioners (PTACs), and unit ventilators.

There is no specific recommendation for equipment sound levels. Specify equipment that has been tested via an industry standard. Small unitary systems are tested via the ARI 270 rating procedure; application guidelines are provided in ARI 275-97. Typical sound power levels for single zone units are 75-82 dBA. While measures to isolate or attenuate equipment noise will be required in all cases to meet recommended indoor sound levels, the selection of quieter HVAC equipment will reduce the need for measures such as fiberglass lined ducts.

The location of the equipment and vibration isolation from the roof structure also affects the indoor background sound levels. Locate rooftop units over central corridors or unoccupied spaces when possible. Try to locate single-zone rooftop units at least 10 ft away from the classroom. Locate larger central units farther from classrooms.

When using split systems where the fan is located close to the occupied space, use multiple speed fans to reduce noise from the indoor fan during low-load periods.

Consider specifying centrifugal fans with airfoil-shaped blades to achieve recommended sound levels. Forward-curved blades should be avoided because they generate excessive low-frequency noise. Select fans so they operate at their maximum efficiency point, to minimize both power consumption and generated sound levels.

Another source of noise is aerodynamically generated sound from air motion through ducts. Low air velocities are desired; a small decrease in air velocity will result in a large decrease in the sound intensity level from air motion. Design ductwork above suspended ceilings to carry a maximum air velocity of 1200 fpm for rectangular ducts, and 2000 fpm for circular ducts. Airflow velocities in branch ducts should not exceed 800 fpm. Ductwork should be installed to achieve a low static pressure loss, as recommended by the Sheet Metal & Air Conditioning Contractors National Association (SMACNA).

Avoid the use of balancing dampers whenever possible because they are potential sources of noise. It is preferable to reduce fan speed or to use appropriately sized branch ducts to balance airflow rather than use dampers if air flow needs to be reduced. If volume dampers are unavoidable, then locate them at least 5 to 10 duct diameters from the terminal device (e.g., diffuser).

Carefully specify the duct layout at the connection between the supply duct and the diffuser so that there is a sufficient length of straight duct. It is important to avoid sharp bends or kinks that create uneven airflow at the inlet to the diffuser.

When selecting terminal units in VAV systems, pay attention to both radiated and discharge noise ratings at design air flow. Also consider design alternatives that isolate the VAV box from the occupied space by, for example, locating the terminal unit above the corridor ceiling.

HVAC Sound Paths

There are several noise paths in HVAC systems: sound transmission through the supply duct, transmission through the return duct, radiated sound from HVAC equipment through the building structure, structure-borne sound from vibration, and duct breakout noise.

One design option to reduce noise transmission is to run a horizontal length of supply duct on the roof, before turning down into the supply plenum. This configuration minimizes the dumping of turbulent air into the supply plenum and provides some noise attenuation if the rooftop duct has internal acoustical lining.

The configuration of the supply air plenum itself also has a significant impact on noise transmission. In general, sound attenuation is a function of interior lined surface area (more is better). In addition, inlets and outlets to the plenum should be oriented to avoid direct line-of-sight sound paths. See the SMANCA HVAC System Duct Design manual for detailed guidance.

Reducing sound from the return duct can be achieved by increasing the duct length, and using 1" acoustic duct liner. Lining ducts is one of the least expensive methods of providing sound attenuation. Adding 1" or 2" thick fiberglass duct liner for the first 10 ft of supply ductwork can help to reduce HVAC noise to recommended levels. The required duct cross-sectional area may increase if duct liner is used, to maintain air velocities under recommended limits. While duct liner is one of the most cost-effective measures to improve acoustics, there are potential impacts to IAQ due to the presence of fiberglass in the airstream. The designer should specify duct liner based on performance results from ASTM C1071, which includes tests for temperature resistance, corrosiveness, surface burning, fungi resistance, acoustical absorption, and odor and moisture sorption.

In general, sound transmission through ducts can be reduced through the strategic use of turns that eliminate the line-of-sight path between noise source and the occupied space. The problem with turns is that they reduce energy efficiency by creating pressure loss. Therefore, turns must be used carefully. Consider the use of turning vanes in large 90° rectangular elbows. Locate branch takeoffs at least five duct diameters from each other. Use 6-ft lengths of straight acoustical flex duct to connect the branch ducts to the diffusers.

A less desirable approach to reducing noise transmission is to use a duct silencer at the intake or discharge of the supply fan. These silencers reduce system efficiency by creating pressure loss and requiring more fan power to achieve desired air flow.

Duct breakout noise is often a problem near the discharge of the supply fan, where the supply air reaches the first transition. There are several approaches to address this problem. An acoustically lined plenum drop on the discharge of the supply fan can reduce breakout noise. Round or rectangular ducts can be taken off the plenum chamber for air distribution. Another approach to reduce duct breakout noise is to use a round drop and a radiused elbow.

Improper air balancing can also lead to increased noise. The primary volume damper in the longest run from the supply fan should be nearly fully open. If the damper is more than 20% closed, the increased air velocity will increase generated noise through all duct elements.

Structural noise transmission can be minimized by use of vibration isolators for mounting of mechanical equipment. Vibrational noise from ducts and pipes can be reduced with the use of neoprene or spring hangers.

Diffuser Selection

Noise Criteria (NC) ratings are provided by diffuser manufacturers. The Noise Criteria rating is determined by plotting sound pressure levels at different octave-band frequencies and comparing the results against an established set of curves. A combined NC rating of 27 for all classroom diffusers roughly corresponds to a background noise level of 35dBA. For a typical installation of four ceiling diffusers, this corresponds to an individual rating of NC18-20 for each diffuser. For displacement ventilation, two corner wall-mounted diffusers are sufficient to serve the needs of the typical classroom. In that case, diffusers with an NC rating of 25 or less should be satisfactory, and should be selected following manufacturer's instructions. To meet recommended indoor noise levels of the ANSI Standard, specify diffusers with a supply outlet velocity of 350 fpm and return opening airflow velocity of 425 fpm.

Evaluating Room Noise: Receiver Correction

The ANSI Standard recommends a background noise level of no greater than 35dBA. The A-weighted scale is a measure of sound loudness and is used for outdoor noises. It can also be used to measure the indoor noise level with the use of a sound meter. However, this scale does not account for the sound quality.

The Room Criteria (RC) rating procedure is the ASHRAE-preferred method for evaluating HVAC system noise. Sound pressure levels are compared against a set of curves. This rating procedure accounts for the quality of sound as well as the sound level. The sound quality is characterized by: N (neutral), LF (low-frequency rumble), MF (mid-frequency roar), or HF (high-frequency hiss). HVAC system design that achieves an RC rating of 25 (N) or better complies with the ANSI S12.60-2002 Standard.

Table 41 – Identifying Noise Sources and Reduction Methods

Noise Source	Measurement Rating /Goal	Strategy
1. From adjacent spaces	STC rating for wall assemblies of 50–60	Use extra gypsum layers, staggered or double studs, extra mass for mass walls
2. Diffusers	NC rating of 25–30	Use multiple diffusers; select for combined NC rating of 27. (Roughly equivalent to NC 18 per diffuser, for four ceiling diffusers)
3. Duct-borne noise	Increase sound attenuation to meet indoor noise criteria	Use acoustic duct liner for return ducts, and for first 10 ft of supply duct runs. Consider a horizontal discharge before the supply drop to reduce duct-borne noise.
4. Electrical appliances and computers	Background indoor noise level of 35 dBA	Determine contribution of noise from appliances to background levels
5. HVAC equipment	dBA	Avoid use of unit ventilators, indoor fan coils; locate rooftop equipment over corridors; select equipment with low noise ratings. Select splits with multiple fan speed options. Specify fan to operate at close to the optimum efficiency point.
6. Outdoor noise	Indoor noise level of 35 dBA	Follow recommendations of Acoustic Design guideline in Building Envelope chapter.

Operation and Maintenance Issues

Regular HVAC equipment maintenance is important in order to identify and remedy sources of noise. Fans, belts, bearings, and compressors can all become sources of unwanted noise if not properly maintained. Vibration isolators on HVAC equipment should also be regularly checked. Dampers and diffusers should be inspected to ensure that they have not been positioned so that they create noise due to excessive air velocity.

Commissioning

Testing the sound levels of an empty classroom requires the use of a Type II sound meter. Typical meters only measure down to 40 dBA; therefore, a reading will not normally register in an unoccupied classroom that meets the recommended 35 dBA background noise level. This type of meter calculates a one-hour average sound level that is required by the ANSI Standard. For a low cost alternative, sound meters are available for as low as $79 that can provide an instantaneous reading to detect problem areas.

References/Additional Information

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GUIDELINE TC2: DISPLACEMENT VENTILATION SYSTEM

Description

Displacement ventilation (DV) systems are different from traditional ventilation systems for schools and offer a number of advantages. Traditional air distribution systems provide conditioned air through ceiling diffusers. Cool supply air is delivered to the room to remove heat from the room and dilute contaminants. Some of the contaminants are removed from the room out the return grille. The goal of this overhead mixing distribution is to cool the entire space to the room setpoint. To achieve a well-mixed airspace, the cold supply air must be dumped out at a high velocity.

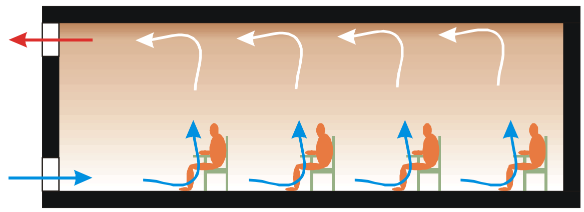


Figure 137—Airflow Pattern with Displacement Ventilation

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	■
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	□
Gym	■	Mountains	▨	Contract Docs.	□
Corridors	□	Desert	■	Construction	□
Administration	■			Commissioning	□
Toilets	□			Operation	□
Other	□				

With displacement systems, air is delivered near the floor, at a low velocity, and at a temperature of 63ºF to 65ºF (compared to around 55ºF for overhead mixing systems). The goal of displacement systems is not to cool the space, but to cool the occupants. Cool air flows along the floor until it finds warm bodies. As the air is warmed, it rises around occupants, bathing them in cool fresh air. It is called displacement ventilation because this cool, fresh supply air displaces the warm, contaminated room air and carries it upwards towards the exhaust. Air quality improves because contaminants from occupants and other sources tend to rise out of the breathing zone. Cooling loads decrease significantly because much of the heat generated by occupants, lights, and computer equipment rises directly out of the occupied zone and is exhausted from the space.

Variations and Options

There are several supply air distribution options:

- Access floor.
- Low wall outlets.
- Infloor outlets.

The best cooling source for a displacement ventilation system is a chilled water coil. The control valve in a hydronic system allows supply of constant 63 ºF to 65 ºF air. A typical direct expansion (DX) system is designed to provide colder 50 ºF to 55 ºF air while the compressor is running and cycles on and off to meet space loads. This lower temperature and larger temperature fluctuations would create a comfort problem in displacement ventilation when the supply air comes in contact with occupants. However, larger DX systems with several compressors and temperature-reset capabilities can be used as an alternative to a chilled water system. For example, a packaged rooftop variable air volume (VAV) system serving several classrooms should be able to provide the necessary supply air temperature control.

Existing packaged DX units in the 3-5 ton size range, used for individual classrooms, do not provide the warmer supply air temperature and temperature control required by DV. A small unit with either multiple cooling stages or a variable capacity compressor could meet displacement ventilation requirements. During low cooling loads, modulating hot gas bypass can be used to raise the supply air temperature. However, this negates much of the energy benefits with DV.

Evaporative cooling is also a potential source because it typically produces higher air temperatures than a DX system.

Applicability

Displacement ventilation is most appropriate for spaces with ceiling height of at least 9 ft to permit stratification; higher ceilings of 12 ft will improve stratification and reduce energy requirements. DV is applicable to classrooms built to 2005 Title 24 standards, in all California climates. DV can effectively handle room design cooling loads of 15 to 25 kBtu/h typical of modern California classrooms. Energy recovery can be a cost-effective option in mountain and desert climates of California that are subject to extreme temperatures. Underfloor air distribution is a great choice where raised access floors are desired for flexibility of power and communication wiring (although access floors are not required for displacement ventilation).

The benefits of displacement ventilation occur when the room has a cooling load. Spaces that have relatively constant, high occupant densities are good candidates for displacement ventilation.

Applicable Codes

Displacement ventilation systems face the same fan power limits and equipment-efficiency requirements as other system types.

Although potentially less outside air could provide the same indoor air quality with DV, code requirements of 15 cfm/person of minimum outside air should be followed.

While not mandated by Title 24, ASHRAE *Standard 55* has specific recommendations for comfort in unmixed conditions that occur with displacement ventilation. The temperature difference between head and foot level of the seated student should not exceed 3.6°F. To achieve this, a minimum supply air temperature of 65°F or higher is usually required. The EnergyPlus simulation program provides thermal comfort predictions for displacement ventilation systems.

Integrated Design Implications

Supply air outlets must be coordinated with the location of furnishings and space usage. The outlets may be integrated with cabinets or seating.

There is an excellent opportunity to integrate electrical and communication wiring with the air distribution either under the floor or along the baseboard.

A displacement system can eliminate the need for a suspended ceiling and allow the ceiling to be clear of supply registers.

If the ceiling is high enough, displacement ventilation can be integrated into portable classroom design, where space for ducting exists in the crawlspace beneath the floor.

Slab floors may be designed with integral ducts or troughs for air distribution.

Consider using variable-speed heating and cooling sources to minimize the on-off compressor cycling and variations in supply air temperature.

Ceiling fans are not recommended with displacement ventilation because they are designed to mix air in a space and will disrupt the stratification created by the displacement ventilation system.

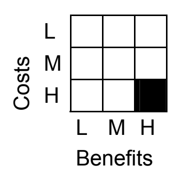
Opening operable windows and doors to let in warm outdoor air can affect the temperature stratification that occurs with DV systems. Consider providing interlocks to shut off mechanical cooling when windows or doors are opened.

Use double-paned, low-e windows to moderate interior surface temperatures in the winter, to reduce potential for cold downdrafts that oppose displacement ventilation airflow.

For cold, mountain climates such as Lake Tahoe, where the winter design temperature is 10°F or colder, a separate perimeter heating system is required to offset heat loss and radiation from cold windows. For all other California climates, heating can be supplied through the low-velocity “displacement” diffusers. In heating a high airflow should be used, since in heating the goal is a well-mixed space.

For rooms with high cooling loads, displacement ventilation can be used in conjunction with supplemental radiant cooling. Radiant cooling can remove the heat gains and displacement ventilation can be used to satisfy outside air ventilation requirements.

Cost Effectiveness



There is not a great deal of experience with displacement ventilation in California classrooms, but it is growing in popularity for new commercial buildings. For the near future, first costs are likely to be higher than standard overhead air distribution.

The displacement diffusers will carry a cost premium of about $1500 per classroom, which may be partially offset by simplified ductwork. Packaged chillers or large packaged VAV systems serving multiple classrooms will carry a higher first cost than packaged rooftop units, but provide for improved comfort and energy savings. If packaged DX units are used, displacement ventilation can reduce cooling energy requirements, and fan energy requirements if variable-speed fans are used. Displacement ventilation may qualify for incentives programs such as Savings by Design.

A displacement ventilation system will probably not provide a short payback based on energy savings alone. However, the system provides additional comfort and air quality benefits. Energy savings will be greater in schools with year-round operation.

Benefits

Advantages

Significantly lower cooling loads result from thermal stratification. For typical classroom loads, DV requires about 20-25% more airflow than overhead mixing ventilation at design conditions. However, with a 65°F supply air temperature, the required cooling capacity will usually be lower with displacement ventilation.

Since air is delivered at 65°F, there are greater hours of free cooling, where the compressor is not required to run.

The use of a higher supply air temperature, and corresponding reduction in latent load, may allow for downsizing of equipment.

For the same outside air volume, air quality will improve compared to systems that mix space air. DV can provide equal or better air quality with less outdoor air due to stratification.

Low air velocities and more neutral supply temperatures can result in improved thermal comfort.

Lower fan energy with lower static pressure may result (depends on distribution type and outlet type).

Low air velocities will normally result in lower background classroom noise levels.

Ceiling remains clear of supply registers, except for exhaust/return grilles.

Disadvantages

Heating performance may be worse than systems providing air at greater velocities. Mixing (i.e., destratification) is desirable for heating. A supplemental heating system will be required in mountain climates of California.

First cost may be higher with displacement ventilation and raised floor systems. Diffuser costs and increased HVAC complexity will tend to increase first costs; however, energy savings should result in lower life-cycle costs.

Packaged rooftop DX units that condition individual classrooms are the most common HVAC system in California. Off-the-shelf units require hot gas bypass, return air bypass or some means of raising the supply temperature to be suitable for DV. Constant volume reheat systems are not allowed by code.

Systems may require more sophisticated controls, to realize the potential energy savings. Rooftop units should have sufficient means to reduce compressor capacity to maintain a stable supply air temperature.

Lack of available design tools makes this a less attractive option at the design stage. This will change as the technology becomes more common in schools. For large spaces such as auditoriums, CFD analysis may be required to ensure air distribution and thermal comfort.

Some floor area or low wall area is required for supply air outlets.

Higher ceilings will tend to increase reverberation of sound in classrooms. See the acoustics material in the Interior Surfaces chapter for more information.

Design Tools

All manufacturers of sidewall displacement diffuser and floor systems offer design assistance and computational fluid dynamics (CFD)-generated graphics that depict air supply patterns with defined supply air temperatures and airflows. Diffusers should be selected with a noise criteria (NC) rating of 25 or lower, following manufacturer's selection guidelines.

CFD software that now runs on personal computers can help predict airflow patterns within a room and resulting occupant comfort, as well as help with the selection and location of supply outlets. CFD is recommended for the design of displacement ventilation in large spaces to ensure that comfort is maintained throughout the space.

Conventional sizing guidelines cannot be used to determine required airflow or cooling capacity. ASHRAE has published design guidelines for thermal displacement ventilation[51]. This guideline provides a procedure for calculating the required air flow and supply air temperature for design cooling conditions.

EnergyPlus (version 1.2) has implemented a displacement ventilation model that accounts for the temperature stratification that occurs with displacement ventilation and other unmixed spaces. This is a useful tool for analyzing annual energy use with displacement ventilation. Other energy simulation tools such as DOE-2 cannot model displacement ventilation effectively, since they do not model unmixed spaces. Special algorithms would be required to model the temperature stratification that occurs with DV.

The Center for the Built Environment at U.C. Berkeley has developed a graphical software tool for predicting thermal comfort in unmixed spaces. A result of extensive research and human subject tests, this software package can be used to evaluate impacts of cool drafts near the floor on occupant comfort.

[51] Chen, Qingyan, and Leon Glicksman, "System Performance Evaluation and Design Guidelines for Displacement Ventilation," ASHRAE Research Project 949, ASHRAE, 2003

Design Details

System Sizing and Equipment Requirements

Provide approximately 1000 to 1200 cfm (1.0 cfm/ft² to 1.2 cfm/ft²) of 65°F air for typical classrooms built to 2005 Title 24 code. Some classrooms with high occupancies and internal loads may need 1500 cfm of supply air at design cooling conditions. The required supply airflow can be up to 20-25% higher than a comparable overhead mixing system. However, due to the warmer SAT, the total cooling capacity will be lower, when using the same amount of outside air.

To determine design airflow and cooling capacity requirements, use a procedure that accounts for the temperature stratification in the space. Conventional sizing methods cannot be used. See the Design Tools section for more details.

Consider using 100% outside air for cooling for temperate coastal climates. Since the design outside air dry bulb temperature is close to the DV return air temperature of 78-82°F, the energy penalty for increased ventilation will be very low. Use return air for inland valley and desert climates where the design dry bulb is above 90°F.

Despite using a higher supply temperature, dehumidification is typically not required in California. If dehumidification is desired, face and bypass dampers or return air bypass can be used to lower the air temperature leaving the coil. In California this might only be required during a mild to warm humid day, for coastal climates.

Deliver supply air for cooling at 63ºF to 65ºF. For heating during occupied hours, use full airflow and design for a heating supply air temperature of 80°F to 85°F.

Room temperature control in cooling can be achieved by one of three control strategies: varying the supply air temperature with constant air volume (CAV), varying the air volume with a constant supply temperature (VAV), or varying both air volume and temperature (VVT). With constant air volume, the system must have the means to modulate capacity to increase the supply temperature as the cooling load decreases. Variable air volume will allow for fan energy savings at part load conditions, and is a good choice for larger packaged systems. VVT offers the greatest degree of control, and is suitable for chilled water systems. Allowing for supply air temperature reset will extend the range of free cooling, maximizing energy savings.

Air Distribution Requirements

Design for air velocity at supply outlets no greater than 25 ft/minute to 50 ft/minute. Therefore, displacement ventilation requires significantly larger supply outlets than an overhead distribution system. Follow manufacturer's recommendations for selecting low-velocity displacement diffusers. Select low-velocity diffusers for a noise criteria (NC) rating of 25 or less.

Try to place sidewall diffusers at the corners of the room. Try to avoid situations where occupants are more than 15 ft from the nearest supply diffuser. Two corner diffusers provide for effective air distribution and good thermal comfort for a 960 ft^2 classroom, under most conditions. Classrooms with very high cooling loads may require additional diffusers to ensure proper comfort.

Locate the return air grille at or near the ceiling. When possible locate the return near exterior walls and windows for most efficient heat removal.

Higher air velocity is desirable in heating mode, so consider a design that reduces supply air outlet area (either manually or automatically) when the system provides heating, or that uses VAV in cooling and full airflow in heating. This is especially important in large halls, such as a gymnasium with sidewall supply. Consider demand control ventilation and variable frequency drive (VFD) in gyms, auditoriums, and cafeterias.

Architectural and Other Considerations

Consider the use of barometric relief dampers when using 100% outside air. In some instances, a powered exhaust relief may be required to meet ADA accessibility requirements.

The thermostat should be located at a height of approximately 40” from the floor. It should be located outside of the “adjacent zone” of the diffusers, where the airflow exceeds 40 fpm (this zone is defined by the diffuser manufacturer). A good choice is to locate it on an interior wall, on the side of the white board closest to the exterior wall.

Minimum ceiling height is about 9 ft for adequate stratification. High ceilings of 12 ft will improve stratification, reducing cooling energy requirements.

Underfloor air distribution (UFAD) is a similar technology that provides good ventilation effectiveness and indoor air quality. Air is typically delivered to a pressurized underfloor plenum and supplied to the air space by VAV diffusers. The airflow pattern is a little different with underfloor air: the air exits the floor at a higher velocity than with displacement ventilation, causing some mixing in the occupied zone. However, many of the energy and IAQ benefits also exist with UFAD. The use of an underfloor plenum allows for great flexibility in locating diffusers, making UFAD an excellent choice for spaces with open floor plans. While typically used in office environments, this application is well-suited to large spaces such as libraries and auditoriums. Raised access floor systems are typically made up of 1-in. to 1.5-in. thick concrete sections. This provides advantages from the standpoint of controlling duct noise breakout and/or radiated noise from VAV or fan powered boxes.

The Center for the Built Environment has a wealth of information on the design of underfloor air distribution (see references below). A guideline on underfloor air distribution is also available from ASHRAE.

Operation and Maintenance Issues

Operating and maintenance requirements are similar to overhead air distribution systems.

Commissioning

Check for proper supply air temperatures. Ensure that air velocity at supply outlets is not too high for comfort. Verify that total airflow meets design requirement. Verify proper control operation and temperature reset for heating or cooling. Verify VAV or VFD operation if demand control is incorporated into an area such as a gym.

References/Additional Information

Boscawen School, NH implemented this type of system. H. L. Turner Group, Architects.

Chen, Qingyan and Leon Glicksman, "System Performance Evaluation and Design Guidelines for Displacement Ventilation," ASHRAE Research Project 949, ASHRAE, 2003. This publication provides a useful design procedure for determining required supply airflow and temperature at design cooling conditions.

EnergyPlus includes special modeling capabilities for displacement ventilation. These are useful for predicting comfort and energy use with TDV. For more info see (www.eere.energy.gov/buildings/energyplus/).

A PIER research project that is investigating thermal displacement ventilation for California schools is in progress. This project includes retrofitting two classrooms with displacement ventilation systems and monitoring their performance. For more information, see www.archenergy.com/ieq-k12.

Bauman, Fred S., "Designing and Specifying Underfloor Systems: Shedding Light on Common Myths," HPAC Engineering, Dec. 2003.

Thermal Comfort Model—this was developed by the Center for the Built Environment at U.C. Berkeley. For more information, see cbe.berkeley.edu/research/briefs-thermmodel.htm.

GUIDELINE TC3: SINGLE-ZONE UNITARY SYSTEM

Recommendation

If choosing a packaged rooftop system or split system, specify a high-efficiency unit with an integrated economizer (depends on the space's natural ventilation design), and design the duct system to allow proper airflow at low or medium fan speed. Properly size the unit to control cooling energy costs and maintain comfort (see Overview). Take special care to control noise from indoor units in split systems.

Figure 138—Packaged Rooftop System

Source: Trane

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	□
Gym	■	Mountains	■	Contract Docs.	□
Corridors	■	Desert	■	Construction	□
Administration	■			Commissioning	□
Toilets	■			Operation	□
Other	■				

Description

A single zone unitary system consists of one or more factory-made assemblies designed to supply heating and/or cooling to a single comfort zone in a building. Unitary systems may be of either single package or split system design. Single zone units are typically controlled from a single space thermostat with one unit provided for each zone.

Single-Zone Packaged Rooftop Unit

A single package unit is fully self-contained and consists of a supply fan, direct expansion cooling coil, filters, compressors, condenser coils and condenser fans. Supply air and return air ducts connect to the bottom (vertical discharge) or side (horizontal discharge) of the unit. Heat is typically provided by a gas furnace within the unit, but a heat pump configuration is also an option. Units are typically mounted on roof curbs but can be also mounted on structural supports or on grade. Supply air and return air ducts connect to the bottom (vertical discharge) or side (horizontal discharge) of the unit.

The most common configuration is to use a separate packaged rooftop unit for each classroom. This design provides low installation cost and good individual room temperature control. However, this option also carries higher maintenance costs.

Small packaged rooftop units that serve single classrooms provide a cooling capacity of 3-5 tons, and one or two stages of heat. Common options for these units are economizers, powered exhaust, additional dehumidification controls, and corrosion protection for marine climates. Thermostatic expansion valves should be specified for refrigerant control, and are offered as a standard option. Direct digital controls are also offered as an option, for integration with the building energy management system (EMS).

Economizers are often standard, cost-effective options for rooftop units (see Guideline TC8: Economizers). A dehumidification option requires an additional sensor and controls, and is typically not required for California climates. Powered exhaust fans are often specified for classrooms to avoid excess indoor space pressure and to ensure compatibility with ADA accessibility requirements. Otherwise, if a system has an economizer and is operating at 100% outside air, an increase in space pressure can increase the effort needed to open doors.

High-efficiency cooling with seasonal energy efficiency ratios in the range of 13 to 16 is commonly available. These units generally incorporate larger evaporator and condenser coils, efficient compressors, improved cabinet insulation, and higher efficiency fans and motors. Some units offer multiple stages of cooling through the use of multiple compressors or variable capacity compressors. However, multiple-stage units are more common on larger systems with cooling capacities of 10 tons or greater.

Packaged units can often utilize energy recovery, either sensible (air to air heat exchanger) or sensible and latent (enthalpy wheel), to provide pre-conditioning of the supply air stream with exhaust air. Energy recovery is available as a factory option with some equipment or as a field add-on. While generally not cost effective for small units, energy recovery may have a short payback for large units in more severe climates. The decrease in design heating and cooling loads will allow for smaller-sized equipment to be used.

For larger packaged units serving multiple classrooms, a variable-speed fan can save a large amount of fan energy. Reducing the airflow and fan speed by one-half will require only about one-eighth of the fan power used at full airflow. Variable-speed drives are cost-effective for larger systems. Refer to Guideline TC4: Variable Air Volume System for more information.

Split Systems

A split system is similar to a typical residential heating and cooling system. The components include an indoor fan unit and outdoor compressor and condenser package. A set of field-installed insulated copper pipes connects the two sections and is called the line set. The indoor unit usually includes a cooling coil and furnace section, although the furnace can be omitted if the compressor is also used for heating in heat pump mode. Supply air from the indoor unit is typically ducted to several supply diffusers in the ceiling. Return air may be ducted or returned directly to the unit through a grille.

An economizer is not standard with split systems but is available as an aftermarket option. The additional equipment includes a mixing box with outdoor and return air dampers and the associated controls. Check with split system manufacturer for control compatibility.

For climates where cooling is unnecessary, then the system can be used for heating only, or for heating and ventilating. Eliminating the cooling coil and outdoor compressor unit reduces the cost significantly. An economizer may be installed to provide free cooling if the space design does not allow for convenient natural ventilation cooling (due to drafts, outdoor noise, dust, or similar problems).

Indoor units are available for either horizontal or vertical installation. Horizontal units are typically installed above the ceiling. Vertical units may be installed in a mechanical closet with flow direction either upwards or downwards.

A wider range of cooling efficiency options is typically available for split systems compared to rooftop packaged systems. In addition, a high-efficiency, condensing furnace is available as an option for most split systems. Annualized fuel utilization efficiency (AFUE) is 90% to 96%, compared to about 80% for standard units.

A two-speed or variable-speed blower and variable output furnace is an option that can provide significant fan energy savings and improve comfort through less on-off cycling.

Two-speed compressors are available that can be controlled together with a two-speed indoor fan for better comfort and humidity control.

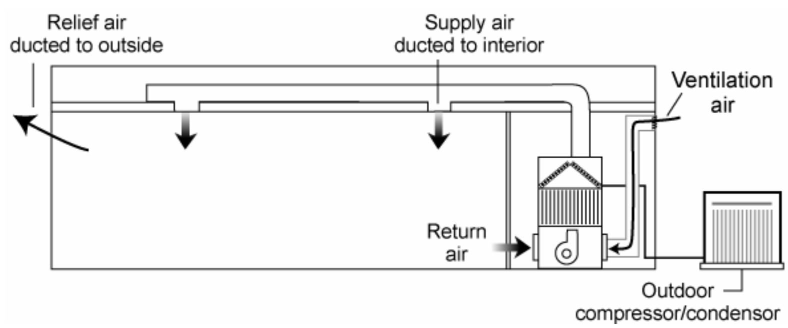


Figure 139—Split System with Vertical Indoor Unit Located in Mechanical Closet

Ductless Split System

A ductless split system consists of an indoor fan coil unit and an outdoor condenser and compressor unit, connected by refrigerant tubing and control wiring run through the wall or roof. The indoor unit contains a cooling coil, fan and filter. Ventilation air can be supplied with an optional duct attachment that passes through the wall. The indoor unit can be mounted high on the wall, at the ceiling or above a suspended ceiling. Wall-mount units are generally limited to 2 tons capacity, while units mounted above suspending ceilings can provide up to 5 tons of cooling.

Heating can be supplied with a heat pump option, or with a supplemental system such as baseboard heaters or a heated floor. Economizers are typically not available as an option. Ductless splits can serve floor spaces up to 1,000 to 2,000 ft^2 and are useful when rooftop space or space for ductwork is not available. These systems can be a good choice when integrated with natural ventilation strategies.

Multiple-speed fans are recommended, and often specified, to limit noise from indoor units. Refer to the guideline on HVAC Acoustics for more information.

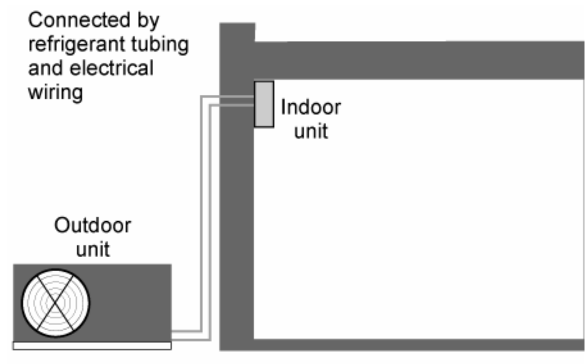


Figure 140 —Ductless Split System with Wall-mounted Indoor Unit

Variable Volume and Temperature

In general, a VAV system is recommended when a single cooling unit is used to serve multiple zones. However, a "single zone" constant volume rooftop unit can condition multiple zones when equipped with special controls and hardware. These are sometimes referred to as variable volume and temperature (VVT) configurations. This type of system includes an automatic damper in the ductwork for each zone, which modulates to control space temperature to the zone setpoint. A monitor controller determines the system mode (i.e. heating or cooling) based on the number of zones with a heating or cooling requirement. Optionally, supplemental heat can be supplied via a hot water valve or electric resistance heater to raise the supply temperature to individual zones. If some zones require cooling while others need heating, then the controller switches the rooftop unit between both modes and the zone dampers will open or close as appropriate. This system may also include a bypass damper between the supply and return that is opened to maintain constant airflow through the rooftop unit when one or more zone dampers are closed.

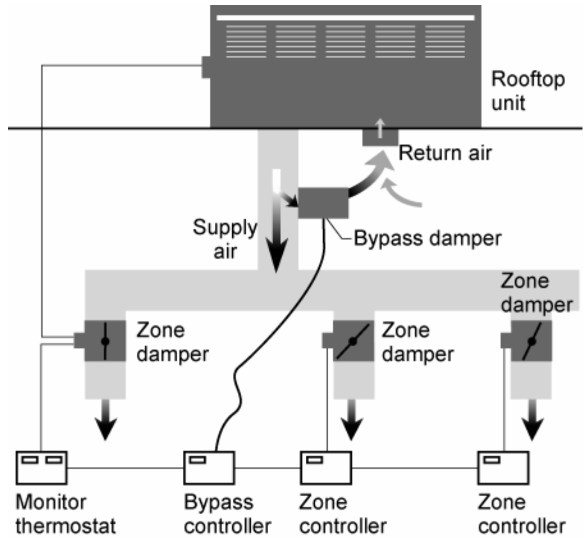


Figure 141—Packaged Rooftop System with Variable Volume and Temperature Control

Applicability

Single-zone unitary systems are applicable for spaces that require both heating and cooling. Single zone units are generally limited to low-rise buildings (three stories or less) to avoid excessively long duct or pipe runs and excessive space for duct chases. (Refer to the system selection tables in the Overview section for more information.)

Split systems are applicable to classroom spaces up to 2,500 ft^2. Packaged rooftop units are available in capacities from 2 tons to more than 100 tons, and can be used for single zones from 600 ft^2 to more than 30,000 ft^2.

Due to the constant volume fan, this system is most applicable where loads and ventilation requirements are relatively constant, such as in classrooms. The system is less applicable for intermittent occupancies such as assembly areas.

Applicable Codes

See Table 42 for minimum cooling efficiency requirements. For units smaller than 65,000 Btu/h, these efficiency requirements are federal regulations. Minimum heating efficiency is 78% AFUE for gas furnaces smaller than 225,000 Btu/h.

Minimum outdoor air ventilation rate is specified by Title 24 (see this chapter's Overview section)

Title 24 requires an integrated economizer for systems with cooling capacity greater than 75,000 Btu/h and supply airflow greater than 2,500 cfm (which is larger than a typical classroom system).

A deadband of 5°F between heating and cooling setpoints is required by code.

Integrated Design Implications

Rooftop units can have a significant visual impact and can create concern regarding noise level at adjacent properties.

Unit location should be considered early in the architectural design process to allow for efficient duct layout. In addition, location of ducts and supply registers should be considered when making lighting system decisions.

System controls should be specified so they integrate with natural ventilation design. Use automatic interlock controls to shut off the system when windows are opened or allow manual fan shutoff. If the space is designed for good natural ventilation, an economizer may not be necessary. Conversely, if natural ventilation is not feasible due to constraints such as outdoor noise, then an economizer can be specified to take advantage of free cooling.

The location of rooftop equipment and indoor fan coils on split systems has a great impact on the noise levels in the classroom. Providing a multiple-speed fan on split systems is one option for reducing noise while also improving energy efficiency.

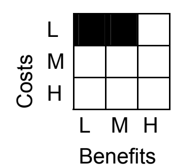
Direct digital controls may be used with an energy management system for scheduling and centralizing diagnostics. This allows district maintenance and operations personnel to manage system scheduling and diagnostics for several campuses from a single office. Refer to the guideline on DDC for more information.

Try to place ducts within the conditioned envelope as much as possible to minimize the impact of leakage and conduction losses, which can be very significant. Insulate under the roof deck rather than on top of a suspended ceiling.

For unitary systems, air distribution can be overhead mixing ventilation, displacement ventilation or underfloor air distribution. See Guideline TC3: Single-Zone Unitary System and Guideline TC2: Displacement Ventilation System for more information.

Cost Effectiveness

Packaged Rooftop Units



The overall cost for a packaged rooftop system can be as low as \$13/ft^2 to \$16/ft^2 (installed cost, including ductwork and controls). Cost of the unit alone ranges from about \$2,325 for a two-ton unit to around \$3,675 for a five-ton unit[52]. For larger packaged units serving a single-zone, equipment costs are slightly less than \$1,000 per ton of cooling. High-efficiency package units (when available) cost 10-30% more than standard efficiency models and can have paybacks as low as three to four years in warm climates.

[52] RS Means 2004, material costs only for rooftop air conditioner, with economizer, gas heat and standard controls.

Single-zone packaged rooftop systems are often the lowest first cost alternative when both heating and cooling are required. However, they are relatively costly to maintain, energy costs are higher than average, and life expectancy is less than 30 years.

Variable speed drives are generally not available as a standard option on small packaged units. The installed cost of a variable-speed drive is roughly $300/hp. For classrooms that require constant fan operation during occupied hours, the payback time can be very short if the fan speed is reduced during low-load periods. However, the use of variable air volume may require more sophisticated controls.

Split Systems

Overall system cost for a gas/electric split system ranges $\$14/ft^2$–$\$17/ft^2$.

A high-efficiency (condensing) furnace adds roughly $700, compared to a standard efficiency unit with a base installed cost of about $550. However, the extra cost may also cover multi-speed fan control and variable furnace output, in addition to better efficiency.

An efficient 3-ton air conditioner with 13 SEER costs roughly $2,500, compared to $1,700 for a SEER 10. The incremental cost is roughly $800. An outside air economizer adds about $300 to $500.

For a 960-ft^2 classroom, the incremental cost for combined measures (cooling efficiency, heating efficiency, and economizer) is roughly $2,000, or $\$2/ft^2$ of floor area. High-efficiency cooling is generally cost effective in warm regions. A high efficiency, condensing furnace should be cost effective in cool climates, especially considering construction cost savings due to more flexibility in locating the low temperature flue vent.

Ductless Splits

In North America, ductless splits are typically more expensive than packaged rooftop units. The unit price for a 2-ton unit is approximately $4,000 to $5,000.

Benefits

Advantages

- Low initial cost for both equipment and installation.
- No inside mechanical equipment space is used with packaged rooftop systems. (Not true of split systems).
- Availability of high-efficiency cooling options and multi-speed fans with split systems.
- An added economizer can take advantage of outdoor air for free cooling (see Guideline TC8: Economizers).
- Systems, parts, and service technicians are widely available.

- Easily allows for individual room operation and temperature control.

Disadvantages

- Single package systems are relatively large and require roof space.
- Air ducts, which can be leaky and inefficient if not installed properly, are required.
- Split systems require space for the indoor unit. The indoor units may generate excessive noise in the classroom space.
- Systems have limited multi-zone capability.
- Poor dehumidification control can occur compared to VAV systems (due to compressor cycling). Poor capacity control may also result in reduced occupant comfort.
- For large facilities, higher total cooling capacity is required than a central plant, since the systems do not take advantage of load diversity. Operating costs may be higher than central VAV systems.
- Higher maintenance costs occur for large facilities compared to central VAV systems.
- Systems have typically shorter lifetimes than central VAV systems.

Design Details

The performance of small packaged systems is characterized by the SEER rating, a measure of the seasonal cooling efficiency of the unit over varying outdoor and load conditions. For all climates, but especially for hot inland climates, specify a unit with a high EER rating as well. The EER rating represents the unit's efficiency at hot outdoor conditions. Since electricity rates are usually higher during hot summer conditions, EER is a better indicator of demand savings potential. Ratings of high-efficiency packaged units are available online in a database maintained by the Consortium for Energy Efficiency and the Air Conditioning and Refrigeration Institute (www.ceehvacdirectory.org/).

The performance of larger units (capacity of 6 tons or greater) is characterized by an EER rating and integrated part load value (IPLV) rating. The IPLV rating is analogous to SEER for larger systems; it is a seasonal average cooling efficiency using a typical commercial load profile.

For heat pumps, the heating performance is characterized by the heating seasonal performance factor (HSPF). The HSPF rating is analogous to the SEER rating: it is an average efficiency over the heating season.

Teacher control of the classroom environment should be considered at the design stage. Some plans specify a control that allows for a user thermostat adjustment 1–2°F up or down to satisfy personal comfort needs. In some climates, peak outdoor conditions occur in the late afternoon, when the classroom is intermittently occupied. Consider implementing a shorter occupancy schedule for HVAC equipment, with the capability for a user occupancy override of 1–2 hours to accommodate flexible teacher schedules.

Consider a morning warm-up operation schedule, where the classroom is heated to the setpoint with no ventilation air. Then outside air dampers can be opened an hour prior to occupancy to meet code requirements.

SEER and EER ratings measure cooling efficiency, but the ratings do not directly address fan energy efficiency. As classrooms require continuous (though not necessarily constant volume) fan operation for ventilation, annual fan energy use of constant volume units can be 50% or more of the annual electricity consumption of the unit.

Most packaged systems have several fan speed options that can be selected in the field when the unit is installed. Careful design of the air distribution system can reduce pressure drop and provide significant savings if the fan is wired for low or medium speed (Guideline TC4: Variable Air Volume System). Airflow settings for small packaged units typically fall between 350 cfm and 450 cfm/ton. Some offer settings as high as 500 cfm/ton; above this airflow, condensate may blow off the evaporator coil.

To improve cooling efficiency in the warm and dry central valley and desert regions, consider increasing the airflow per ton of cooling. This will increase the sensible heat ratio and sensible cooling capacity of the unit. For typical packaged units, increasing the airflow from 400 cfm/ton to 500 cfm/ton will result in sensible cooling capacity increases on the order of 10%. This increase in sensible capacity may allow for the use of lower tonnage equipment. However, it is important when making a specification to evaluate the tradeoff between increased cooling efficiency and higher fan energy.

The incremental equipment cost for packaged rooftop equipment is not too large for an increase in size from say, two to four tons. Therefore, the temptation is strong to specify the larger unit for safety's sake. However, there are performance penalties for oversized systems; compressor cycling will result in higher energy use and poor humidity control. Bigger is not always better. Do not rely on rules of thumb to select airflow, cooling capacity, or heating capacity. Consider the school calendar and occupancy schedule when design for peak cooling. See this chapter's Overview section for a discussion of load calculations and the impact of cooling capacity oversizing.

Economizers are often field-installed add-ons that are prone to failure. Therefore, factory-installed economizers are recommended whenever possible. See the guideline on Economizers for details.

For marine climates, corrosion protection is offered as an option on packaged rooftops, with protective coatings for the cabinet, condenser and evaporator coils.

Vibration isolation is often provided internally. Internal isolation should be reviewed for proper spring type and static deflection. If internal isolation is not provided, or is unacceptable, external spring isolators should be utilized. Refer to 2003 ASHRAE Handbook – *HVAC Applications* Chapter 47 for recommended vibration isolation. If external isolation is used, all internal spring isolators should not be released from their restraining bolt.

The unit should be located above unoccupied spaces (i.e., storage, stairwells, etc.) whenever possible to minimize noise problems.

For split systems, space must be available above the ceiling or in a mechanical closet for the indoor unit.

For split systems, to reduce noise, isolate the unit from the occupied space, as well as provide appropriate noise control measures at the intake and discharge, and adequately size ducts and registers to avoid excessive air velocity.

Nearly all packaged units 20 tons or smaller use air-cooled condenser coils. However, evaporatively cooled condensers are sometimes an option on larger units and remove heat more effectively, improving efficiency.

With all cooling systems, water may condense on the indoor coil. Sometimes for split systems, depending on the location of the indoor unit, a pump may be required to remove water from the condensate drain pan to an appropriate receptacle.

Several manufacturers offer environmentally-friendly alternatives to R-22 refrigerant, a hydrochlorofluorocarbon (HCFC) that contributes to ozone depletion. Several alternatives are available; the most commonly used one is R-410A. As R-22 is phased out, R-410A will become a more common option with packaged units.

Teacher control of the classroom environment should be considered at the design stage. Some plans specify a control that allows for a user thermostat adjustment 1°F–2°F up or down to satisfy personal comfort needs. In some climates, peak outdoor conditions occur in the late afternoon, when the classroom is intermittently occupied. Consider implementing a shorter occupancy schedule for HVAC equipment, with the capability for a user occupancy override of 1–2 hours to accommodate flexible teacher schedules.

Consider a morning warm-up operation schedule, where the classroom is heated to the setpoint with no ventilation air. Then outside air dampers can be opened an hour prior to occupancy to meet code requirements.

Table 42—Standards for Efficiencies of Air-Cooled Unitary Equipment

Type	Capacity (Btu/h)	Minimum	Recommendation
Single package gas-electric rooftops, single-phase power	< 65,000	13.0 SEER	11.3 EER 13.0 SEER
Single package gas-electric rooftops, three-phase power	< 65,000	9.7 SEER	11.3 EER 13.0 SEER
Other air conditioners, single-phase power	< 65,000	13.0 SEER	11.6 EER 13.0 SEER
Other air conditioners, three-phase power	< 65,000	10.0 SEER	11.6 EER 13.0 SEER
Single package heat-pumps, single-phase power	< 65,000	13.0 SEER 7.4 HSPF	11.0 EER 13.0 SEER
Single package heat-pumps, three-phase power	< 65,000	9.7 SEER 6.6 HSPF	11.0 EER 13.0 SEER
Other air-cooled heat pumps, single-phase power	< 65,000	13.0 SEER 7.4 HSPF	
Other air-cooled heat pumps, three-phase power	< 65,000	10.0 SEER 6.8 HSPF	
Air-cooled air conditioners	> 65,000 and <135,000	10.1 EER 10.3 EER (elec res/none)	11.0 EER
Air-source heat pumps	> 65,000 and <135,000	9.9 EER 10.1 EER (elec res/none) 3.2 COP (47°F) 2.2 COP (17°F)	11.0 EER 3.4 COP (47°F) 2.4 COP (17°F)
Air-cooled air conditioners	>135,000 and < 240,000	9.5 EER 9.7 EER (elec res or none)	10.8 EER
Air-source heat pumps	>135,000	9.1 EER 9.3 EER (elec res or none) 3.1 COP (47°F) 2.0 COP (17°F)	3.3 COP (47°F) 2.2 COP (17°F)

Source: CEC Appliance Efficiency Regulations, 2003

Operation and Maintenance Issues

Maintenance requirements for a packaged rooftop system are very similar to other system types. However, all compressor-cooling systems require additional maintenance skills and cost more to maintain compared to heating-only systems.

Recommended maintenance tasks include:

- Replacing filters regularly.
- Cleaning indoor and outdoor coils regularly.
- Checking refrigerant charge.
- Cleaning and draining cooling coil condensate pan, and specify pans that are pitched to drain continuously under all operating conditions.
- Lubricating and adjusting fan as recommended by the manufacturer.

Commissioning

- Record equipment nameplate information and obtain operation and maintenance manuals for all equipment. Obtain a report of functional testing performed with unitary equipment.
- Measure total supply airflow with a flow hood or comparable measuring device. Make sure that airflow is within 10% of design value. If airflow is low, then check ducts for constrictions and check that filters and coils are free of obstructions. Larger ducts or shorter duct runs may be necessary. Reduce the number of duct turns to a minimum. If airflow is high, then reduce fan speed if possible, according to manufacturers' instructions. Avoid using balancing dampers to reduce air flow because they are less efficient and are also a potential source of noise.
- Ensure that condensate is routed to a roof drain or other drain, not over the side of a building.
- Check current draws of compressor and fans.
- If an economizer is installed, then verify proper operation (see Guideline TC8: Economizers).
- Check and calibrate thermostats.
- Verify that fans operate continuously during occupied hours.

References/Additional Information

Jacobs, Pete, "Small HVAC System Design Guide," California Energy Commission, 2003.

Architectural Energy Corporation, "Integrated Design for Small Commercial HVAC," Energy Design Resources Brief, Southern California Edison, 2002.

GUIDELINE TC4: VARIABLE AIR VOLUME SYSTEM

Recommendation

Consider choosing a variable air volume (VAV) reheat system for large administration or classroom facilities, especially multi-story buildings.

For reheat VAV boxes use a "dual maximum" control logic, which allows for a very low minimum airflow rate during no- and low-load periods.

Select VAV boxes for a total pressure drop of 0.5 in. H_2O at design air flow.

Specify variable-speed fan control, low face velocity cooling coil and filters, bypass damper, supply air temperature reset control and supply duct pressure reset control.

Consider a dual-fan, dual-duct VAV system in order to eliminate reheat energy.

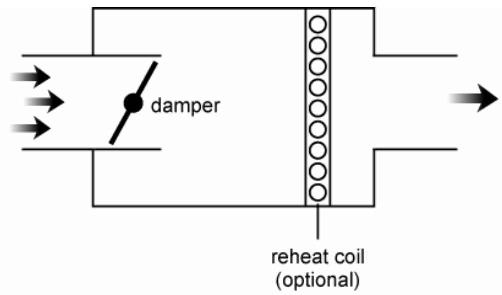


Figure 142—VAV Box

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	■
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	□
Gym	□	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	□
Administration	■			Commissioning	□
Toilets	□			Operation	□
Other	□				

Description

VAV is a general term for a type of HVAC system that supplies only the amount of air needed to satisfy the load requirements of a building zone and that can supply different volumes to different zones at the same time. The result is that the total supply of cool air changes over the course of the day, depending on the heat gains in different building areas at different times.

In a VAV system, a central supply fan sends air through ductwork to terminal units (VAV boxes) throughout the building. The airflow to each zone—a space or group of similar spaces—is controlled by the VAV box (a "smart damper"), which varies the airflow in response to the space temperature. As cooling loads in the zone drop, the damper continues to close until it reaches a minimum position. The minimum position provides the occupants of the zone with adequate ventilation air. Some VAV boxes, especially those in perimeter zones, contain a reheat coil for times when the minimum airflow provides too much cooling. The reheat coil—typically hot water, but sometime electric resistance—prevents zones from being overcooled. The reheat coil also provides winter heating, typically during a morning warm-up period prior to occupancy when the outdoor air dampers are closed.

A duct-mounted pressure sensor that decreases the fan output as the VAV box dampers close controls the main system fan.

See also Table 38 for an evaluation of a dual-fan, dual-duct VAV system.

Variations and Options

VAV air handlers may be purchased as factory fabricated units or may be assembled from components in the field (built-up). In either case, cooling can be provided with a chilled water coil or a direct expansion refrigerant coil.

- A common choice for schools is the packaged rooftop VAV air conditioning system. The self-contained unit consists of a variable-volume supply fan; direct-expansion cooling coil; heating (when required) with gas furnace, hot water, or steam; filters; compressors; condenser coils; and condenser fans.
- Facilities with a central chilled water plant often use factory-fabricated air handlers with chilled water coils. In this case, the unit includes a supply fan, cooling coil, filters, and perhaps a heating coil.

VAV systems usually include economizer controls. Several VAV box types are available and some can be combined within the same system:

- Most common for new buildings are pressure-independent boxes with DDC-controlled actuators.
- Fan-powered mixing boxes recirculate room or plenum air and are available in two types: series fan or parallel fan. The series fan box requires the fan to operate at all times. The parallel fan box fan activates only when reheat is required.
- Dual-duct VAV boxes contain two dampers controlling a cool duct inlet and warm duct inlet. Typically the warm duct damper is closed during cooling periods. When cooling load drops and the cool duct damper reaches its minimum position, then the warm duct damper begins to open to prevent overcooling in the space.

A dual-fan, dual-duct VAV system is an alternative to VAV reheat and requires less reheat energy. The warm duct recirculates indoor air and adds heat if necessary. The cool duct provides ventilation air and cooling. Rather than using a reheat coil to avoid overcooling at minimum ventilation position, the dual duct system mixes warm return air to offset cooling.

Applicability

VAV systems are appropriate for administration buildings or large classroom buildings with peak cooling load greater than 20 tons. The minimum size for a packaged VAV system is about 20 tons.

The overall efficiency of VAV systems depends on the diversity of zone heating and cooling loads. If a particular building has very similar zones and constant loads (such as classrooms with identical occupancy schedules in an extremely well-insulated building), the potential for savings from a VAV system are reduced.

Applicable Codes

Title 24 restricts simultaneous heating and cooling (e.g., reheat) unless certain conditions are met. Either the system must be capable of reducing airflow to 30% before reheating, or reducing to 0.4 cfm/ft², or to 300 cfm, whichever is larger.

Supply air temperature reset controls are required.

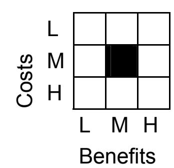
Integrated Design Implications

VAV systems require space for ductwork and should be considered early in the design process.

Requirements for fire separations can affect duct layout and architectural design. Fire separation is less of an issue with single zone systems because all the ductwork is typically within a single fire zone.

Shaft space may be required in multi-story buildings to deliver air to the lower floors.

Cost Effectiveness



A typical VAV reheat system costs $18/ft^2–$22/ft^2 of floor area. This cost is greater than packaged single zone systems and roughly equal to a unit ventilator system, but offers far greater performance and control.

A VAV system is usually cost effective for larger buildings. It is the most common system type for new multi-story commercial facilities.

Benefits

Advantages

- Better comfort control results from steady supply air temperature (vs. single zone systems that are constant volume and variable temperature).
- Moderate initial cost for buildings that require multiple zones.
- Better dehumidification control than packaged single zones.
- Energy efficiency of variable air volume.
- Larger and more efficient fans than single zone systems.
- Centralized maintenance for coil cleaning and filter replacement.
- Relatively simple to add or rearrange zones.

Disadvantages

- Sometimes higher fan pressure occurs than with variable-speed single zone systems, depending on load matching of design. This may lead to higher energy consumption.
- Requires more sophisticated controls than single zone systems.
- VAV box can generate noise that radiates out of the sheet metal walls (radiated noise), and travels down the supply duct (discharge noise).

Design Details

See the *Advanced Variable Air Volume System Design Guide* (reference below) for detailed design recommendations.

A variable-speed fan is the recommended approach to control duct air pressure in a VAV system although several methods are possible. Variable-speed drives are the most efficient and have the added advantage of limiting current inrush for startup of large motors (“soft-start” feature). Other less effective duct pressure control devices are variable inlet vanes, inlet cones, sliding covers, and discharge air dampers.

For direct-expansion VAV systems, multiple-step unloading or variable speed compressors should be specified, which prevents frosting of the evaporator coil at low cooling loads (particularly important for units equipped with economizers). Greater numbers of unloading steps also improves supply air temperature control by allowing a smaller throttling range.

Select VAV boxes for a total (static plus velocity) pressure drop of 0.5 in. H_2O. For most applications, this minimizes lifecycle cost. For a given design airflow rate, more than one box size can meet the load, so the question is which size to use. The larger a VAV box is, the lower its pressure drop, and in turn, the lower the fan energy. However, a larger VAV box will have a higher minimum controllable airflow setpoint, which in turn may increase the amount of reheat and fan energy.

For reheat boxes use a “dual maximum” control logic, which allows for a very low minimum airflow rate during no- and low-load periods. Set the minimum airflow setpoint to the larger of the lowest controllable airflow setpoint allowed by the box controller and the minimum ventilation requirement. VAV box manufacturers typically list a minimum recommended airflow setpoint for each box size and for each standard control options (e.g., pneumatic, analog electronic, and digital). However, the actual controllable minimum setpoint is usually much lower than the box manufacturer’s scheduled minimum when modern digital controls are used.

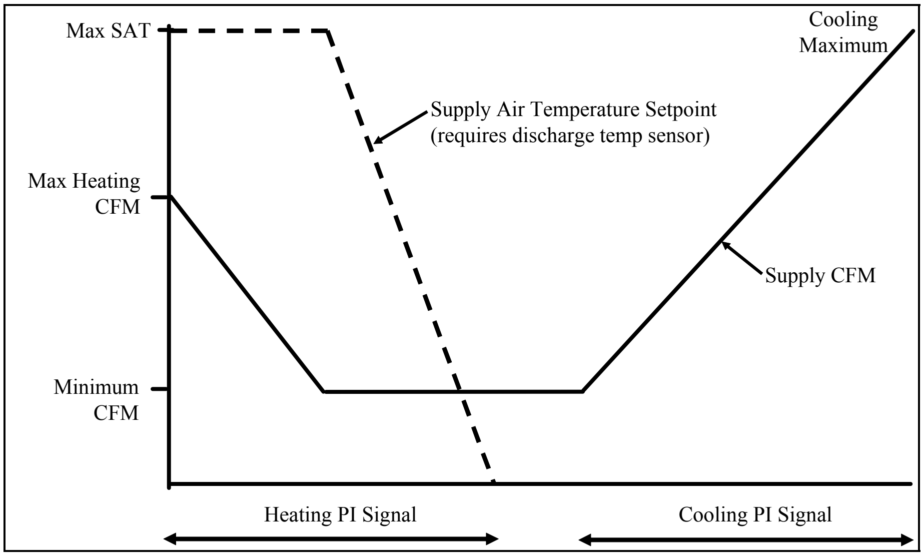


Figure 143—Dual Maximum Control Strategy
(Source: Advanced Variable Air Volume System Design Guide)

Supply air temperature reset. Specify controls that will adjust the supply air temperature according to demand for cooling. As cooling demand drops, supply air temperature may be increased so that compressors operate more efficiently, and outside air can provide a larger fraction of cooling. However, more airflow is required with higher supply air temperature and at some point, the extra fan energy exceeds the cooling energy savings. Generally it is optimal to reset the temperature based on zone loads during periods when outside air temperature is lower than return air temperature. At higher outdoor air temperatures, the supply air temperature should be set to the design value (e.g., 55°F) to minimize fan energy. Otherwise, computer simulations can help to determine optimal settings.

Supply air pressure reset. Significant fan energy savings are possible when controls minimize the supply air pressure to that required to meet all zone loads. Typically the supply fan is controlled to maintain a constant static pressure of around 1.5 in. water column in the duct upstream of the VAV boxes. However, lower pressure may satisfy airflow demands at many times of the year and can save fan energy. Automatic reset controls can monitor damper position in all VAV boxes and lower the supply duct pressure when all dampers are partially closed.

Ventilation air control can be tricky in a VAV system due to varying supply airflow. One option is to modulate the outdoor air damper based on measurement of outdoor airflow. This modulating damper method can also allow demand ventilation control to reduce airflow when spaces have low occupancy (see Guideline TC26: Demand Controlled Ventilation). Another option is a separate outdoor air fan that injects a constant volume of ventilation air into the supply air stream when the system is not in economizer mode. See the Advanced Variable Air Volume System Design Guide for recommendations.

Zone controls should also be tied to a central energy management and control system (EMCS). An EMCS reduces operation and maintenance cost by allowing remote monitoring and control.

To minimize air pressure drop across the cooling coils, limit the face velocity to 300 fpm, which requires a larger coil as well as larger equipment and floorspace. Also consider specifying a bypass damper that opens when the cooling coil is not needed, such as in economizer mode. Both these measures help reduce fan energy consumption.

Maximize air filter face area in order to minimize pressure loss. More filters may be required, but maintenance costs will not necessarily increase because filters replacement intervals can be increased.

Rather than installing a return air fan, consider using a relief fan or barometric relief dampers to minimize fan energy.

Design duct systems to minimize pressure drop and leakage. For recommendations on duct design, see Guideline Guideline TC18: Hydronic Distribution: Air Distribution Design Guidelines.

VAV boxes should not be located over noise sensitive areas (i.e., classrooms) when an acoustical tile ceiling system is being used. A gypsum board ceiling will do a better job of reducing VAV radiated noise than a typical ceiling tile system. For this reason most VAV boxes can be located above noise-sensitive areas where a gypsum board ceiling, which has all penetrations and joints well sealed, is installed.

Size interior zone airflow based on the fully reset supply air temperature (e.g., 60°F) so that interior cooling loads can be satisfied when the supply air temperature is reset upwards during cool outdoor conditions.

Operation and Maintenance Issues

VAV system operation requires a skilled commissioning staff to ensure that controls operate efficiently. However, maintenance is relatively simple once the system is operating. Maintenance is centralized for boilers and chillers rather than being distributed to individual units. Many tasks are centralized and take less time than for a system with single zone units.

VAV boxes typically have DDC interfaces allowing space conditions to be monitored from a central building management system. The information and remote control capability helps reduce maintenance costs.

Commissioning

Calibrate zone airflow sensors, and confirm minimum and maximum flow for each VAV box.

Calibrate all system temperature and pressure sensors. Confirm supply air temperature, reset supply pressure, and reset control operation.

Calibrate outside airflow measurement (if one is installed) and ensure that minimum ventilation airflow is provided under varying conditions.

Confirm proper functioning of all valves and dampers.

Verify that supply air flow stably tracks from the minimum to the maximum in cooling mode.

Confirm that the VAV boxes are stably controlling to the scheduled minimums in the deadband.

References/Additional Information

Hydeman, Mark; Steve Taylor, Jeff Stein, and Erik Kolderup. *Advanced Variable Air Volume System Design Guide*. California Energy Commission publication number P500-03-082-A-11. October 2003. Available at: www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF.

GUIDELINE TC5: FAN-COIL SYSTEM

Recommendation

If choosing a fan coil system, pay attention to the acoustic impact and maintenance issues related to location of fan coil units. Ducted systems are preferred over classroom ventilators for acoustics. For effciency, consider units with multiple-speed fans, two-way control valves and economizer controls. Also specify variable-flow chilled water and hot water distribution systems. Consider choosing a fan coil system for displacement ventilation applications.

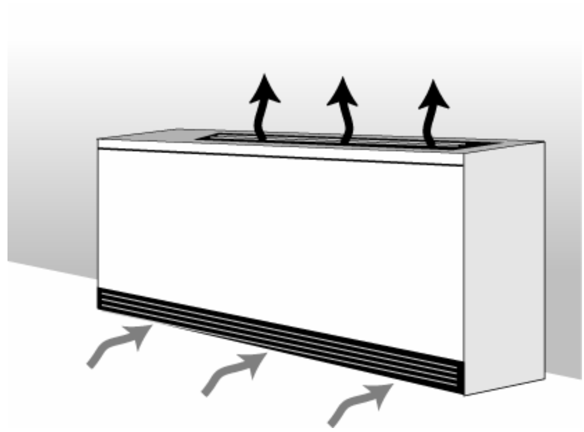


Figure 144—Unit Ventilator, a.k.a. Classroom Ventilator.

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	□	Central Valley	■	Design Dev.	□
Gym	□	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	□
Administration	□			Commissioning	□
Toilets	□			Operation	□
Other	□				

Description

Fan coils provide heating and cooling for each room. A dentral air-cooled or water-cooled chiller provides chilled water to the fan coils. A central boiler provides hot water. Fan coils typically provide constant-volume air supply, and space temperature is controlled by varying the supply air temperature. There are several possible configurations: above the ceiling, on the roof, console style under the window (unducted), or in a separate mechanical closet. Outside air for ventilation may be ducted directly from outdoors to each fan coil, or may be supplied by a central ventilation air handler and ducted to each fan coil.

For acoustic performance, the preferred configuration is to locate the fan coil outside of the space, for example in a mechanical closet or above a corridor ceiling, and duct the supply air to the space. Use of unit ventilators, sometimes called classroom ventilators, that are located within the conditioned space are an option, but are generally not recommended in classrooms due to the difficulty in meeting modern acoustic performance standards. Two-pipe fan coil systems are limited to providing either heating or cooling at one time to all spaces. Four-pipe systems can simultaneously heat some spaces while cooling others, but they have higher initial cost.

A two-pipe system (i.e., one supply pipe and one return pipe) is also known as a changeover system, if it provides both heating and cooling. The same piping is used for both hot water and chilled water, and the central plant produces either one or the other. During mild weather periods, the system may be required to switch from heating to cooling as the day warms up. Therefore, two-pipe systems must be designed to account for the potential thermal shock to the equipment. Two-pipe systems likely need supplemental natural ventilation to accommodate swing seasons.

Four-pipe systems can circulate hot water and chilled water throughout the facility simultaneously. The advantage is better zone control because some zones may be heating while others are cooling. The main disadvantage is higher initial cost.

The control valve within a unit ventilator may be a two-way or three-way valve. In both cases, the valve modulates the flow of water through the coil. The difference is how the valve affects flow in the rest of the distribution system. A three-way valve provides a bypass so total flow through the fan coil unit is constant even though flow through the coil changes. A two-way valve modulates the total flow through the unit. A distribution system with two-way valves will have variable flow and potentially lower pumping energy consumption, especially if pumps are controlled with variable-speed drives.

Economizer controls are an option for some units. An actuator controls outdoor air and return air dampers to take advantage of free cooling when it is available.

Some fan coil units offer a heat recovery option that uses exhaust air to preheat or precool the outdoor ventilation air. Options for this heat recovery function include an air-to-air heat exchanger and a heat pipe.

See also Table 36 for an example system selection evaluation of a fan coil system.

Applicability

Fan coils are an excellent choice for spaces with displacement ventilation because the modulating chilled water and hot water valves can provide stable supply air temperature control.

Fan coils work well in spaces with exterior wall access for ventilation and exhaust air.

Fan coils are a good choice in existing facilities with central chilled water and hot water distribution. These are typically large schools that are fairly centralized (to minimize length of chilled water and hot water distribution piping). However, small chillers are available that can provide chilled water to as few as a handful of fan coils.

In spaces where ceiling height is restricted, unit ventilators are an option because ducts are not necessary. However, measures to mitigate fan noise may be necessary in unducted systems.

Applicable Codes

Energy code requirements include limits on fan energy, chiller efficiency, cooling tower efficiency, and boiler efficiency. Title 24-2005 also addresses pumping system efficiency.

An economizer is not required for unit ventilators smaller than 2,500 cfm, which includes typical classroom units.

Integrated Design Implications

Ducted fan coils require similar coordination as packaged systems or VAV systems. Space for overhead ducts and diffusers or displacement ventilation diffusers is necessary. In addition, an acoustically isolated location for the fan coil unit is necessary, which could be a mechanical closet, a ceiling space above and adjacent corridor, or a framed in portion of the classroom ceiling.

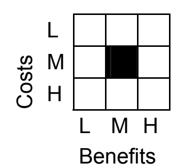
Unit ventilators require more coordination with classroom space planning. They are relatively high maintenance items, and the system layout must be planned for easy access. Casework systems are available to integrate the unit with classroom fixtures. An exterior wall with clean outdoor air must be available for unit ventilator installation.

Hydronic distribution may free up space normally reserved for ducts, permitting lower floor-to-floor heights or enabling higher ceilings and better daylighting performance. Hydronic piping should not be run in floor trenches as they are impossible to clean and often grow mold, which can impact indoor air quality since the unit ventilator always pulls some air from the trench.

With unit ventilators as well as other hydronic system types, pay attention to site planning and building layout to minimize the length and complexity of piping between the central plant (chiller and/or boiler) and the terminal units.

As with other system types, controls should be designed to allow simple manual or automatic interlock with natural ventilation systems. In addition, economizer controls may be unnecessary if the space is designed to encourage occupants to use operable ventilation openings during mild weather.

All fan coil units need easy maintenance access to allow frequent air filter replacement.



Cost Effectiveness

A system consisting of fan coils, a chiller, boiler, and two-pipe distribution costs roughly \$16/ft^2 to \$19/ft^2 of floor area served. Cost for a four-pipe system is \$18/ft^2 to \$22/ft^2.

A fan coil system may be cost effective in specific cases, but in many cases other system types will be either lower cost and/or higher performance.

Benefits

Advantages

- Relatively low duct friction losses due to shorter duct runs.
- Cooling can be very efficient if water-cooled chillers and a well-designed pumping system are installed.
- Constant, or slowly varying, supply air temperature (through modulation of control valves).

- Multiple-speed fans are available in some units.
- Provides flexibility for heating or cooling different parts of the building with four-pipe configuration.

Disadvantages

- Potential for noise, particularly for student sitting adjacent to unit.
- Unit ventilators are vulnerable to student abuse.
- Air intakes can gather pollutants from mowing, rain intrusion, and vehicle exhaust.
- Relatively high first cost.
- Relatively inefficient fans.
- Unit ventilator console units or fan coils in mechanical closets take up floor space within the room.
- Significant maintenance needed in each classroom.
- Typically limited to poor air filtration.
- Energy recovery difficult or expensive.
- Multiple controls and valves located in every classroom.
- Unit ventilators provide poor air distribution, subject to drafts.

Design Details

Ensure that the outdoor air intake area is free from potential pollution sources.

Provide a proper condensate drain path.

If unit ventilators are chosen, make sure to locate the unit to minimize drafts indoors. Air from the units must not be discharged on the occupants, and seating should never be immediately adjacent to the unit. The top of the unit should not be used for storage.

Specify the lowest possible noise levels. If possible, specify a unit with multiple-speed fan control so that normal ventilation occurs at low fan speed. For chiller, boiler, and hydronic distribution system design details, see those individual guidelines. Specify two-way valves in all unit ventilators and variable-flow chilled water and hot water systems.

Load calculations are important, but oversizing of cooling and heating capacity, as long as it is not excessive, is less of a concern with unit ventilators (and with most other hydronic system terminal units) because control valves can modulate output rate. On/off cycling and partial load efficiency degradation is less of a concern, especially with variable-speed fan control. Note, however, that overall facility load calculations are still very important for central plant equipment sizing, where oversizing penalties do occur.

Two-pipe systems should be avoided where heating and cooling may be needed on the same day (or even the same week). The switch from heating to cooling wastes energy and can take a long time. In some cases, the cooling tower and a heat exchanger are used at switchover to cool the loop. The chillers are engaged once the loop has dropped to a tolerable temperature.

Operation and Maintenance Issues

Fan coil ma maintenance can be significant, and requires a high skill level for all the controls that are involved in keeping discharge temperatures correct. They can difficult to access due to location above the ceiling or within the classroom. Chiller and boiler maintenance requires a relatively high skill level, but is a centralized activity.

Maintenance tasks include:

- Cleaning cooling coil condensate pans to prevent mold growth.
- Replacing filters at least three times a year.
- Cleaning coils to prevent mold growth.
- Cleaning outdoor air intake louvers.
- Lubricating fans if required by manufacturers.
- Lubricating and adjusting outdoor air and return air dampers.

Commissioning

Check fan speed setting and airflow. Check stable control valve operation and thermostat operation. Confirm staging of fan speed if applicable. Check coil connections for proper water flow direction. Check outdoor air supply, economizer operation, and economizer airflow. Make sure the outside air duct boot is sealed to the building shell and that water will not enter into it.

References/Additional Information

None.

GUIDELINE TC6: WATER SOURCE HEAT PUMP SYSTEM

Recommendation

Consider water source heat pump systems in facilities with simultaneous heating and cooling loads in different zones.

Consider ground-coupled systems in locations with extreme outdoor temperatures, or when heating fuel is expensive.

Figure 145—Geothermal Heat Pump System

Heat from the water is extracted by the heat pumps to heat the greenhouse air, and the cooled water is discharged into a recharge well at Johnson High School, Mountain City Tennessee. This geothermal heat pump is used primarily as an aquaculture facility, but also heats the greenhouse and the school. Photo courtesy National Renewable Energy Laboratory (PIX # 07191).

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	□	Programming	□
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	□
Gym	■	Mountains	■	Contract Docs.	□
Corridors	■	Desert	□	Construction	□
Administration	■			Commissioning	□
Toilets	■			Operation	□
Other	▒				

Description

In a water-source heat pump system, individual units are typically located either above the ceiling or console style under the window. A two-pipe (i.e., supply and return) tempered water circulating loop provides a heat sink for heat pumps in cooling mode and heat source in heating model. Excess heat is removed from loop by a cooling tower, and heat deficits in the circulating loop are made up by a central boiler.

As an alternative or supplement to the cooling tower and boiler, the tempered water may be directed through a ground heat exchanger that cools the water in summer and warms the water in winter. When a ground heat exchanger is used, then these systems are called various names such as geothermal, earth-coupled, geoexchange, and ground-coupled heat pump systems.

Ventilation air can be delivered to the heat pump units through intakes in the exterior wall ducted to each individual unit. Alternatively, outside air can be delivered by a central air handler and ducted to each heat pump.

Ground-coupled systems can be grouped into two types: closed-loop and open systems. An open-loop system takes water directly from a well, a lake, a stream, or other source; filters it and passes it directly through the condenser loop of the heat pump system. When in a cooling mode the water is warmed, and in a heating mode the water is cooled. The heated or cooled water is then released into another well or stream. Open systems are not permitted in most areas.

The closed-loop systems circulate a fluid (usually an antifreeze solution) through a subsurface loop of pipe to a heat pump. The subsurface loop typically consists of polyethylene pipe, which is placed horizontally in a trench or vertically in a bore hole. This thin-walled pipe is a heat exchanger, transferring heat to and from the earth.

See also Table 39 for an example system selection evaluation of a water-loop heat pump system.

Applicability

These systems are applicable to all interior school spaces, including classrooms and administration facilities. The systems can also be used to heat water for the facility.

Applicable Codes

Title 24 sets fan power limits and also includes minimum efficiency requirements for water source heat pumps.

Economizers are required on units larger than 2,500 cfm air flow and 75,000 Btu/hr cooling capacity.

Integrated Design Implications

If a ground heat exchanger is used, then sufficient exterior space must be provided.

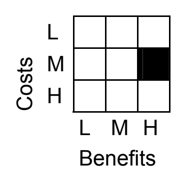
Just as with fan coil systems, an acoustically isolated location is necessary for water source heat pumps serving classroom spaces. However, compressor noise from the heat pump units creates an additional challenge compared to fan coil systems.

Access for ventilation air is required either through the exterior wall or via a central ducted system.

Electrical distribution is required to each of the heat pump units.

Cost Effectiveness

Large systems tend to have first costs that are similar, or slightly higher, to other high quality HVAC systems.



For ground-coupled systems, vertical bore field loop costs depend on the driller experience, capability, site conditions and design. Complete costs typically range from \$1,200–\$2,000 per ton (at \$8+/ ft of bore). Open loop and pond systems are generally less expensive to install than vertical bore fields. Costs range from \$500–\$750 per ton.

Benefits

Peak electric demand is typically lower than air-cooled HVAC systems.

Water consumption is reduced in ground-coupled systems compared to water-cooled HVAC systems.

Waste heat from the system can be used to heat water when the system is cooling the building.

Since piping and pumps are buried or enclosed in the building, damage caused by inclement weather, insects, and vandalism can be greatly reduced.

Systems promote better aesthetics since no equipment needs to be placed on rooftops or outside the building envelope. They can be used with sloped roofs and work well with historic buildings, since the equipment is easily hidden from view.

Design Tools

Design tools available for GSHP systems include:

- HEATMAP© Geo, Washington State University Energy Program.
- GchpCalc Design Software for vertical ground coupled heat pump systems design for commercial and institutional buildings, Version 3.1, Energy Information Services, Tuscaloosa, AL.
- Cycle Analysis Software Tool, National Renewable Energy Laboratory.
- Geocrack2D, Kansas State University.
- GEOCALC, Design Software, Developed by Ferris State University, Released by Thermal Works Software, Grand Rapids, Michigan.
- Wright Soft Geothermal Heat Pump Software, Lexington, MA.
- GL/GW-Source, Design Software, Kansas Electric Utilities Research Program.
- Geothermal Heat Pump Pipe and Fitting Program, Geothermal Heat Pump Consortium.
- Energy-Smart Choice for Schools, HVAC comparison tool, Geothermal Heat Pump Consortium.
- BuilderGuide, National Renewable Energy Laboratory, Golden, CO.

However, none of these tools are approved for use with Title 24.

Design Details

Heat pumps are available in a wide variety of configurations including vertical, horizontal, counter-flow, split, rooftop and console; but the vertical and horizontal designs are most frequently employed.

The tempered water loop should be designed for variable flow, and specify heat pump units with automatic valves that shut off water flow through the unit when the compressor is not running. In addition, use variable speed controls for the tempered water pump.

High efficiency heat pumps should be selected, and consideration should be given to units with non CFC or HCFC refrigerants. Most manufacturers now offer alternative refrigerants. Also consider units with dual speed controls to improve part-load performance.

Heat pumps designed to operate in standard water source heat pump systems, which employ a cooling tower and boiler to control loop temperatures, will not perform adequately in a ground-coupled system because they are designed to operate with water temperatures in the range of 60° to 90°F.

For ground-coupled applications, heat pump units must be of the “extended range” type, designed to operate with entering water temperatures in the 32°F to 100°F range.

For closed-loop ground-coupled systems consider the following:

The heat transfer between the loop and the surrounding soil or rock depends on thermal conductivity, which is an important consideration when designing closed-loop systems. Consult a geological expert to evaluate the soil conditions at the site.

Non-toxic, biodegradable circulating fluids, such as food-grade propylene glycol or potassium acetate, are recommended for use in GSHP systems.

Loops should be at least 25 ft from any septic systems.

Configuration of subsurface loops can be almost any shape, including long trenches, parallel shorter trenches, radiating, coiled, and vertical borings.

Backfilling or grouting must be done at the end of the installation process to help provide good thermal contact and to protect the pipes.

Operation and Maintenance Issues

Individual heat pump units require standard maintenance such as filter replacements, coil cleaning and condensate pan cleaning. Easy access must be provided for these frequent tasks.

A standard water loop system requires periodic cooling tower, boiler and pump maintenance. A ground coupled system can reduce maintenance requirements if a cooling tower and/or boiler are not required.

Commissioning

Closed-loop ground-coupled systems require flushing the loops will help to ensure the system is in good operating order. This process consists of debris flushing, air purging, pressure testing, and final charging of the system with antifreeze.

Also, the system “heat of extraction” and/or “heat of rejection” needs to be calculated, which can be done by non-technical staff using a probe thermometer and a probe pressure gauge. By measuring the temperature and pressure across the source heat exchanger and performing some basic calculations, the operating capacity of the system is determined. This capacity value is then compared with the manufacturer's printed capacity value.

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GUIDELINE TC7: DEDICATED OUTSIDE AIR SYSTEM

Recommendation

Consider introducing outside air through a separately controlled system that responds to occupancy and dehumidification requirements only.

Figure 146—Rooftop Air-to-Air Heat Exchanger

Source: Lennox.

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	□	Design Dev.	□
Gym	■	Mountains	■	Contract Docs.	□
Corridors	□	Desert	□	Construction	□
Administration	□			Commissioning	□
Toilets	□			Operation	□
Other	□				

Description

With a Dedicated Outside Air System (DOAS), the flow of ventilation air is through a separate supply system and is controlled independently in response to both ventilation and dehumidification requirements. Outside air is delivered to each space, either constant volume or a varying amount based demand controlled ventilation using carbon dioxide concentration differential. Sensible heating and cooling is provided by a separate system such as radiant panels, radiant floors, chilled beams, fan coils or other in space device. A central air-cooled or water-cooled chiller provides chilled water, and a central boiler provides hot water.

The rationale for the system is to provide more ideal control of ventilation and dehumidification by making this control independent of sensible temperature control for climates in which conditioning of ventilation air represents a significant energy expenditure. By this separation, improved indoor air quality, comfort and energy efficiency may be achieved. Outside air systems can be designed with ducted return or with relief dampers to outdoors. Systems with ducted return air can recover exhaust heat with an air-to-air heat exchanger. Systems without a heat exchanger usually need some means to temper the outside air, especially during winter.

Small systems are available that can serve individual rooms, while larger systems can serve an entire building. With larger centralized ventilation systems, evaporative cooling or waste heat recovery may be economical for tempering outdoor air.

See Table 40 for an example system selection evaluation of a DOAS combined with radiant cooling panels.

Applicability

Locations with extreme outdoor temperatures or humidity and with relatively few hours when economizer operation would be beneficial.

Appropriate for spaces with hydronic heating systems and natural ventilation. This design strategy is not as applicable for spaces that have conventional air conditioning because outside air ventilation would be provided by the air conditioning system.

Dedicated outside air ventilation is especially appropriate in combination with baseboard or radiant heating systems, where a fan is not required for heating. However, even with forced air heating systems, a separate ventilation system may be appropriate if access to clean outdoor air is difficult from each individual room. In these cases, a central air handler can supply tempered ventilation air to each room, while each space heater recirculates indoor air and runs only when there is a demand for heating.

A dedicated ventilation system may also be appropriate where natural ventilation access is difficult due noise, extreme temperatures, dust, security, or lack of physical access to outdoors.

Applicable Codes

See the Ventilation section of this chapter's Overview for more details.

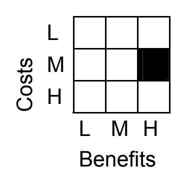
Integrated Design Implications

As with any ducted HVAC system, architectural coordination is important in locating relief dampers and in routing ventilation ducts.

Dedicated Outside Air Systems are typically implemented in concert with some form of sensible heating and cooling system to maintain dry bulb temperature setpoints in the conditioned space. By definition, Dedicated Outside Air Ventilation Systems do not function as primary heating and cooling devices. They are also often utilized with heat recovery equipment to exchange sensible and latent heat between the exhaust stream and the incoming ventilation stream.

Often, the Dedicated Outside Air System is implemented with Demand Controlled Ventilation.

Cost Effectiveness



A dedicated outside air system may add cost to the overall HVAC system, but when combined with, for example, a well-designed displacement system in a coordinated building, it would be expected to be competitive with a well-designed, high-quality conventional HVAC system.

The U.S. Environmental Protection Agency has created the School Advanced Ventilation Equipment Software that uses DOE-2 and code by the Florida Solar Energy Center and others to show that dedicated outdoor air supply systems utilizing energy recovery ventilation components have a payback of under seven years in most parts of the country.

Benefits

These systems may reduce energy costs if demand control ventilation is employed and/or if heat recovery is used.

Humidity control is typically improved, providing potential comfort and air quality benefits.

Design Tools

Most popular energy simulation programs, such as DOE-2, do not have the capability to directly model dedicated outside air distribution systems. However, there are some tricks that can give an approximation of the energy use.

Design Details

In both hot and cold climates, consider using an enthalpy air-to-air heat exchanger to precondition outside air that is brought into the building. This will also reduce winter dryness.

Provide dampers that can automatically minimize and shutoff ventilation air to each classroom if it is not occupied. Consider using a motion sensor already installed for lighting as a control.

Consider variable-speed controls for central ventilation fans, so that airflow can be reduced when some rooms are unoccupied.

Use gravity type or automatic relief dampers in each classroom, unless exhaust air is ducted to a central unit for heat recovery.

Size the system to provide at least 15 cfm per person in classrooms and other spaces. If a classroom is expected to have 30 students, 450 cfm should be delivered. If a classroom is expected to have 24 students, 360 cfm is appropriate.

Use filters to remove dust and other particles from outside air.

Isolate unit from occupied spaces. Provide appropriate intake and discharge noise control consistent with meeting the Noise Criteria.

Locate rooftop units above unoccupied spaces and away from pollution sources on the roof.

Operation and Maintenance Issues

A Dedicated Outside Air System requires similar service to any other air system. Filters must be changed; cooling coils must be cleaned periodically, etc.

Commissioning

Provide documentation regarding the design intent to contractors and building operators to ensure that the system gets implemented properly.

Systems should be balanced and controls commissioned so that adequate air is delivered to each classroom.

For Dedicated Outside Air Systems that utilize Demand Controlled Ventilation, calibration of the carbon dioxide sensors with one another is essential. Because the alteration of delivered air volume to each space is a function of the carbon dioxide concentration differential between the space and the outside air, absolute calibration is not so essential as comparative calibration between all of the sensors in the system. Commissioning efforts should verify that the system is capable of responding appropriately to the CO2 concentrations read in each space.

References/Additional Information

Professor Stan Mumma at Penn State University has been involved with research, monitoring, and documentation of DOAS for a number of years. Pennsylvania State University maintains a Web site concerning this technology: http://doas-radiant.psu.edu/.

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GUIDELINE TC8: ECONOMIZERS

Recommendation

Incorporate economizer dampers and controls on HVAC systems that utilize return air.

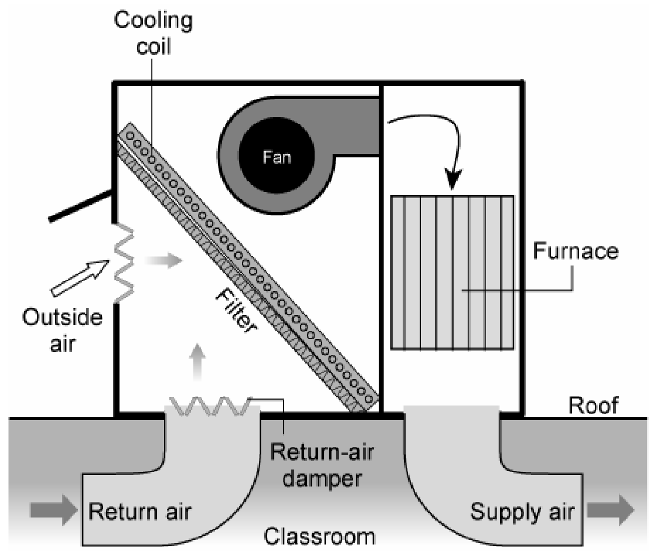


Figure 147—Components of an Economizer in a Packaged Rooftop Unit

Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose / Cafeteria	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

Climates	
South Coast	■
North Coast	■
Central Valley	■
Mountains	■
Desert	■

When to Consider	
Programming	□
Schematic	■
Design Dev.	■
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Description

An outdoor air economizer is a damper arrangement and automatic control system that allows a cooling air handler to supply outdoor air instead of recirculated air to reduce or eliminate the need for mechanical cooling during mild or cold weather.

At low outside air temperature (below 65°F), the economizer dampers modulate to minimum ventilation position unless more outside air is needed for cooling. This minimizes the heating load and protects the cooling coils from frosting at low loads. At high outside air temperature (above about 75°F), the economizer dampers also return to this low ventilation position. At these temperatures, the recirculated space air takes less energy to cool. Between these points, the economizer dampers modulate from minimum ventilation to 100% outside air, acting as a first stage of cooling in attempt to maintain the desired supply air temperature.

Integrated economizers allow simultaneous economizer and mechanical cooling. Non-integrated economizers first attempt to cool with outside air; if that does not satisfy the load, the economizer dampers return to minimum position and mechanical cooling is initiated.

There are three common control methods:

- *Fixed temperature setpoint* economizers close to minimum position when outdoor air exceeds a fixed temperature setpoint, typically 72° to 74°F.

- *Differential temperature* economizers will operate whenever the temperature of the outside air is below the temperature of the return air.
- *Differential enthalpy* economizers compare the enthalpy of the outside air and return air streams and operate whenever the outside air has less heat content. Enthalpy economizers are most important in humid climates.

For moderate climates like much of California, economizers can be a significant means of minimizing space-conditioning costs, because outside air will be within the comfort range for much of the school day throughout the year.

Applicability

Economizers make the most difference for systems serving spaces with low occupant density, such as libraries, administration, and other areas. In those spaces, the normal ventilation rate is fairly low and little free cooling occurs without an economizer. In classrooms and assembly areas, where high occupant density will dictate a large minimum position on the outside air damper (30% or above), economizers controls will have less impact. However, they will still be cost effective due to higher cooling loads in these spaces.

On many existing systems, economizers can be added as a retrofit.

Economizers will not be as useful for spaces designed to use natural ventilation for cooling. In those cases, the cooling system may run only during hot periods when an economizer would be at minimum position anyway.

Economizers should not be installed in facilities do not receive maintenance because a failure can increase energy consumption.

Applicable Codes

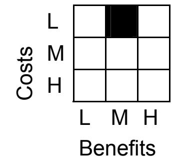
Title 24 requires integrated economizers on all systems providing more than 2,500 cfm of supply air and 75,000 Btu/hour of cooling capacity. No economizer is required for smaller units.

Integrated Design Implications

Economizers are especially valuable with displacement ventilation systems because the higher supply air temperature may allow an economizer to provide 100% of the cooling demand for a greater number of hours each year.

It is important to determine early in the process if the ceiling plenum can be used for return air or if the return air must be ducted. For example, if there is a choice between wood structure (combustible) or steel construction (non-combustible) then the mechanical engineer may be able to sway the decision to steel by explaining the HVAC first cost and energy savings of a steel structure.

An economizer may be unnecessary in spaces with good natural ventilation design.



Cost Effectiveness

The cost premium is $200 to $500 to add an economizer to a small packaged rooftop system.

Economizers are very cost effective for spaces without natural ventilation.

Design Tools

Energy simulation software such as DOE-2.1E can give predictions of energy savings for economizer controls.

Design Details

For economizers on packaged equipment:

Specify factory-installed and run-tested economizers. Although most manufacturers offer a factory-installed economizer, the majority of economizers are installed by the distributor or in the field. Specifying a factory-installed and fully run-tested economizer can improve reliability.

Specify direct drive actuators. Economizers with direct drive actuators and gear driven dampers can reduce problems with damper linkages that can loosen or fail over time.

Specify differential (dual) changeover logic Differential temperature or enthalpy changeover logic instead of single point changeover systems eliminates problems with improper setpoint and maximizes economizer operation.

Specify low leakage dampers. Low leakage dampers with blade and jamb seals will improve economizer effectiveness by limiting return air leakage during economizer operation and outdoor air infiltration when the unit is switched off. Specify low leakage dampers for outside air and (if available) return air dampers.

For small packaged units, the barometric relief dampers that come with the economizer are typically too small to adequately exhaust 100% of the supply air. In order to achieve proper economizer operation, power exhaust or a secondary barometric damper is often required. Based on our experience, power exhaust is less expensive.

For economizers on larger air handlers and VAV systems, the ASHRAE Guideline 16-2003 “Selecting Outdoor, Return, and Relief Dampers for Airside Economizer Systems,” available at www.ashrae.org, contains practical and detailed information on damper selection and guidance on control of economizer dampers.

Common to all airside economizer systems is the need to relieve up to 100% design airflow minus anticipated exfiltration and building exhaust, due to the fact that the economizer could be providing up to

100% outdoor air. Exfiltration to maintain a mild pressurization (between 0.03 in. and 0.08 in. above ambient) in a typical commercial building can be assumed to be approximately 0.05 to 0.15 cfm/ft².

Economizers can be designed with barometric relief, relief fan(s), or return fan(s). The choice of system return/relief path configuration is usually driven by a number of design issues including physical space constraints, the pressure drop in the return path, the need for interspatial pressurization control, acoustics and others. From an energy standpoint, the choices in order of preference (from best to worst) are as follows: barometric relief, relief fans and return fans. Each of these options are described below.

Adequately sized barometric relief dampers should be the system of choice for small HVAC systems and for single-story buildings. Relief fans are better than return fans where relief dampers cannot be used and where return air pressure drop is relatively low, typical of systems with return air ceiling plenums. Return fans are the system of choice for applications with high return air pressure drops, such as ducted return systems.

In VAV systems, modulate the outdoor and return air dampers in series, rather than in parallel. As more cooling is needed, first open the outside air damper fully before closing the return air damper.

Of all of the options, dry bulb temperature controls prove the most robust as dry-bulb temperature sensors are easy to calibrate and do not drift excessively over time. Differential control is recommended throughout California and the sensors should be selected for a through system resolution of 0.5°F. Dry-bulb sensors work well in all but humid climates, where they can bring in cool humid air that actually increases the cooling load. Differential enthalpy controls are theoretically the most energy efficient. The problem with them is that the sensors are very hard to keep calibrated and should be recalibrated on an annual or semi-annual basis.

For retrofit applications, care must be taken to protect the cooling coil and compressor from damage during low loads. With existing direct expansion systems, either non-integrated economizers should be installed or controls should be added to prevent compressor cycling and cutout on low evaporator temperatures. Economizer retrofits are likely to be cost effective only for larger systems (above 7.5 tons).

Operation and Maintenance Issues

Clean and lubricate dampers and control linkages. Maintenance is critical to ensure that economizers work properly for the lifetime of the system.

Include monitoring of air temperatures in order to track economizer performance. A check of outside air temperature, return air temperature and mixed air temperature can determine whether the economizer dampers are opening and closing properly.

A maintenance program should include an annual check of economizer function. See Volume IV of the Best Practices Manual for details.

Commissioning

A functional test is critical to ensure that economizer controls are operating properly. With the system running during mild weather (outdoor cooler than indoor air), set the space thermostat to a low value to call for cooling and check that the outside air dampers are completely open. Then use a heat source, such as a hot-air gun, to warm the outside air temperature sensor and check that the outside air damper closes to its minimum position. Remove the heat source and check that the damper reopens (after the sensor has cooled).

For integrated economizers, also check that the outside air dampers remain completely open when the compressor is running and outdoor air is cool.

References/Additional Information

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *ASHRAE Guideline 16-2003. Selecting Outdoor, Return, and Relief Dampers for Airside Economizer Systems*. www.ashrae.org

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *ASHRAE Research Project 1045-RP. Verifying Mixed Air Damper Temperature and Air Mixing Characteristics*. Configuration of dampers for adequate mixing of outside and return air streams is the subject of the ASHRAE Research Project 1045-RP, Verifying Mixed Air Damper Temperature and Air Mixing Characteristics. This study found somewhat improved mixing when the return air was provided on the roof of the mixing plenum over the outdoor air rather than side-by-side or opposite wall configurations. There were no strong trends or generalizations observed among design options such as damper blade length, blade orientation, and face velocity.

Energy Design Resources Design Brief, *Economizers*, www.energydesignresources.com

Energy Design Resources Design Brief, *Integrated Design for Small Commercial HVAC*, www.energydesignresources.com.

Hydeman, Mark; Steve Taylor, Jeff Stein, and Erik Kolderup. *Advanced Variable Air Volume System Design Guide*. California Energy Commission publication number P500-03-082-A-11. October 2003. Available at: www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF.

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GUIDELINE TC9: EMS/DDC

Recommendation

Use a direct digital control (DDC) system with a graphical user interface to integrate multiple components of HVAC and other building systems and manage them from a single (local and/or remote) location.

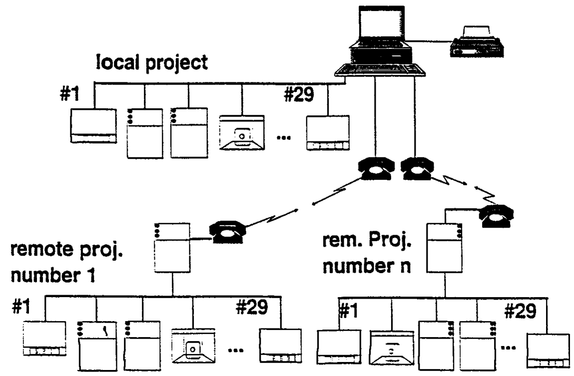
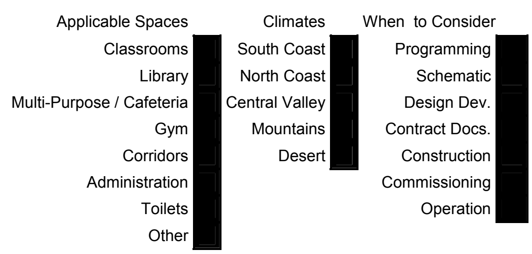


Figure 148—EMS Structure



Description

Automatic control of multiple pieces of HVAC equipment and other systems may be integrated using computerized systems known variously as DDC, energy management systems (EMS), energy management and control systems (EMCS), building management systems (BMS), building automation systems (BAS), etc. The added expense and complexity may be justified by the equipment optimization and increased convenience of maintenance possible with such a system.

DDC systems generally perform three functions: equipment on/off control, space temperature control, and equipment status monitoring. A single system can control lighting, security, central plant equipment, and space conditioning equipment. Systems may be specified to allow local override and temperature adjustment at selected space temperature sensors. Graphical user interfaces may be custom configured with different levels of access to allow limited adjustment of schedules and other system parameters by various personnel. While a DDC system will permit the implementation of energy and cost saving measures not otherwise possible, the advantages will only be realized if the system is initially programmed correctly and checked periodically by adequately trained personnel.

DDC systems can also be used to record valuable information about system performance. That information can be used to identify system failures and can allow evaluations of a system's performance in terms of comfort, air quality and energy efficiency.

DDC systems consist of individual controllers that communicate with one another over a network linked by two-conductor cable or other means. Each controller is wired directly to relays, valve and damper motors, temperature sensors, etc., in order to control and monitor specific equipment. Controllers generally require line voltage power to control panels containing one or more controllers. All other wiring is generally low voltage. The systems may connect directly, via a local-area network (LAN) or modem to a desktop or laptop computer for monitoring and adjustment. A “user-friendly” graphical interface is desired. Systems may be programmed to retain and plot temperature and other status data for performance analysis over limited periods.

Applicability

DDC systems may not be appropriate for small schools with very simple HVAC systems. Their applicability increases with the size of the facility, the complexity of the HVAC system, and the size of the district.

Applicable Codes

Title 24 requires a seven-day time clock with a manual override as a minimum level of automatic control over HVAC systems.

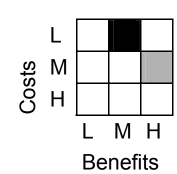
Integrated Design Implications

Coordination between mechanical and electrical consultants is necessary for supplying power to a DDC system. If the system is to integrate control of lighting and other building systems, significantly greater coordination will be required. It may also be desirable to have the DDC system use the building (or district-wide, if available) LAN for communications between controllers and with users. These decisions must be made early in the design phase to allow for coordination throughout the design.

When laying out the HVAC system, it is important to consider the location of sensors because in many cases the effectiveness of the sensor depends on placement. For example, many flow sensors must be located in a straight length of duct or pipe to make an accurate reading. After the ducts or pipes is installed is too late to learn that there is no adequate location for an important sensor.

An EMCS can also be an integral part of a maintenance system. Some equipment is now able to provide automatic fault detection and diagnostics functions, and these capabilities are likely to improve in the future.

The DDC system can serve as an extremely valuable tool during the commissioning process. Therefore, it is important to consider at the design phase whether additional points such as system electric demand should be added even though they are not absolutely required for control. Such points can be used to determine whether the system is operating at intended efficiency and are often worth the extra cost.



Cost Effectiveness

System costs range from \$1.00//ft^2 to \$4.00/ft^2. Much of the variation depends on the number of input or output “points,” which cost from \$300 to \$1,000 each. When considering cost effectiveness it is also important to note that special operation and maintenance training is required to operate, maintain, and troubleshoot DDC systems. In addition, there are periodic expenses such as recalibration of sensors and software upgrades. The life expectancy of major system components may be as low as eight to 10 years due to the rapid pace of development of computer technologies.

Cost effectiveness can be very good, with simple paybacks commonly estimated at four to 15 years. However, benefits will only be realized when certain conditions are met: the system must be programmed carefully, checked out thoroughly, and maintained actively. If operation and maintenance personnel are not comfortable with the system, it is likely to be bypassed, so good training is critical. Many school districts find that the greatest benefit of a DDC system is as a maintenance tool, allowing remote adjustment and troubleshooting of equipment.

Benefits

Energy savings may be realized from a DDC system that is correctly installed and actively maintained. Additionally, comfort conditions may be more easily and consistently attainable, and improvements can be made in operation and maintenance resource utilization, through the use of the DDC system for fine tuning, analysis, and trouble shooting.

Peak electric demand savings are possible through load management controls. A DDC system can be programmed to shutoff or reduce power to specific loads during times of high peak demand charges. The savings can be significant, especially if implemented throughout a district.

Comfort improvements and energy savings may be achieved through such features as adaptive optimum start programs that learn when to start morning warm-up to achieve comfort at occupancy time for different operating conditions such as Monday mornings (when the building may have cooled off more than on other mornings).

DDC systems can also offer remote monitoring of system status from a central office and help reduce time spent on maintenance and trouble calls.

DDC systems have the added benefit of eliminating the air compressors required for pneumatic control systems, together with associated maintenance costs, failures, etc.

Design Tools

Control system manufacturers and their representatives are usually eager to assist with the design process (or take it over, if possible). This resource should be used with care, so as to not overlook the design engineer's responsibility to specify a well-engineered system. Close attention to the development of operation sequence is always worthwhile. Software is available, both commercially and from control manufacturers, to chart sequences of operation in block diagrams or flow charts.

Design Details

Selection of a DDC system is complicated by the fact that several control and communication protocols are available. Some protocols are proprietary to a specific control manufacturer and others are "open" to varying degrees, allowing components from one manufacturer to communicate with components from another. Pay attention to communication protocols to ensure that different parts of the system can talk to each other. In many cases, the decision will be based on compatibility with existing controls.

- Keep controls as simple as possible for a particular function. They will generally be operated (or bypassed) to the lowest level of understanding of any of the operation and maintenance personnel responsible for the HVAC system.
- Rooftop units are often available with optional factory-installed control modules that will interface with the DDC system as an independent "node," allowing a high level of monitoring and control.
- Discharge air temperature sensors are necessary for troubleshooting, even if not required for control.
- Specify temperature sensors with adjustable set point to give teachers some level of control.
- Specify training. Since operation and maintenance personnel will "inherit" the system, and its performance will ultimately depend on them, involve them as much as possible in design decisions.
- Specify at least a one-year warranty, including all programming changes.
- By specifying the configuration of specific data trend logs (not just the capability to collect them) and their submittal for review and approval at system completion, some system commissioning may be accomplished by the design engineer and/or other owner's representatives.
- Specify all software necessary for efficient system operation by operation and maintenance personnel to be provided as part of the system installation.
- Local DDC contractors will usually be willing to provide design assistance or even a "complete" design package. Great care should be taken in such collaboration, for it is unlikely that thorough engineering will be applied to the design. The control system should be carefully specified by the design engineer, and details left up to the installing contractor only after careful consideration.
- Control algorithms that may be specified to increase energy efficiency include: optimal start time calculation based on learned building behavior; operation of central equipment based on zone demand, including supply temperature or pressure reset; night purge ventilation to cool building interiors with cool nighttime air in hot climates; heating and cooling system lockouts based on current or predicted outside air temperature; or heating and cooling lockout when windows or doors are opened for natural ventilation (using security system sensor switches).
- Automatic alternation of redundant and lead/lag equipment based on runtime should be accomplished by the DDC system, with provision for operator override.

- See the HVAC section of Volume IV, Maintenance & Operations, for recommendations regarding DDC points that are useful for monitoring system performance in terms of thermal comfort, indoor air quality, and energy efficiency.

Operation and Maintenance Issues

Calibration of critical points is required annually or semi-annually. Alternation of redundant or lead/lag equipment for even wear may be triggered automatically or manually. Operation and maintenance requires special training, particularly in the case of software, and therefore consistency with existing systems may be desirable. Permanent software changes should be carefully limited. Periodic checkout is necessary. Some controls manufacturers now offer systems with automated fault detection and diagnostics capabilities, which can help identify problems before major failures occur.

Commissioning

Careful commissioning is critical for success of DDC system installations, and proper control operation is necessary for proper equipment operation. Since DDC software may be somewhat esoteric, lack of commissioning may mean that this important aspect of the contractor's work may never be inspected and may never be finished to the desired level. Therefore, it is a very good idea to provide for some commissioning of the control system by an independent party or organization representing the owner's interests. Submittal and review of contractor's input and output point verification test documentation should be required. Field calibration of any temperature sensors that must be accurate for proper control is necessary. (Factory calibration is adequate only for non-critical sensors, such as room temperatures with adjustable set points.) One minimal but effective commissioning method is to specify submittal of trend data logs showing system operation in specified modes, for review by the design engineer. User interfaces including graphics (when specified) should also be reviewed.

References/Additional Information

California Energy Commission's PIER program. Reference Specifications for Energy and Resource Efficiency. This document includes sample EMCS specifications (Division 17) and was developed with funding from the California Energy Commission. www.archenergy.com.

DDC-Online. Unbiased information on Direct Digital Controls (DDC) and an easy searchable guide to DDC manufacturers. www.ddc-online.org.

Energy Design Resources. Design Brief: Energy Management Systems. www.energydesignresources.com.

Lawrence Berkeley National Laboratory. The Control System Design Guide and Functional Testing Guide for Air Handling Systems. Available for no-cost download at http://buildings.lbl.gov/hpcbs/FTG The control design guide portion is targeted at designers but will also be a useful support tool for commissioning providers. It includes information on the control design process, standard point list templates for various air handling system configurations, valve sizing and scheduling tools, damper sizing and scheduling tools, information on sensing technologies and application recommendations, and sample standard details that can be opened in AutoCAD® and used as starting points by designers.

PECI. Energy Management Systems: A Practical Guide. A guidebook covering the following topics: evaluating an existing EMS; specifying and selecting a new EMS; commissioning new EMS; service contracts for EMS; strategies for optimizations; using EMS for operational diagnostics; non-energy control applications; sample control specification language; and using spreadsheets for graphing and analyzing trend data. 80 pages plus appendices. www.peci.org/om/index.html.

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GUIDELINE TC10: DEMAND CONTROLLED VENTILATION

Recommendation

Specify controls to adjust ventilation rate for spaces with varying occupancy to prevent unnecessary cooling or heating of large quantities of outside air, and insure that adequate ventilation is provided when needed.

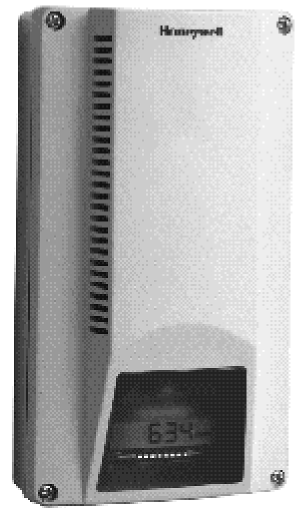
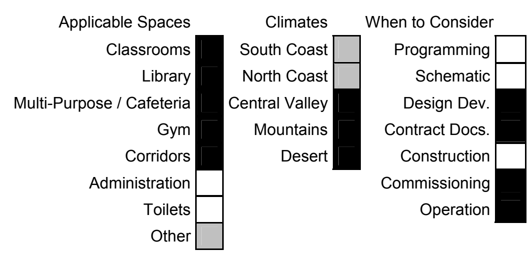


Figure 149—CO_2 Sensor

Source: Honeywell



Description

High density spaces can have very high ventilation requirements (e.g., 60% of design flow), which results in wasted heating or cooling energy when the space is not fully occupied. Demand control ventilation (DCV) can be used to estimate the number of occupants in a space and reset the ventilation rate from the design occupancy down to the actual occupancy. Carbon dioxide (CO_2) sensors are the only currently accepted method of DCV. For example, a CO_2 concentration of 1,100 ppm or 700 ppm above ambient outdoor concentration indicates an outside air flow rate of 15 cfm/person.

Applicability

DCV is most applicable for spaces in schools that have "dense" occupancy but experience this occupancy level sporadically or occasionally. Examples include gymnasiums, cafeterias, and auditoriums. DCV is easiest to implement when these spaces are served by single-zone HVAC systems, but it is also possible to implement DCV controls for multiple-zone VAV systems.

Classrooms are also good candidates, but DCV is typically less cost effective in classrooms because they have more constant occupancy rates than spaces such as auditoriums and each controller serves a smaller area.

DCV will be most cost effective in climates with extreme hot and/or cold temperatures such as deserts and mountains.

Applicable Codes

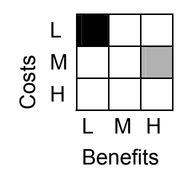
Title 24-2005 requires that demand control ventilation be used for all single-zone systems that have an economizer where the design occupant density is higher than 40 ft^2/person. This requirement typically applies to auditoriums, gymnasiums, and cafeterias. Classrooms often fall within this density limit as well, but the standard provides a specific exemption for classrooms because their occupancy is typically fairly constant during occupied hours.

To meet the standard, the system must either be controlled to maintain CO2 concentration at 1000 ppm or less, or if the system also measures outdoor CO2 concentration, then the indoor levels must not exceed 600 ppm higher than outdoor concentration. However, in neither case does the ventilation rate have to exceed the standard rate that would be required based on design occupancy.

Where DCV is required, the sensors must be mounted between one and six ft above finished floor, which is the occupant breathing zone. (Locating sensors in return air ducts or plenums is not allowed since the sensor reading will be skewed by outdoor air leakage into the duct, mixing with return air from other zones, and possible short-cycling of supply air from diffusers into return air inlets. CO2 sensors must have an accuracy of no less than 75 ppm and be certified from the manufacturer to require calibration no more frequently than every 5 years.

Title 24 also establishes a “floor” for ventilation rates of 0.15 cfm/ft^2 that must be provided during occupied hours regardless of CO2 concentration.

See the Overview section of this chapter for more discussion of ventilation requirements.



Cost Effectiveness

Each CO_2 sensor costs approximately $400. Installation, testing, and adjustment ranges from $500 to $1,500 per system. A hand-held CO_2 sensor that can be used for calibration costs $500.

For CO_2 sensor-based control, cost effectiveness depends on the climate being “severe” enough, and the required ventilation rate being large enough, so that the heating and cooling load reduction saves enough energy costs to offset the first cost of the CO_2 sensing equipment.

Benefits

- Reduced energy consumption.
- Reduced wear on equipment.
- Confirmed/documented interior air quality.

Design Tools

Energy simulation programs such as DOE-2 can be used to estimate the energy impact of demand control ventilation.

Design Details

Demand controlled ventilation responds to human occupancy only. Other sources of internal pollutants must be addressed with per-area baseline ventilation, targeted ventilation, etc. This should be considered very carefully before applying this type of control, especially to classrooms, where various odor sources may be used.

Sensors should be located within the occupied space rather than in the return air duct.

DCV controls are often offered as an option for packaged HVAC equipment, easing the specification and implementation of DCV systems.

DCV control in VAV systems is more complex than in single zone systems. In a VAV system a CO_2 sensor is required in each zone, because a single sensor located in the return air path will not ensure that each zone is receiving adequate ventilation. See the *Advanced VAV System Design Guide* for recommendations.

Operation and Maintenance Issues

Periodic sensor calibration is required. If possible, the CO_2 concentrations should be recorded as a trend log in the DDC system, and a periodic review should be made to determine if the system is maintaining appropriate CO_2 levels.

Commissioning

Review system operation under varying occupancy. Correlate with balance report data for minimum and maximum outdoor air damper positions. Verify acceptable levels of CO_2 concentration in space when occupied using hand-held sensor. Perform all testing in non-economizer mode.

References/Additional Information

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Standard 62.1-2004*.

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Standard 62.1-2004 User's Manual.*

Hydeman, Mark; Steve Taylor, Jeff Stein, and Erik Kolderup. *Advanced Variable Air Volume System Design Guide*. California Energy Commission publication number P500-03-082-A-11. October 2003. Available at: www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF.

GUIDELINE TC11: ADJUSTABLE THERMOSTATS

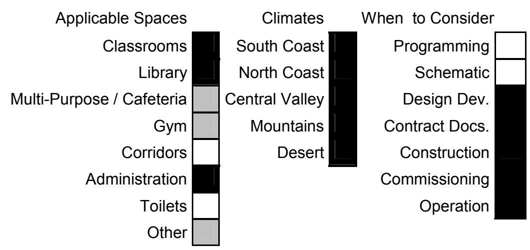
Recommendation

Specify thermostats or temperature sensors that will allow classroom teachers control over temperature in their classroom (within limits).

In spaces with operable windows designed for natural ventilation, provide a clear way for teachers to shut off the fan manually when desired (or use an automatic interlock switch on the windows). Otherwise, ensure that the fan is set to run continuously for ventilation during occupied hours.

Figure 150—Adjustable Thermostat

Source: NREL/PIX04899



Description

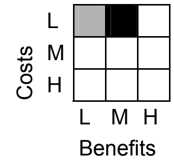
Teachers find it helpful to have control over conditions in their classrooms because different conditions may be appropriate at different times. For example, cooler temperatures may be appropriate after recess or for a more active group. It may be appropriate to turn off mechanical ventilation when windows are open. Where an energy management system is not used for temperature control, programmable thermostats can allow implementation of energy-saving and comfort-enhancing measures, but only if programmed and maintained properly. Care should be taken to select a model that is very easy to program. Otherwise, it is likely to be overridden or set for continuous operation.

For schools without DDC systems, thermostats with network connection capabilities can provide a modest level of central control and monitoring. Thermostats with wireless communication are also available.

Applicable Codes

Title 24 requires set-back thermostat, time of day control, a 5°F deadband between heating and cooling setpoints, and override. A programmable thermostat is a cost effective way to satisfy these requirements when a DDC system is not installed.

Cost Effectiveness



For a premium programmable thermostat, expect to pay $50–$200.

Programmable thermostats are highly cost effective. For a relatively small incremental increase over conventional thermostats, a carefully selected and programmed model will provide teachers with control over their classroom environment while combining time of day and override functions. Direct digital control (DDC) system sensors with adjustable set point have a greater incremental cost impact over plain sensors, but the benefits of giving teachers control should not be underestimated.

Benefits

Improved comfort and sense of control may foster a better attitude and teaching environment. Some energy savings may be realized due to stopping mechanical ventilation when windows are open. Service requests may be reduced compared to situations where teachers must request a set point change from operations and maintenance personnel. Programmable thermostats replace time clocks, eliminating associated first and maintenance costs.

Design Tools

None.

Design Details

- Specify programmable thermostats for control, adjustment, time clock, and override functions when no DDC system will be used for temperature control.
- With DDC systems, sensors should allow occupants to adjust temperature setpoint. Specify limits within which the set point may be varied and the time period after which an overridden value or state will revert to the standard “automatic” (default) value or state.
- If it is necessary to have thermostat covers that lock, provide a means for faculty access.
- Place the thermostat on an interior wall in a location out of direct sun and away from heat sources such as copiers or computers. A point close to the return air or exhaust air inlet is often a good choice.
- Programmable thermostats selected for schools should not allow the fan to be set for intermittent operation. Continuous fan operation is required for ventilation during occupied periods.
- Ensure that the selected thermostat has the capability for separate heating and cooling setpoints, with a 5°F deadband between them. For example, the heating should be set to maintain 70°F and

the cooling set at 75°F. The deadband helps ensure that the system will not cycle back and forth between heating and cooling modes, wasting significant amounts of energy.

Operation and Maintenance Issues

Faculty may require repeated training on programmable thermostat operation. Unlike DDC system temperature sensors with adjustable set point, which can be programmed to revert to standard operation after a specified period, programmable thermostats may allow the HVAC system to be switched off, rather than overridden. This can defeat morning warm-up, resulting in comfort problems and complaints. Specify that simplified one-page instructions be provided by the installing contractor and kept on file at school office with copies distributed to teachers for adjustable sensors or programmable thermostats. Programmable thermostats may require periodic replacement of back-up battery.

Commissioning

Proper functioning of any thermostat or temperature sensor must be verified prior to acceptance of the installation. Programmable thermostats and temperature sensors with adjustable set point necessitate a slightly more involved verification procedure.

References/Additional Information

None.

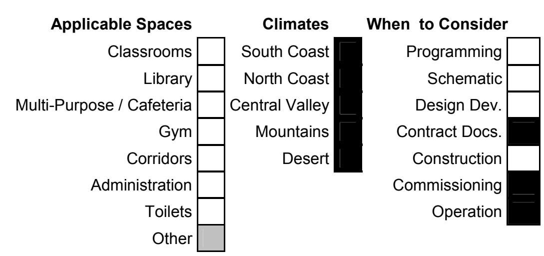
GUIDELINE TC12: CO SENSORS FOR GARAGE EXHAUST FANS

Recommendation

Use carbon monoxide (CO) sensors to prevent parking garage exhaust fans operating when they are not needed.

Figure 151—CO Monitor

Carbon Monoxide monitors, like this PG-2000 series by Arjay Engineering, are used in parking facilities, warehouses, and chiller rooms to reduce energy consumption from heating and cooling loss, fan run time, and fan maintenance. They also provide personal protection from high levels of carbon monoxide. Courtesy Arjay Engineering.



Description

Parking garage ventilation is often provided by an exhaust fan operated during normal occupancy hours. However, the high ventilation rate required when traffic is present need not be maintained most of the time, when no vehicles are operating. Substantial energy savings may be realized by limiting fan operation to only those periods during normal occupancy when carbon monoxide concentration in the garage rises above acceptable levels. Carbon monoxide concentration sensor technology has advanced substantially in recent years, reducing cost and improving reliability.

Applicability

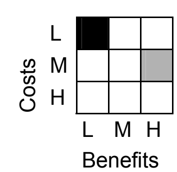
School buildings with enclosed parking garages requiring mechanical ventilation.

Applicable Codes

Uniform Mechanical Code

Cost Effectiveness

Estimated cost of \$0.20/ft^2–\$0.40/ft^2 of garage, or \$1,000–\$2,000 per sensor installation.



Benefits

Benefits include energy savings, wear reduction, and noise reduction.

Design Tools

None.

Design Details

- Diesel exhaust does not contain high levels of CO. Consider nitrogen dioxide (NO_2) sensors if substantial traffic or idling of diesel vehicles is anticipated.
- Include time of day control in addition to CO concentration control.
- Sensor coverage area is limited, so multiple sensors may be required.
- Specify calibration tools provided to operation and maintenance personnel at time of training.

Operation and Maintenance Issues

Annual calibration of sensors is required.

Commissioning

Verify threshold adjustment and function. Also verify training of operation and maintenance personnel, including calibration.

References/Additional Information

None.

GUIDELINE TC13: CROSS VENTILATION

Recommendation

Provide equal area of operable openings on the windward and leeward side. Ensure that the windward side is well shaded to provide cool air intake. Locate the openings on the windward side at the occupied level.

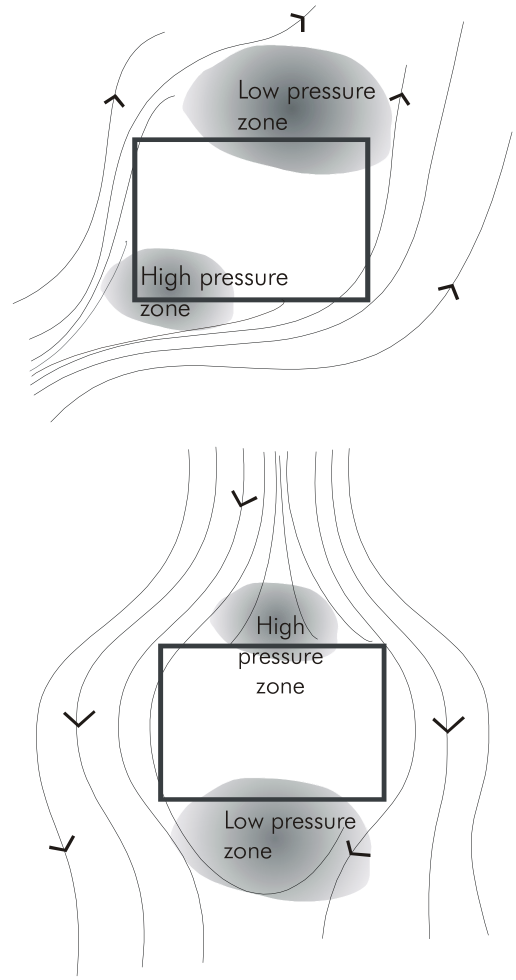
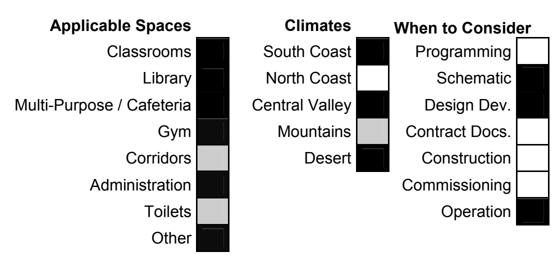


Figure 152—Cross Ventilation Patterns

Description

Wind driven ventilation is one of two methods of providing natural ventilation. All natural ventilation strategies rely on the movement of air through space to equalize pressure. When wind blows against a barrier, it is deflected around and above the barrier (in this case, a building). The air pressure on the windward side rises above atmospheric pressure (called the pressure zone). The pressure on the leeward side drops (suction zone), creating pressure gradient across the building. To equalize pressure, outdoor air will enter through available openings on the windward side and eventually be exhausted through the leeward side.

Pressure is not uniformly distributed over the entire windward face, but diminishes outwards from the pressure zone. The pressure difference between any two points on the building envelope will determine the potential for ventilation if openings were provided at these two points. The airflow is directly proportional to the effective area of inlet openings, wind speed, and wind direction.



Applicability

Cross ventilation is a very effective strategy for heat removal and providing airflow in mild climates. In coastal climates, the need for a cooling system may be eliminated by a carefully designed natural ventilation system. In most other climates, it can alter interior conditions only modestly. Hybrid systems work best in such situations. In humid climates, natural ventilation cannot replace the moisture removing capabilities of air-conditioning (although desiccant systems that remove moisture from the space can be used for more effective natural ventilation). Introducing humid air (even if it is relatively cool) into a space will add a substantial load on the cooling system in hybrid systems. However, even extreme climates experience moderate conditions during spring and fall, and natural ventilation should be designed to take full advantage of these conditions.

This strategy relies heavily on two parameters that may change continuously: wind availability and wind direction. Consequently, it is a somewhat unreliable source for thermal comfort. Spaces, like computer rooms and laboratories, that need strict maintenance of indoor temperature and humidity should definitely use hybrid systems for both cooling and ventilation. Introducing natural ventilation in a building may cause increased levels of dirt, dust, and noise, which could also be a serious limitation for certain types of spaces.

Cross ventilation has to be an integral part of the design schematic and design development phases. An effective natural ventilation design starts with limiting space sizes to facilitate inward flow of air from one face and outward flow from the other—architectural elements can be used to harness prevailing winds. This may alter building aesthetics and needs to be addressed early in the design phase.

Applicable Codes

"Section 121-Requirements for Ventilation" of Title 24 only apply to spaces that are ventilated naturally (i.e., without mechanical means). These requirements include:

- The total area of the openings should be at least 5% of the total floor area (based on classroom dimensions of 30 ft x 32 ft x 9 ft-6 in., a minimum openable area of 48 ft^2 should be provided for each classroom).
- All spaces should be within 20 ft of an operable opening in the wall or roof.
- All openings provided for natural ventilation should be readily accessible to occupants of the space at all times when the space is occupied.
- All naturally ventilated spaces should have direct outdoor air flow from openings in the wall or roof. This airflow should remain unobstructed by walls or doors.

Codes related to fenestration performance and maximum allowable window area are also relevant:

- Maximum-allowable window wall ratio limits the area of openings to 40% of the gross wall area under the prescriptive compliance method. The code also specifies minimum performance levels for fenestration. See Envelope Guidelines for more information on performance levels for glazing.

Fire safety codes might limit the ability to use openings that allow air to travel through the building from one side to the other.

Integrated Design Implications

Design Phase

Cross ventilation can (or should) very strongly influence building aesthetics and site planning. Natural ventilation codes will dictate space widths and minimum opening sizes. To maximize the effectiveness of openings, the long façade of a building should be perpendicular to the prevailing wind direction. Narrow and woven plans with more surfaces exposed to the outside will work better than bulky plans with concentrated volumes. Singly-loaded corridors will provide better airflow than doubly-loaded ones. An open building plan with plenty of surface area exposed to the outside will work well for cross ventilation. Architectural elements like fins, wing walls, parapets, and balconies will enhance wind speeds and should be an integral part of cross ventilation design.

Thermal Mass

Cross ventilation should be combined with thermal mass to take advantage of large diurnal temperature swings. Mass walls can act as heat reservoirs, absorbing heat through the day and dissipating it at night. At night, natural ventilation can be used to increase the rate of heat dissipation. This will reduce the load on the cooling system by pre-cooling the building. A large diurnal temperature swing (as in desert areas) will ensure that the building is more effectively “flushed.”

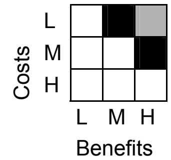
Integration with Daylighting and View Windows

The apertures for cross ventilation will also serve as view windows and luminaires for side lighting. All architectural elements intended to enhance one strategy should also work for the other. Orientation that works for ventilation (openings on the windward side) may not be the ideal direction for bringing in daylight. West orientation for windows will increase heat gain and cause glare, but may be the best orientation for bringing in outside air in the coastal areas. Prioritize the needs of the space based on function and climate. For instance, benefits of daylighting in a cold climate outweigh those of cross ventilation, therefore orient the building based on daylighting considerations.

Integration with HVAC

Natural ventilation may be intended to replace air conditioning entirely or, as is more often the case, to coexist with mechanical systems in a “hybrid mode.” Also, natural ventilation may occur in “change-over” (windows are shut when mechanical system is on) or “concurrent” modes. Fewer systems are compatible with the concurrent mode. These factors need to be carefully considered before selecting a system (for more information on system selection see this chapter’s Overview).

Cost Effectiveness



Low to moderate. Buildings that use natural ventilation may have higher initial costs, due to the higher cost of operable windows. Operable windows typically cost 5% to 10% more than fixed glazing. Based on average installed cost for metal frame, double glazed, fixed windows of $20/ft² to $30/ft², the operable window should cost a few hundred dollars more per classroom.

Benefits

Moderate to high. This varies significantly depending on climatic conditions and natural ventilation design.

- In a moderate climate like that of the north coast, wind-driven ventilation can meet the cooling loads most of the time. In such climates, the simple payback period will vary between eight to 12 years. At times, a good natural ventilation design may completely eliminate the need for a cooling system. This design will result in huge savings that offsets the cost of installing operable windows and lowers the simple payback period to one to four years.
- Buildings located in harsher climates will use "mixed-mode" systems. In such climates, natural ventilation may have limited application resulting in higher payback periods of 12 to 15 years.
- Cross ventilation alleviates odors and quickly exhausts contaminants from a space.
- Increased airflow in a space results in higher thermal comfort levels and increased productivity.
- Operable openings at the occupied level instill the occupants with a sense of individual control over the indoor environment.
- An intangible benefit of natural ventilation is the establishment of a connection with the outdoors (both visual and tactile), weather patterns, and seasonal changes. This results in higher tolerances for variations in temperature and humidity levels.
- Natural ventilation systems are simple to install and require little maintenance.

Design Tools

Opening areas may be derived using spreadsheet-based calculations. These estimates use approximation techniques but are good numbers to start with. The following algorithm shows the rate of wind-induced airflow through inlet openings:

$$Q = C_4 C_v A V$$

where,

Q = airflow rate, cfm
C_v = effectiveness of openings (C_v is assumed to be 0.5-0.6 for perpendicular winds and 0.25 to 0.35 for diagonal winds)
A = free area of inlet openings, ft^2
V = wind speed, mph
C_4 = unit conversion factor= 88.0

The following algorithm calculates the required airflow rate for removal of a given amount of heat from a space (see section on Load Calculations for estimating the amount of heat to be removed):

$$Q = \frac{60q}{c_p \rho (t_i \quad t_o)} \qquad\qquad Q = \frac{Btu/h}{1.08\Delta T}$$

where,

Q = airflow rate required to remove heat, cfm
q = rate of heat removal, Btu/h
C_p = specific heat of air Btu/lb°F (about 0.24)
ρ = air density, lb_m/cf (about 0.075)
t_i-t_o = indoor-outdoor temperature difference, °F

Many computer programs are available for predicting ventilation patterns. Some that use the “zonal” method may be used to predict ventilation rate (mechanical and natural), magnitude and direction of air flow through openings, air infiltration rates as a function of climate and building air leakage, pattern of air flow between zones, internal room pressures, pollutant concentration, and back drafting and cross-contamination risks. These models take the form of a flow network in which zones or rooms of differing pressure are interconnected by a set of flow paths. This network is approximated by a series of equations representing the flow characteristics of each opening and the forces driving the air flow process. Widely available codes include BREEZE and COMIS.

A computational fluid dynamics (CFD) program is a more accurate and complex tool for modeling airflow through a space based on pressure and temperature differentials. These programs can simulate and predict room airflow, airflow in large enclosures (atria, shopping malls, airports, exhibitions centers, etc.), air change efficiency, pollutant removal effectiveness, temperature distribution, air velocity distribution, turbulence distribution, pressure distribution, and airflow around buildings. Some CFD programs provide calculations of comfort indices such as predicted mean vote or percentage of people dissatisfied.

Design Details

- Orient the building to maximize surface exposure to prevailing winds.
- Provide the inlets on the windward side (pressure zone) and the outlets on the leeward side (suction zone). Use architectural features like wing walls and parapets to create positive and negative pressure areas to induce cross ventilation. Air speed inside a space varies significantly depending on the location of openings (see table below). As far as possible, provide openings on opposite walls. Using singly loaded corridors will facilitate provision of openings on opposite walls. Limit room widths to 15 ft to 20 ft if openings cannot be provided on two walls. Windows placed on adjacent walls also perform very well due to the wall-jet phenomenon wherein the inflowing air moves along the nearest wall surfaces. This positioning should be limited to smaller spaces (less than 15 ft x 15 ft).

- Air inlet and outlets should be designed to minimize noise transfer from the exterior to the interior and to adjacent occupied spaces.

Table 43— Average Indoor Air Velocity as a Percentage of the Exterior Wind Velocity for Wind Direction Perpendicular to and 45° to the Opening

Window Height as a Fraction of Wall Height	⅓	⅓	⅓
Window Width as a Fraction of Wall Height	⅓	⅔	1
Single Opening	12%–14%	13%–17%	16%–23%
Two Openings on Same Wall	—	22%	23%
Two Openings in Adjacent Walls	37%–45%	—	—
Two Openings on Opposite Walls	35%–42%	37%–51%	46%–65%

Source: Givoni, Baruch; Man, Climate, and Architecture*, London: Applied Science, 1976.*

- A free ventilation area of 1.5% to 2% (of the floor area), which is the recommended minimum area for operable windows only, will meet the ventilation requirements. Daylighting considerations will require a larger window area. Also, if the space is solely dependent on natural ventilation then code requirements will set the minimum operable window area to 5% of the floor area. Although this area will meet the ventilation requirements of a space during mild climatic conditions, larger window areas should be provided for occupant cooling through increased air movement. For cooling purposes provide 5% to 8% of the floor area as free ventilation area. Equal inlet and outlet areas maximize airflow whereas outlets that are 2% to 5% larger than inlets produce higher air velocities.The inlet location affects airflow patterns far more significantly than outlet location. Inlet location should be a higher priority (if faced with a choice) as a high inlet will direct air towards the ceiling and will almost bypass the occupied level. Locate inlets at a low or medium height.For natural ventilation to function properly, solar gains should be minimized. Direct sunlight penetrating into the space during periods of natural ventilation may make it difficult or impossible to achieve comfortable conditions with natural ventilation alone. Use shading devices to like overhangs, awnings, and fins to control solar gains.

- The incoming air may be cooled through good site planning, landscaping, and planting strategies. If a water body is planned for the site, place it on the windward side to pre-cool the incoming air through evaporative cooling. Planting tall deciduous trees on the windward side will lower the temperature of the inflow and shade the openings. Provide windows with shutters that can be opened or shut in increments. This allows the occupants to vary the inlet and outlet areas according to seasonal variations.

- Use features like overhangs, awning windows, eaves, and porches to protect the openings from rain and to minimize excess heat gain from direct sunlight. Awning windows work very well for cross ventilation because they provide more airflow than double hung windows (for the same glazed area) and also provide protection from rain. Casement windows provide maximum airflow in both perpendicular and oblique wind conditions.

- Ensure that vents and windows are accessible and easy to use. Avoid blocking windows with exterior objects such as shrubs and fences, but do not eliminate shading.

- Provide inlets for cross ventilation openings at the occupied level. Stagger the outlet openings both vertically and horizontally by a few feet to achieve longer air paths. Concentrate ventilation openings in spaces most likely to require cooling.
- Use overhangs, porches, and eaves to protect windows and vents from rain to extend the amount of time that natural ventilation can be used.
- Ensure that openings can be tightly sealed in winter or when using air conditioning.
- Provide secure natural ventilation openings that can be left open for beneficial night cooling.
- HVAC systems should be designed to work in harmony with natural ventilation. The objective of a concurrent natural ventilation system is to meet the outside air requirement using the least possible opening area. The objective of a changeover natural ventilation system is to meet the outside air requirement as well as provide cooling. The HVAC and natural ventilation system are mutually dependent. See the Overview for a detailed discussion.

Operation and Maintenance Issues

This strategy is largely dependent on manual operation for its success. Automated operation may make sense for very large commercial buildings, but typically not for schools.

- Encourage students and teachers to open/close openings regularly.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Periodically clean windowsills, panes, fins, screens, and louvers to ensure healthy air intake for the space.
- Assign responsibility of ensuring that openings are shut during cold weather and the hours of operation of the mechanical system. Also ensure adequate opening area is available for nighttime ventilation in hot dry climates.

Commissioning

None.

References/Additional Information

Passive Cooling by Jeffrey Cook (Ed.), MIT Press, Cambridge, USA, 1989.

Sun, Wind, and Light by G.Z. Brown, John Wiley & Sons, New York, 1986.

GUIDELINE TC14: STACK VENTILATION

Recommendation

Use inlets and outlets of equal area and maximize the vertical distance between these two sets of apertures. Place inlets close to the floor or at the occupied level. Locate the outlets closer to the ceiling on the opposite wall. To facilitate varying summer and winter strategies, provide incrementally operable shutters.

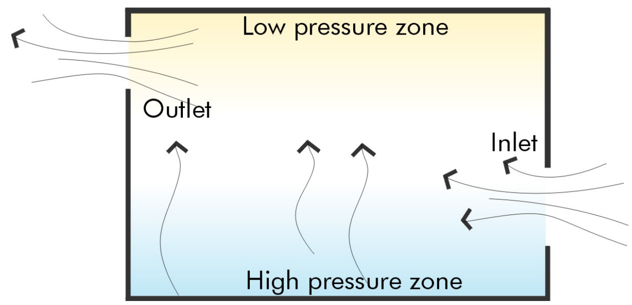
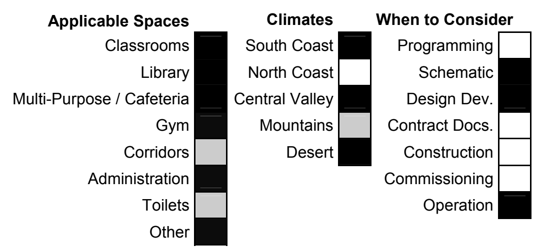


Figure 153—Stack Ventilation Pattern

Description



Stack ventilation utilizes the difference in air densities to provide air movement across a space. At least two ventilation apertures need to be provided; one closer to the floor and the other high in the space. Warmed by internal loads (people, lights, equipment), the indoor air rises. This creates a vertical pressure gradient within the enclosed space. If an aperture is available near the ceiling, the warmer air at the upper levels will escape as the lower aperture draws in the cool outside air. Indoor temperatures must be higher than outdoor temperatures for stack ventilation to occur.

The airflow induced by thermal force is directly proportional to the inlet-outlet height differential, the effective area of the aperture, and the inside-outside temperature differential.

Applicability

Pressure differential driven natural ventilation is an effective strategy for meeting minimum airflow requirements, especially during winter, when the inside-outside temperature differential is at a maximum. It is also appropriate for providing cooling during mild weather conditions.

Applicable Codes

See the section on Cross Ventilation for code requirements related to ventilation openings.

Integrated Design Implications

Design Phase

Using the stack effect for ventilation requires an integrated design approach. Stack ventilation will affect building mass and aesthetics. Vertical airshafts for providing stack ventilation also need to be considered early in the design phase.

Thermal Mass

Nighttime ventilation coupled with thermal mass is a very effective strategy for heat removal from space in hot, dry climates.

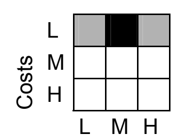
Integration with Daylighting and View Windows

Apertures for stack ventilation need to be located close to the floor and ceiling for best results. The high apertures can couple as clerestories or side lighting luminaries. Benefits of daylighting and natural ventilation need to be considered in conjunction with each other to arrive at the ideal location and size for openings.

Integration with HVAC

Stack ventilation can be useful for providing ventilation when heating-only systems such as a radiant floor or baseboard is used. Stack ventilation can also be used in hot and dry climates for nighttime cooling. In order to avoid cold winter drafts, a heat source may be necessary at the stack ventilation inlet to temper the outdoor air. For details, see the Overview section.

Cost Effectiveness



Low to moderate. Stack ventilation may not add to overall costs significantly if integrated with view windows, high side lighting, and other daylighting strategies. However, an additional cost of $2/ft^2 may be associated with ensuring that all openings are operable. Adjustable frame intake louvers may cost up to $25/ft^2 (this includes installation costs). Additional cost of installing windows high in the space will range from $15/ft^2 to $30/ft^2.

Benefits

Low to moderate. The benefits depend largely on weather conditions (indoor-outdoor temperature differential), and the design of openings.

- In a moderate climate like that of the north coast, a combination of wind-driven and stack ventilation strategies can meet the cooling loads most of the time. In more extreme climates (with a large diurnal range of temperature), stack ventilation can operate in “mixed-mode” systems and reduce the peak demand through nighttime flushing, resulting in lower utility bills and first costs. In such climates, the simple payback period will be eight to 12 years. For most other climates, the simple payback period will be 10 to14 years.

- Stack ventilation apertures can also double as side and high side lighting strategies.
- Stack ventilation effectively removes contaminants and pollutants from space.

Design Tools

The airflow (cfm) required can be reasonably estimated using spreadsheet-based calculations. The following algorithm defines the airflow as it varies with the area of openings, indoor temperature, outdoor temperature, and location of the inlet and outlet:

$$Q = 60 C_D A \sqrt{2g \Delta H_{NPL} (T_i - T_o) / T_i}$$

Q = airflow rate, cfm
C_D = discharge coefficient for opening
A = inlet free area for ventilation (ft^2)
g = gravitational constant (32.2 ft/s^2)
ΔH_{NPL} = height from mid-point of lower opening to Neutral Pressure Level (NPL), ft
T_i = indoor temperature, °F
T_o = outdoor temperature, °F

Use this algorithm to estimate the aperture area required for a particular hour of a day to provide the desired ventilation rate (e.g.,15 cfm/person). Figure 154 illustrates the result of this equation, showing how airflow depends on outdoor temperature as well as opening area.

A number of computer tools are available for simulating pressure driven airflow. Refer to Guideline TC13: Cross Ventilation for details.

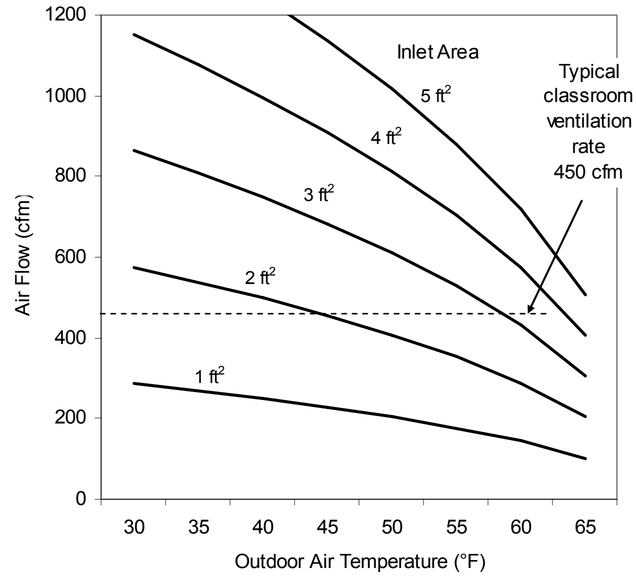


Figure 154—Stack Ventilation Rate

Assuming 70°F Indoor Temperature and 5 ft Height Difference Between Inlet and Outlet

Design Details

- Provide equal inlet and outlet areas to maximize airflow. Airflow will be dictated by the smaller of the inlet and outlet areas.
- The width to height ratio of openings should be more than one as far as possible, i.e., orient openings horizontally.
- The free ventilation area of the inlet and outlet should be at least 1% of the total floor area of the room (4.8 ft^2 per classroom, based on 32 ft x 30 ft x 9 ft-6 in. classrooms). This is typically adequate to meet outdoor air requirements with low temperature differentials that occur during summer months. However, smaller opening areas may be appropriate if stack ventilation is to be used only for cool-weather ventilation (assuming that, for example, additional cross-ventilation openings will be used during warmer conditions). Lowering the air intake of these openings during winter or completely shutting some of these openings may avoid uncomfortable winter conditions.
- Allow for at least a 5 ft center-to-center height difference between the inlet and the outlet. Increasing the height differential further will produce better airflow.
- Use stairwells or other continuous vertical elements as stack wells by providing adequate apertures. Such spaces may be used to ventilate adjacent spaces because of their ability to displace large volumes of air (because of greater stack height). Make sure that these connections are allowed by fire codes.

- Combine stack ventilation with cross ventilation elements. Set the inlet openings for cross ventilation lower in the wall so that they can double as inlets for stack ventilation during cool weather.
- Use louvers on inlets to channel air intake. Use architectural features like wind towers and wind channels to effectively exhaust the hot indoor air.
- HVAC systems should be designed to work in harmony with stack ventilation (see the Overview section for a discussion of passive ventilation with heating-only systems).
- Air inlet and outlets should be located or designed to minimize noise transfer from the exterior to the interior and to adjacent occupied spaces.
- Large openings may require installation of security grills.
- Openings, louvers and other elements of the stack ventilation design should be easily accessible for periodic cleaning.

Operation and Maintenance Issues

This strategy is largely dependent on manual operation for its success:

- Openings should be appropriately operated according to indoor-outdoor temperature differentials.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Windowsills, fins, screens, and louvers should be periodically cleaned to ensure healthy air intake for the space.
- Assign responsibility of ensuring that openings remain shut during the mechanical system's hours of operation unless the ventilation is designed to work concurrently.

Commissioning

If stack ventilation is used as part of a ventilation strategy for indoor air quality, then airflow testing should be included as part of the commissioning process. However, accurate measurements may be difficult due to low air velocities and the impact of varying outdoor wind and temperature conditions. Therefore, the test procedure must clearly describe the type of measurement equipment and the measurement procedures. The testing requirements should also describe how air flow is expected to vary with outdoor air temperature, and should call for seasonal testing to verify performance over a range of outdoor conditions.

References/Additional Information

Cook, Jeffrey. *Passive Cooling*. MIT Press, Cambridge, USA, 1989.

Brown, G.Z. Sun, Wind, and Light. John Wiley & Sons, New York, 1986.

GUIDELINE TC15: CEILING FANS

Recommendation

Use ceiling fans in classrooms to provide enhanced thermal comfort for occupants through higher air velocity. Use the ceiling fans instead of air conditioners in mild coastal climates. In more extreme climates, use ceiling fans as a supplement to cooling systems.

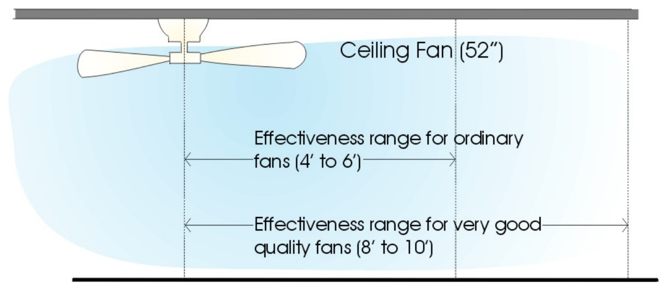
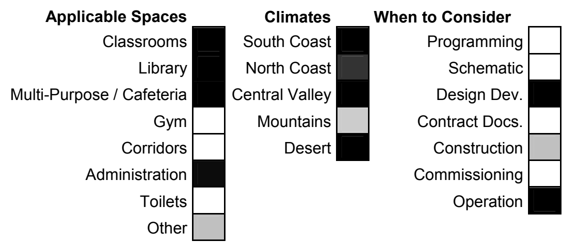


Figure 155—Ceiling Fan Effectiveness Range

Description



A ceiling fan is a device for creating interior air motion. It is a permanent fixture operated by a switch or a pull string. The air movement provided by a ceiling fan helps maintain acceptable comfort levels when air temperatures rise above the customary comfort zone. Generally, for air speeds above 30 fpm, most people will perceive a 15 fpm increase in air to be equal to 1°F decrease in temperature. This phenomenon is commonly called "chill factor."

In the winter, fans can ceiling fans can help "destratify" the warm air layer that collects near the ceiling, and distribute it to the lower part of the space for thermal comfort.

The interior air motion caused by ceiling fans varies as a function of fan position, power, blade speed (measured in rpm), blade size, and the number of fans within the space. Moreover, air speeds within a space vary significantly at different distances from the fan.

The normal current draw will range from approximately 15 W at low speed to 115 W at high speed.

Applicability

Ceiling fans are appropriate for classrooms and administration areas. Noise produced by ceiling fans may be an issue in auditoriums or classrooms if fans turn at too high a velocity.

Ceiling fans are suitable for most climates that require cooling. Combined with other passive strategies they may eliminate the need for air conditioning in the coastal regions. They are not as useful in humid climates.

Ceiling fans should be considered in the design development stage due to electrical wiring and ceiling height issues, although adding fans to existing spaces is feasible too.

Applicable Codes

Electrical codes apply.

Integrated Design Implications

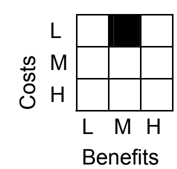
Using ceiling fans does not significantly impact other design decisions, except when a displacement airflow design is being considered.

- A minimum ceiling height of 9 ft must be provided to accommodate a fan such that its blades are at a distance of at least 8 ft from the floor and 1 ft from the ceiling.
- Ceiling fans should be combined with natural ventilation strategies for best results.

Cost Effectiveness

Ceiling fans cost between $75 and $200. The typical cost of a professionally installed fan is about $250. Fans with features such as light fixtures, reverse or multiple speed settings, and extended warranties may cost more. Some ceiling fans are very economical to operate as they consume very little energy. Others have very inefficient motors and add considerable heat to the room. Careful selection should be made.

Benefits



Moving air extends the comfort range and allows occupants to feel comfortable at higher temperatures. It also helps occupants feel dry. Wind speed is one of the six factors that affect thermal comfort indices like the predicted mean vote (PMV). For a detailed discussion, see this chapter's Overview section.

In the heating season, ceiling fans can help bring the warmer air that stratifies near the ceiling down to where the occupants are located. A low speed that does not create a significant breeze is best for this heating season application.

Design Tools

Use the following charts to size ceiling fans according to largest room dimension and room area:

Table 44—Fan Diameter Selection Based on Space Dimensions

Largest Dimension of Room	Minimum Fan Diameter
12 ft or less	36 in.
12–16 ft	48 in.
16–17.5 ft	52 in.
17.5–18.5 ft	56 in.
18.5 ft or more	2 fans needed

Table 45—Fan Diameter Selection Based on Space Area

Room Area	Minimum Fan Diameter
100 ft^2	36 in.
150 ft^2	42 in.
225 ft^2	48 in.
375 ft^2	52 in.
400+ ft^2	2 fans needed

Sources: Consumer Guide to Home Energy Saving (1995) by the American Council for an Energy Efficient Economy.

Design Details

Use ceiling fans in frequently occupied spaces.

Use “Quiet Type” energy-efficient fan and motor assemblies.

A larger fan provides a greater range of airflow settings and ventilates a larger area at lower velocities, with less noise, and only slightly more power than similar smaller units. Use two 48 in. fans in classrooms (based on 30 ft x 32 ft classrooms). These will move air most effectively in a 4 ft to 6 ft radius, and somewhat less effectively for another 3 ft to 4 ft radius. At the level of seated occupants, this will achieve air speeds ranging from 50 fpm to 200 fpm. Beyond 30 fpm, every additional 15 fpm results in a perceived 1°F drop in temperature. The more blade surface, the more air it will catch.

Ceiling fans work best when the blades are 8 ft to 9 ft above the floor and at least 10 in. to 12 in. below the ceiling. Placing fans so the blades are closer than 8 in. to the ceiling can decrease the efficiency by 40%. Fans also require at least 18 in. of clearance between the blade tips and walls.

Two types of mountings are available for ceiling fans—rod and hugger. In rod fans, the motor housing is suspended from the mounting bracket by a rod. With hugger fans, the motor housing is mounted directly to the ceiling box. Hugger fans are not as efficient as rod fans in the down motion, especially at higher speeds. The blades will starve themselves for air when they are too close to the ceiling.

Use ceiling fans to supplement air movement in natural ventilation strategies.

Select a fan with at least a two-speed control for better regulation of air movement. Variable-speed fans are preferable so that the lowest speed can be used in the heating season to accomplish destratification without causing excessive draft. If using a reversible fan, ensure that the fan has a setting low enough to circulate the air without creating too much of a breeze.

Fans should be on only when the space is occupied; otherwise the movement of the motor is also introducing some heat in the room without any cooling benefits. Remember that ceiling fans cool people, not spaces. Consider using an occupancy sensor.

Operation and Maintenance Issues

Ceiling fans should be operated only when the rooms are occupied. A motion sensor or a clear policy of operating ceiling fans only when using the room is needed.

Ensure that all blades are screwed firmly into the blade holder and that all blade holders are tightly secured at the fan. This should be checked at least once a year.

It is important to periodically clean the fan, as the blades tend to accumulate dust on the upper side. An anti-static agent can be used for cleaning, but do not use any cleaning agents that can damage the finish. Never saturate a cloth with water to clean the ceiling fan.

For a fan to perform efficiently, it is very important that the blade be aerodynamically shaped to increase its efficiency, similar to an airplane propeller. "Balanced" blades; that is, blades that are electronically matched at the factory; are sold as balanced four- or five-blade sets, depending on the design of the fan. For this reason, never interchange blades between fans.

Use durable fans with longer warranties. Use fans with metal motor housings—these may require annual oiling (while plastic motor housings will not), but may have better warrantees and be worth the added maintenance.

Commissioning

Ensure that fan controls operate properly, that fans rotate in the proper direction, that excessive drafts are not created, that fans are solidly mounted, and that no excessive noise or vibration occurs.

References/Additional Information

AIRBASE (database of over 7,000 abstracts of international papers on infiltration and ventilation), Air Infiltration and Ventilation Centre, Sovereign Court, University of Warwick Science Park, Sir William Lyons Road, Coventry, CV4 7EZ, U.K. Tel: 44-203-692050, Fax: 44-203-416306.

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE 62-Ventilation for Acceptable Indoor Air Quality.* 1791 Tullie Circle NE, Atlanta, GA, 30329-2305. Tel:(404) 636-8400; Fax:(404) 321-5478.

Bower, John. *Understanding Ventilation: How to Design, Select, and Install Residential Ventilation Systems.* The Healthy House Institute, 430 N. Sewell Rd., Bloomington, IN 47408.

The Home Ventilating Institute. *The Certified Home Ventilating Products Directory.* 30 West University Dr., Arlington Heights, IL 60004-1893. Tel:(708) 394-0150.

Oikos/Green Construction Source (Features REDI 96, an online directory of products, including ventilation fans, devices, and controls.) Iris Communications, P.O. Box 5920, Eugene, OR, 97405-0911, Tel:(541) 484-9353. Web site: www.irisinc.com/oikos.

Parker, Danny, et al, Development of a High Efficiency Ceiling Fan, "The Gossamer Wind," Florida Solar Energy Center (FSEC) and AeroVironment, Inc. publication FSEC-CR-1059-99, www.fsec.ucf.edu/Bldg/pubs/cr1059/.

GUIDELINE TC16: AIR DISTRIBUTION DESIGN

Recommendation

Design the air distribution system to minimize pressure drop and noise by increasing duct size, minimizing duct turns and specifying low-loss duct transitions and plenums. Use lowest possible fan speed that maintains adequate airflow. Pay special attention to the longest or most restricted duct branch.

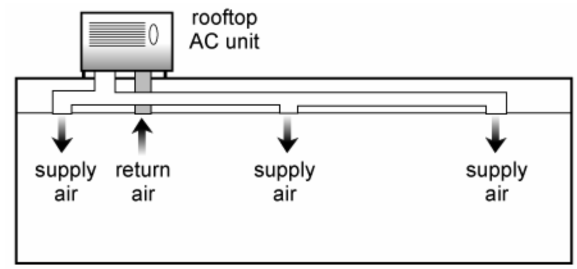
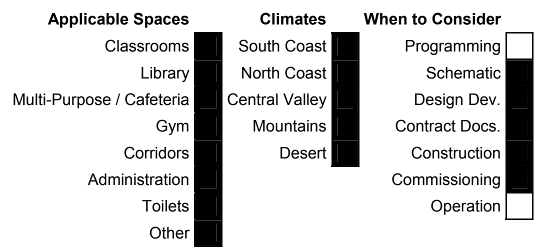


Figure 156—Basic Air Distribution System

Description



Optimal air distribution system design is fairly complicated. An optimal design balances the need for comfort and low noise with overall HVAC system and energy costs. Many factors affect performance: diffuser type, number of diffusers, diffuser size, duct size, duct material, plenum type and size, fitting types, length of ducts, number of turns, type of turns, location of duct system (e.g., unconditioned attic or within conditioned space), priority for heating performance vs. cooling performance, and fan characteristics (pressure vs. airflow).

Due to the complexity of design, a detailed analysis is uncommon for small systems. Typically, contractors rely on experience or rules of thumb in choosing system components.

This guideline addresses small, constant-volume duct systems that are common in California schools. It covers design targets for air velocities and pressure loss that help ensure an efficient and quiet system. For recommendations regarding duct design in larger systems, such as VAV systems, see the Advanced VAV System Design Guide.

Applicability

All ducted air systems.

Applicable Codes

Title 24 requires that most ducts be insulated (depending on duct location).

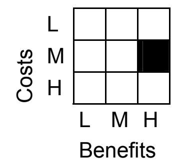
Integrated Design Implications

Air distribution design options are closely tied to the architectural design. The choice of duct type is often limited by space availability.

Ducts may be located outside, in unconditioned space, or within the conditioned space. The most energy efficient option is usually within conditioned space. More expensive sheet metal ducts are usually required for exposed ducts in conditioned space, but they need not be insulated. If ducts are located in an unconditioned attic, then the roof must be insulated and/or equipped with a radiant barrier to reduce heat gain to the ducts.

Location of supply air outlets must be coordinated with lighting design (if located in ceiling) or space plan and furniture (for wall or floor outlets).

Cost Effectiveness



Sometimes extra costs for low-loss fittings or larger ducts are necessary to achieve a high performance design.. However, many air distribution improvements have little or no extra cost.

Design Tools

Numerous duct sizing computer programs are commercially available.

A common tool is a “Ductulator” by the Trane Company, which is a manual device used to calculate pressure loss for different types of ducts.

Design Details

These guidelines are intended to cover typical, small, single zone systems.

Airflow

- *System cooling airflow.* Total system airflow should generally fall between 350 cfm/ton and 450 cfm/ton for systems with cooling. If airflow is greater than about 500 fpm then condensation might blow off the cooling coil. If airflow is less than 350 cfm/ton, the cooling capacity and efficiency drop. The capacity loss due to low airflow is worst in dry climates where latent cooling loads are low. In humid climates slightly lower airflows may be appropriate; see the manufacturer’s performance data for the cooling coil to determine the appropriate airflow to meet latent loads in humid locations.

- *System heating airflow.* For heating-only systems, a good target is 25 cfm per kBtu/h of heating capacity, providing about 105°F supply air. Heating airflow should not be lower than 15 cfm per kBtu/h because supply air temperature will exceed 135°F. If the airflow is low, supply air will be too warm and air velocity too low, and poor mixing occurs in the room. Excessive airflow during heating creates more noise and can cause uncomfortable drafts.

- *Airflow adjustment.* After system installation, airflow can be adjusted by either changing the fan speed or altering the duct system. To reduce airflow, lower the speed of the fan rather than install dampers. Try to use the lowest fan speed possible because fan energy consumption drops rapidly as fan speed decreases. If possible, specify a variable-speed fan or multiple-speed fan. To increase airflow, try to modify the duct system rather than increase the fan speed. Possible measures include replacing the most restrictive ducts with larger sizes, improving duct transitions to reduce pressure loss, and eliminating duct turns or constrictions (especially in flex duct).

- *Supply diffuser.* Most diffusers also have a minimum velocity both for proper mixing and to avoid dumping cool air on occupants. Refer to manufacturers' guidelines for specific types of supply diffusers. When choosing diffusers based on Noise Criteria (NC), remember that manufacturers' data are usually at ideal conditions (long, straight duct attached to diffuser) and actual noise level is likely to be higher. To account for this, diffusers should be selected for five to 10 NC points below the NC criteria of the room. Refer to table below for suggested air velocities.

Table 46—Air Velocities for Supply Outlet and Return Inlet

	Design Criterion NC or RC(N)	Neck Air Velocity (fpm)
Supply Outlet	45	625
	40	560
	35	500
	30	425
	25	350
	20	300
Return Inlet	45	750
	40	675
	35	600
	30	500
	25	425
	20	375

(Source: 1999 ASHRAE Application Handbook)

- *Return grille.* The return air grille(s) must be larger than the total supply air diffuser area to avoid excessive noise. Refer to table above for suggested air velocities.

- *Duct.* Air velocity should not exceed 700 fpm in flex ducts and 1,200 fpm in sheet metal ducts above occupied areas. Higher flow creates excessive turbulence and noise. There is usually a practical lower limit to duct air velocity, where the duct becomes too large and expensive.

- *Cooling coil.* Air velocity through the cooling coils should be minimized to reduce pressure loss. A good target is 300 fpm. However, designers seldom have a choice of coil area in small packaged HVAC units. It is still as good idea to compare airflow and fan power data from different manufacturers to identify units with lower internal pressure loss.

Duct type

Flexible

Flexible ducts are widely used. They offer a number of advantages when properly installed but also have some disadvantages.

Flex ducts are most popular for their low cost and ease of installation. In addition, they attenuate noise much better than sheet metal ducts, but allow noise to escape into the ceiling plenum, which may not be acceptable if noise levels at the flex duct are excessive. Flex duct also offers lower air leakage, are usually pre-insulated, and provide some flexibility for future changes.

On the down side, pressure loss is greater in flex ducts, even when they are properly installed. They are also prone to kinking, sagging, and compression, which are problems that further reduce airflow and create noise. And since they are flexible, flex ducts are usually installed with more turns than sheet metal ducts. Actual performance of flex ducts in the field is often poor due to these installation problems. As a final disadvantage, flexible ducts are typically warranted for only about 10 years and will need replacement more often than a sheet metal equivalent.

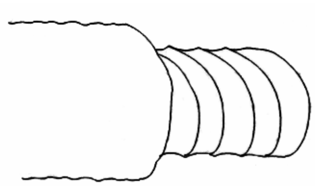
If flex duct is used, several important points to consider are:

- The duct must be large enough for the desired airflow (see table below).
- The ducts must be properly suspended according to manufacturer guidelines without compression or sagging.
- All ducts must be stretched to full length (see table notes below).
- Keep flexible duct bends as gentle as possible; allow no turns of more than 45°.

Fasten all flex ducts securely to rigid sheet metal boots and seal with mastic (see Guideline TC17: Duct Sealing and Insulation).

- Limit duct lengths to no longer than about 20 ft (otherwise pressure loss may be too high).

Table 47—Maximum Airflow Values for Flex Duct



Flex Duct Diameter (in.)	Maximum Airflow (cfm)
4	60
5	100
6	140
7	190
8	240
9	310
10	380
12	550

* Maximum airflow limits correspond to velocity of 700 fpm. Higher flows create turbulence and noise in flex ducts.

† The airflow values in the table assume that the flex duct is stretched to its full length. Airflow resistance increases dramatically if flex duct is compressed in length. Pressure loss doubles if the duct is compressed to 90% of its full length and triples if it is 80% compressed.

Sheet Metal

The advantages to sheet metal ducts are lower pressure loss, longer life, greater durability, and the potential for reuse or recycling at the end of the system's life. They are the only option for long duct runs or medium-to-high pressure duct systems. In addition, sheet metal ducts may remain exposed in conditioned spaces.

Disadvantages to sheet metal ducts are higher cost, higher sound transmission (sometimes they require noise attenuation measures that offset some of the pressure loss advantage), insulation requirement, and potentially greater leakage (though leakage is not an issue if they are properly sealed).

From a pressure loss standpoint, round sheet metal ducts are preferred over rectangular when adequate space is available. Round sheet metal ducts keep noise inside better than rectangular ducts. This may be preferred if the ducts are running over a noise sensitive space, and duct noise breakout is a concern. However, because round ducts do not allow noise to escape as easily as rectangular ducts, noise will not be reduce as quickly as the noise travels down the duct system. When ducts cannot be lined with internal glass fiber, rectangular ducts are preferred to allow low frequency noise to escape the duct before reaching the diffuser. Rectangular ducts are susceptible to noisy drumming at high airflow.

Reducing pressure loss

A number of measures may be taken to reduce pressure loss and improve airflow. Knowledge of the following simple principles may help the designer improve airflow:

- Air resists changing direction. The pressure drop of a turn can be reduced dramatically by smoothing the inside and outside radius. When possible, avoid sharp turns in ducts and never allow kinks in flexible ducts. Turning vanes are another option to reduce the pressure drop in a sharp turn.

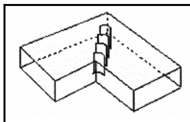
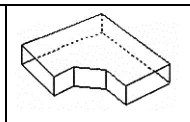
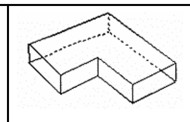
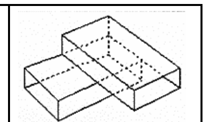
				
	BEST	GOOD	FAIR	POOR
Relative Pressure Loss	1.0	X 1.3	X 4.7	X 13.0

Figure 157—Pressure Loss for Duct Turns

Note: Total pressure loss calculated at 800 fpm air velocity.

- Airflow into branch ducts will be improved by using angled transitions (or conical taps) rather than typical straight connections. The angled transition is especially useful for critical branches that are not getting enough air.
- From a pressure loss standpoint, the fewer turns the better. However, turns help to reduce noise, particularly at high frequencies, as it travels through the duct system.

Other Design Issues

Pay special attention to the duct branch with the greatest pressure drop, either the longest branch or the one with the most constricted turns. For longer branches, either larger duct size or low loss duct transitions will be required to achieve proper airflow.

Do not place balancing dampers directly behind diffusers. If they are necessary, then dampers should be located as close to the fan as possible to minimize noise and air leakage in the supply duct.

Connections to ceiling diffusers should have two diameters of straight duct leading into the diffuser. Otherwise noise and pressure drop can increase significantly.

Avoid placing ducts in a hot attic. The roof can reach 150°F on a sunny day and the radiant heat load on the duct is significant. If ducts are above the ceiling, insulation must be installed on or under the roof or a radiant barrier must be installed under the roof deck.

In many cases, if the pressure loss in the air distribution system can be reduced by as little as 0.15 in. SP, fan speed can be reduced and fan power decreases significantly. In the case of a 3-ton rooftop packaged unit, energy savings can be $200 to $300 over a 10-year period. Manufacturer’s data for a typical 3-ton unit shows that the fan can supply 1,100 cfm at 0.8 in. w.c. external static pressure, if the fan is set to high speed. The fan can provide the same airflow at 0.65 in. w.c. at medium speed. Therefore, if the duct system is carefully designed and installed it may be possible to run at medium speed. The fan power then drops from 590 W to 445 W. For typical operating hours and electricity rates, the savings are about $30/year. As an additional benefit, the fan noise drops significantly as the fan speed is reduced.

See the HVAC Acoustics guideline for more information about designing ducts to minimize noise.

For recommendations regarding duct design in larger systems, such as VAV systems, see the *Advanced VAV System Design Guide*.

Operation and Maintenance Issues

Filters must be replaced regularly to maintain airflow. Fans and drives must be lubricated to maintain proper operation.

Commissioning

Measure supply airflow and external static pressure to compare with design values. If airflow is low, take measures to reduce restrictions in duct system rather than increasing fan speed.

Consider a duct leakage test to confirm that the system is properly sealed.

References/Additional Information

American Society of Heating, Refrigeration and Air Conditioning Engineers. *ASHRAE Handbook—2001 Fundamentals*. Atlanta, Georgia.

Hydeman, Mark; Steve Taylor, Jeff Stein, and Erik Kolderup. *Advanced Variable Air Volume System Design Guide*. California Energy Commission publication number P500-03-082-A-11. October 2003. Available at: www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF.

Sheet Metal and Air Conditioning Contractors National Association. *HVAC Systems Duct Design*. Chantilly, Virginia.

GUIDELINE TC17: DUCT SEALING AND INSULATION

Recommendation

Create strong and long-lasting connections by mechanically fastening all duct connections and using mastic to seal connections and transverse joints (those perpendicular to airflow). If choosing pressure-sensitive tape as a sealant, then specify foil-backed tape with 15-mil butyl adhesive.

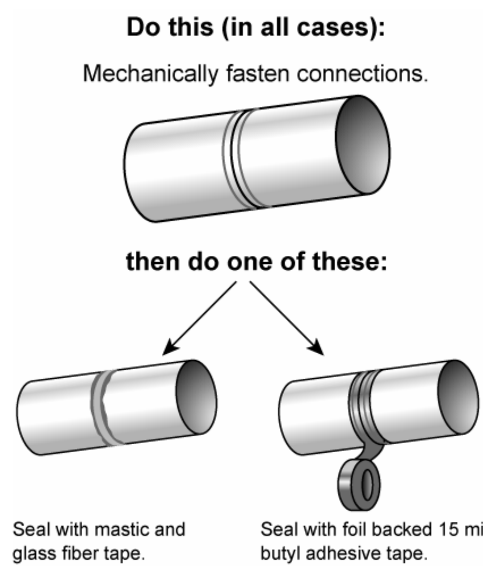


Figure 158—Duct Sealing

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	■	Mountains	■	Contract Docs.	■
Corridors	■	Desert	■	Construction	■
Administration	■			Commissioning	□
Toilets	■			Operation	□
Other	■				

Description

Duct leakage has a big impact on system efficiency and capacity. Studies of residential systems conducted by the Lawrence Berkeley National Laboratory show that 20% loss is common.[53] Similar problems exist in commercial duct systems.

Other studies have shown that some types of pressure-sensitive tape fail quickly in the field. Therefore, duct-sealing systems must be specified carefully for longevity as well as strength and air-tightness.

Depending on duct location, insulation also plays a critical role in ensuring system efficiency and capacity.

Supply and return air plenums must be sealed as well. These are usually the areas of greatest pressure in the air distribution system, and small holes create significant leaks.

Applicability

All ducted air systems.

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53 www.lbl.gov/Science-Articles/Research-Review/Highlights/1998/v3/EES_duct.html.

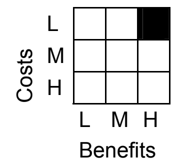
Applicable Codes

Title 24 requires R-4.2 duct insulation unless the duct is completely within conditioned space. The code also requires mechanical connections; tape or mastic alone is not allowed. In addition, sealing is required using mastic, tape, aerosol sealant, or other system that meets UL 181. (However, an UL 181 rating should not be the only consideration in choosing at duct sealing material. UL 181 does not test longevity of the sealing system.)

Integrated Design Implications

Duct leakage problems can be avoided by placing ducts within the conditioned envelope or by eliminating them altogether (e.g., hydronic heating and cooling).

Cost Effectiveness



Using mastic for duct sealing may increase material costs, but many find that labor costs drop compared to sealing with tape. Therefore, good duct sealing should not have a significant cost impact.

Benefits

Careful duct-sealing and insulation application will allow use of smaller cooling and heating equipment or at least allow the use of smaller safety margins in sizing calculations. Lower equipment cost may be a result.

Lower cooling and heating costs result. Other benefits include improved system performance, potentially better comfort, and reduction in infiltration and potential moisture problems within envelope components.

Design Tools

None.

Design Details

Do not rely on sealants, such as tape or mastic, to provide a mechanical connection. Specify screws, draw bands, or other mechanical fastening devices as appropriate for the duct type.

As a first choice, use mastic to seal all connections and transverse joints. Mastic is a liquid applied sealant that can also be used together with a mesh or glass fiber tape to provide added strength or to span gaps of up to about ¼ in. Specify mastic in a water-based solvent with a base material of polyester/synthetic resins free of volatile organic content.

If choosing pressure-sensitive tape as a sealant, specify foil-backed tape with 15-mil butyl adhesive. Butyl tape has been found to have greater longevity in the field. Use of tape with rubber or acrylic adhesive should be avoided.

Flexible ducts must be mechanically fastened with draw bands securing the inner and outer plastic layers to the terminal boot. Specify that the draw bands be tightened as recommended by the manufacturer using an adjustable tensioning tool.

Seal both supply and return ducts and plenums.

Commissioning

Inspect duct connections.

Test duct leakage with smoke testing or pressure testing.

References/Additional Information

None.

GUIDELINE TC18: HYDRONIC DISTRIBUTION

Recommendation

Consider using a variable flow system with variable-speed drive (VSD) pumps, but be careful to keep turbulent flow in the fintube during cold weather. Insulate exposed hydronic heating/cooling piping. Make early decisions regarding the placement of heating/cooling components (radiators, ceiling panels, slab floors, boilers, chillers. etc.). Use this information to create a system layout that minimizes piping material (pipes, bends, etc.) and head loss. When possible, use larger pipe diameters and smaller pumping equipment to conserve energy.

Figure 159—Loop Water Pumps and Piping

Part of a geothermal heat pump system being used by Nebraska schools to save money and energy on heating and cooling. NREL/PIX07415

Applicable Spaces	Climates	When to Consider
Classrooms	South Coast	Programming
Library	North Coast	Schematic
Multi-Purpose / Cafeteria	Central Valley	Design Dev.
Gym	Mountains	Contract Docs.
Corridors	Desert	Construction
Administration		Commissioning
Toilets		Operation
Other		

Description

Significant amounts of energy must be used to distribute water for heating and cooling. Proper design can result in substantial economic and energy savings. Unfortunately, hydronic distribution design is often governed by past practices and not necessarily best practices. This factor makes the design process quick and easy, but not always the most economical or energy efficient. A hydronic distribution system consists of pipes, fittings, tanks, pumps, and valves.

Applicability

Applicable in all areas.

Applicable Codes

- Title 24 Section 123 details pipe insulation requirements.
- ANSI/ASHRAE/IESNA Standard 90.1 details requirements for various pump sizes.
- Consult Title 24 Mechanical Code regarding seismic support.

Integrated Design Implications

Hydronic distribution is related to nearly all aspects of building design and construction. It is crucial that the HVAC piping contractor be involved throughout the design and construction process in order to maximize the efficiency and cost effectiveness of the hydronic distribution system. Simply laying out heating and cooling elements (baseboards, ceiling panels, chillers, boilers, etc.) in such a way that minimizes the required pipe material and maximizes straight-running pipe can save significant amounts of energy. Maximizing the amount of straight-running pipe also simplifies the insulating process.

Cost Effectiveness

Initial cost for hydronic distribution depends on the quantity, size, and type of piping, valves, and pumps. Initial cost can be minimized through proper planning, sizing, and placement of each.

When doing life-cycle cost analysis, compare incremental cost of increased pipe diameter to energy savings, and savings from decreased size and cost of pumping system.

Benefits

- A properly sized and installed system will provide quiet, efficient, and virtually maintenance-free operation at minimal cost.
- Properly insulating all exposed piping will save energy and money, which can be cost effective at levels beyond code requirements.
- Increasing piping diameter significantly decreases the pumping power required. Pressure head loss due to friction decreases by the fifth power with pipe diameter.
- Oversized piping allows for increases in load requirements from add-ons or renovations without complete system overhaul.

Design Tools

Use a CAD-based program to design pumping layout.

ASHRAE *Handbook—Fundamentals* outlines the process for determining pressure drop through piping layout.

Pipe diameter selection involves balancing the following:

- Location of pipe in the system.
- First costs of installed piping.
- Pump costs (capital and energy).

- Erosion considerations.
- Noise considerations.
- Architectural constraints.
- Budget constraints.

Design Details

Piping Circuits

There are four general types of piping circuits: series, diverting series, parallel direct-return, and parallel reverse-return. The series circuits are one-pipe circuits, and are the simplest and lowest-cost design. Both the series and diverting series involve large temperature drops; however, only the latter allows for control of individual load elements.

The advantage of parallel piping circuits is that they supply the same temperature water to all loads. Direct-return networks are sometimes hard to balance due to sub-circuits of varying length. Reverse-return networks are designed with sub-circuits of nearly equal length. Parallel circuits are two-pipe systems.

Piping attached to vibration-isolated equipment (typically with the first 25 ft to 30 ft from the equipment) should be supported with vibration isolators, similar in type and static deflection to the vibration isolation being used for the associated equipment.

Fluid flow should be limited to 4 fps in 2-in. diameter pipes and below. For larger pipes a flow velocity of 6 fps is recommended.

Maintain a maximum of 50 psig water pressure at plumbing fixtures.

Valves

In general, either two-way or three-way control valves are used to manage flow to the load. A two-way valve controls flow rate to the load through throttling, which causes a variable flow load response. Three-way valves are used in conjunction with a bypass line to vary flow to the load. Because the water that does not go to the load simply passes through the bypass line, three-way valves provide a constant flow load response. Significant energy savings can be realized when two-way control valves are used in conjunction with VSD pumps.

It is recommended that ball valves or butterfly valves be used for all isolation and balancing valves. These valves are reliable and offer a low-pressure drop at a low cost.

Pumps

Centrifugal pumps are most commonly used in hydronic distribution systems. The use of VSD pumps can save significant amounts of energy and simplify the distribution system. Pump power falls at a cubed rate with speed and thus a VSD pump can be extremely cost effective for systems with significant load variations. Also, variable flow networks with VSD pumps use a simple two-way valve and do not require balancing valves. For systems that use supply air temperature reset controls, specify a clamp on the speed of the pump in order to avoid excessive energy use during system startup.

Refer to 2003 ASHRAE Handbook – HVAC Applications Chapter 47 for recommended vibration isolation.

Dual-Temperature Systems

When a space requires both heating and cooling, either a two-pipe system or four-pipe system can be used. In a two-pipe system, all the loads must be either heating or cooling congruently. Two-pipe systems cannot be used when some spaces on the piping network need cooling, while others need heating. Switching from one mode of operation to the other increases overall energy usage and can be a fairly time consuming process. A four-pipe system is more complex, but it allows for heating and cooling on the same network and is more convenient than a two-pipe system when frequent changeovers are required.

Expansion Chamber

Closed systems should have only one expansion chamber.

Expansion tanks open to the atmosphere must be located above the highest point in the circuit.

Air Elimination

Measures such as manual vents and air elimination valves should be taken to purge any gases from the flow circuit. Failure to do so can lead to corrosion, noise, and reduced pumping capacity.

Insulation

The insulation process becomes significantly easier when the piping network is laid out properly. Install all valves with extended bonnets to allow for the full insulation thickness without interference with valve operators. It may be cost effective to insulate pipes beyond code requirements.

Water Treatment

Care should be taken to avoid scaling and biological growth within the distribution system. Significant fouling resulting from either source is detrimental to system performance. The degree to which scaling can occur is dependent upon temperature, pH level, and the amount of soluble material present in the water. Scale formation can be controlled through several means including filtration and chemical treatments.

Biological growth is generally a larger problem for cooling systems. Heating systems typically operate at temperatures high enough to prohibit substantial biological growth. Chemical treatments with biocides such as chlorine and bromine have traditionally been used to control this growth. Alternatives to these chemicals include ozone and UV radiation. Ozone itself is toxic; however it readily breaks down into non-toxic compounds in the environment. UV radiation is completely non-toxic, but is only effective when turbidity levels are low. Mechanical methods such as blow downs can also be utilized to control fouling and decrease chemical use, but these methods increase water usage.

Operation and Maintenance Issues

Water quality should be checked on a regular basis to ensure fouling due to scaling or biological growth is not occurring.

Periodically check piping insulation. Insulation adhesive can fail and expose piping.

Check pressures, pumps, and valves on regular basis to ensure system is performing as intended.

Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. Water flow should be measured and adjusted accordingly. System head should be measured and compared to design system head.

References/Additional Information

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Handbook—HVAC Systems and Equipment*. 2000.

CoolTools: Chilled Water plant Design Guide. Available from Pacific Gas and Electric, P.O. Box 770000, B32. San Francisco, CA 94177. www.hvacexhange.com.

Hydronics Institute, Berkeley Heights, NJ 07922. Phone: (908) 464-8200.

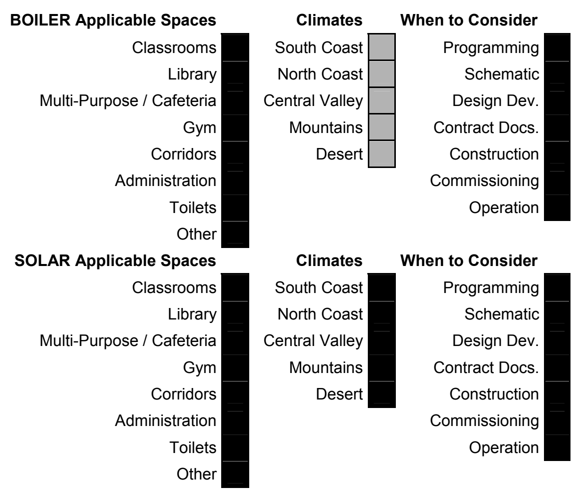
GUIDELINE TC19: HOT WATER SUPPLY

Recommendation

Consider high-efficiency, gas-fired boilers for space heating and domestic hot water. If demand is large and variable, install several smaller modular boilers instead of one large unit. If conditions permit, augment boiler with solar thermal system and/or recovered thermal energy.

Figure 160—Solar Hot Water Panels

Source: NREL/PIX05183



Description

Boilers

Boilers are pressure vessels that transfer heat to a fluid. They are constructed of cast-iron, steel, aluminum, or copper. There are two basic types: fire-tube and water-tube. Fire-tube configurations heat water by passing heated combustion gases through a conduit that is submerged in the water. This system generally uses natural gas or oil as the combustion fuel. Water-tube configurations pass water in pipes through the heated combustion gases and can use natural gas, oil, coal, wood, or other biomass. The air needed for combustion can be supplied by either mechanical or natural (atmospheric) means. Hot water boilers are generally classified as either low temperature (less than 250°F) or high temperature (250°F–430°F), and are rated by their maximum working pressure. All boiler systems have the following components in common:

- *Fuel supply:* natural gas, oil, wood, or other biomass.
- *Burner:* The burner injects a fuel-air mixture in the combustion chamber.
- *Combustion chamber:* Location in boiler where combustion occurs.
- *Heat exchange tubes:* Tubes within the boiler that contain water for a water-tube model and combustion gases in a fire-tube unit.

- *Stack:* The stack is the chimney through which combustion gases pass into the atmosphere.
- *Hydronic distribution system:* Supplies feed water to the boiler and distributes hot water to the facility.

Solar Thermal

A solar thermal system can be either direct or indirect and classified as either active or passive. A direct system heats water directly in solar collectors. An indirect system uses a working fluid (usually a glycol-water mixture) in conjunction with a heat exchanger to increase the water temperature. Direct systems contain fewer elements and are less expensive, but they are prone to freezing and cannot be used in most climate zones without drain back systems. Indirect systems use an antifreeze mixture and can be used in any climate zone. Active and passive refers to the method by which fluid reaches the collector. If the fluid moves through natural convection, the system is termed passive, and if pumps are used, it is active. Solar thermal systems consist of the following elements:

- *Solar radiation collector:* Collects solar radiation for heating.
- *Heat exchanger:* A heat exchanger is used in an indirect system to pass heat from the working fluid to the water supply.
- *Hydronic distribution system:* Supplies water to the collector for direct systems and to the facility for both direct and indirect systems.
- *Storage tank:* Stores heated water for facility use or for boiler feed water supply.

Applicability

Applicable in any situation where a significant amount of space heating and/or water heating are required. A solar thermal water heating system has the potential to be the main hot water source in some situations. For example, an elementary school in the desert could easily meet most of its hot water needs through solar energy utilization. In most areas it could at least augment the boiler system.

Applicable Codes

Title 24 include pipe insulation and hot water storage tank insulation requirements.

Boilers

Title 24 also specifies the minimum efficiency requirement for boilers to be 80% to 83% depending upon combustion fuel and size.

The boiler should comply with the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. This includes codes regarding suggested maintenance.

Stack placement should adhere to ASHRAE 62 Standards. Stack emissions must conform to requirements set forth by the Clean Air Act under jurisdiction of the applicable air quality district.

The stack will transmit vibration and noise if the stack is not decoupled from the building structure. Ensuring that the stack is isolated from the building structure is particularly important when the stack is close to occupied areas.

Solar Thermal

Solar specific components should be certified by the Solar Rating and Certification Corporation.

Integrated Design Implications

A certain amount of hot service water will always be needed for restroom facilities. Any additional need is dependent upon the choice of space heating system (air or hydronic) and whether or not the building design includes a swimming pool and/or commercial sanitation and food preparation equipment. The actual heating load is dependent upon climate and decisions regarding fenestration, hydronic distribution, building envelope, indoor equipment, and building orientation. The placement of boiler or solar thermal components affects requirements of the hydronic distribution system. Try to make these decisions early in order to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

If a central cooling plant is being considered for the facility the possibility of using recovered thermal energy should be considered. Using this technique could affect many aspects of design including chiller choice.

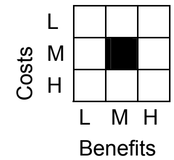
Solar Thermal

A radiant slab heating system works extremely well with solar thermal water heating. Solar thermal systems can generally achieve the low inlet temperatures (90°F–120°F) required by a radiant slab system.

Because the performance of a solar thermal system is dependent upon the weather, it works best when used in conjunction with another heating system. Depending upon the situation, the solar system can be the primary heat source or can be used to augment and increase the efficiency of a boiler system. The increased efficiency is accomplished by preheating boiler feed water with solar thermal energy.

The use of a solar thermal system must be addressed early in the planning stages, as its viability is highly dependent upon available roof space and building orientation. It is also important to plan the placement of any other roof systems to avoid shading by packaged HVAC systems, stacks, walls, etc.

Cost Effectiveness



Boilers

Total installed costs between $35/kBtu/h and $52/kBtu/h depending on efficiency. Some maintenance costs exist, but they can help prevent huge repair costs in the future.

Condensing boilers cost from 30% to 60% more than standard units up to 500 kBtu/h. Incremental costs for more efficient boilers range from \$0.23/ft^2 to \$0.35/ft^2 depending on climate. The more efficient boilers realize simple payback period of five to 10 years.

Solar Thermal

Initial costs are higher than that for a boiler system. Most systems cost between \$30/ft^2 and \$90/ft^2 of collector area. Maintenance costs are low, and fuel expenses are zero.

The initial cost for solar thermal systems is somewhat more than boilers. However, the fuel is free and thus the system will eventually pay for itself. For a slab system it may be the more cost effective option since it is heating to its maximum while a boiler would need to be run at a lower, less efficient setting. The cost effectiveness of a solar system varies from site to site, as the payback period is dependent upon climate and available solar radiation. Solar thermal systems will be most cost effective in schools with substantial summer occupancy, as this is the time of greatest available solar radiation.

Benefits

Boiler

- Longer life span than standard storage water heaters.
- Can be more efficient than a furnace, but not always.
- Gas boilers burn significantly cleaner than oil, coal, and wood fired units.

Solar

- Free fuel.
- Do not have to worry about changing fuel prices.
- Non-polluting. No fumes means healthier for students and teachers. No operational greenhouse gas emissions.
- Great for teaching. The system itself can be a topic in science classes.

Design Tools

Boiler

The use of boilers with various efficiencies can be modeled using DOE-2 and VisualDOE.

Solar Thermal

The Transient System Simulation Program (TRNSYS) developed by the University of Wisconsin-Madison Solar Energy Lab is capable of modeling entire solar water heating systems.

The National Renewable Energy Lab has extensive data regarding annual totals of solar radiation for different cities in California.

Solar Engineering of Thermal Processes by John Duffie and William Beckman is a great resource for solar energy applications.

Design Details

Boiler

Large systems are 75%–85% efficient.

New condensing gas-fired boilers are up to 96% efficient.

Boiler energy saving add-ons:

- Economizers preheat feed water with energy from stack gases before it goes to the boiler.
- Air preheaters preheat the air that is mixed with the fuel for combustion, leaving more energy to heat the water.
- Turbulators increase the convective heat transfer rates in fire-tube boilers by inducing higher levels of turbulence.
- Oxygen trim controls measure and adjust oxygen levels in the inlet air before combustion.
- Boiler reset controls automatically change the high-limit set point based on changes in outdoor temperatures.
- Since boilers are generally most efficient at their rated capacity, it is better to have several smaller boilers rather than one large unit that is rarely used at its most efficient setting.
- Condensing boilers produce acidic condensate that is corrosive to some materials such as steel or iron. Make sure to account for proper condensate drainage and follow manufacturers specifications for exhaust flue design if specifying a condensing boiler.

- Refer to 2003 ASHRAE Handbook – HVAC Applications Chapter 47 for recommended boiler vibration isolation.

Solar Thermal

The system requires use of a differential thermostat to ensure heat is not being dumped to the collectors. The most important element of a solar thermal system is the solar collector. Solar collectors can be either fixed or track the sun. The latter is generally more expensive and is saved for high-temperature applications. Fixed collectors should be oriented facing south and tilted based on seasonal load. A good rule of thumb is to use the location's latitude as the tilt angle with respect to the horizontal.

- Flat-plate collectors consist of a metal frame box containing a layer of edge and backing insulation, an absorber plate with parallel piping, and glazing. The absorber plate is generally constructed of copper or aluminum with a high absorbance coating. The glazing layer reduces convective and radiation heat loss and involves one or more sheets of glass. Solar thermal systems with flat-plate collectors are very common.
- Integral collector storage (ICS) systems use the storage tanks themselves as solar collectors. The tanks are painted black and are set on the roof alone or in insulating boxes with transparent covers angled south. ICS systems are applicable only in mild climates, as freezing and significant heat loss become issues in colder regions. This system is very simple and cost effective.
- The evacuated tube collector is a long and thin version of a flat-plate collector where the box has been substituted by a glass tube and the insulation by a vacuum. These collectors are extremely efficient but are fragile and expensive.
- Concentrating collectors use a curved surface to reflect and concentrate the solar radiation onto a pipe containing fluid. These collectors are generally used for high-temperature applications and are almost always configured to track the movement of the sun.

Operation and Maintenance Issues

Boiler

Performing basic operating and maintenance practices on boilers is very important. Regular inspection of boiler system components ensures safe and efficient operation. Proper maintenance can lead to energy savings of 10%–20%, reduce harmful emissions, and increase the lifespan of the system.

Fire-side maintenance:

- Minimize excess combustion air and monitor stack gas O_2 and CO_2 to ensure proper percentages. Too little air can cause increased CO and particulate emission, while too much can lower efficiency.
- Clean heat transfer surfaces.

Water-side maintenance:

- Perform regular 'blow downs" to reduce the level of total dissolved solids (TDS) in the system. High TDS levels cause pipe fouling that reduces the heat transfer rate and increases the pressure drop.
- Insulate boiler walls and piping.

Solar Thermal

Collector glass should be cleaned regularly to ensure maximum efficiency.

Direct systems must be drained when freezing conditions exist.

Commissioning

Boiler

Commissioning should be performed to ensure proper installation and operation. It is particularly important to properly train maintenance operators. The safety and efficiency of a boiler system is highly dependent upon the duties performed by boiler personnel.

Solar Thermal

Commissioning is important for solar thermal systems because the general contractor may not be familiar with them. Solar systems must be considered whenever rooftop decisions are made. The efficiency of the system is wholly dependent upon collector orientation and minimizing shading. It is important to have a solar expert on hand whenever the system is being considered, even for such things as storing collectors before installation. (Some collectors can be damaged if stored in the sun without fluid passing through them.)

References/Additional Information

Boiler

American Society of Mechanical Engineers. *Boiler and Pressure Vessel Codes.* New York: ASME. 1998.

New Buildings Institute, Gas Boilers, November 1998. www.newbuildings.org

Solar Thermal

Albion Elementary School, Near Mendocino, CA. Hot water supplied by 22 panel solar thermal system.

American Society of Heating, Refrigerating and Air-Conditioning Engineers. *ASHRAE Handbook: HVAC Applications*, 2003.

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Beckman, J.A. and Beckman, W.A., *Solar Engineering of Thermal Processes.* Wiley-Interscience: New York. 1991.

Solar Engineering Laboratory. University of Wisconsin-Madison, 1500 Engineering Drive, Madison, WI 53706. Phone: (608) 263-1589. Fax: (608) 262-8464. Email: trnsys@sel.me.wisc.edu. Web site: sel.me.wisc.edu/trnsys.

U.S. Department of Energy. Energy Efficiency and Renewable Energy Network. www.eren.doe.gov.

U.S. Department of Energy. Federal Energy Management Program. www.eren.doe.gov/femp/.

GUIDELINE TC20: RADIANT SLAB SYSTEM

Recommendation

Install radiant slab-on-grade systems in rooms with heating demand. When conditions permit, use solar thermal and/or recovered thermal energy for the hot water supply.

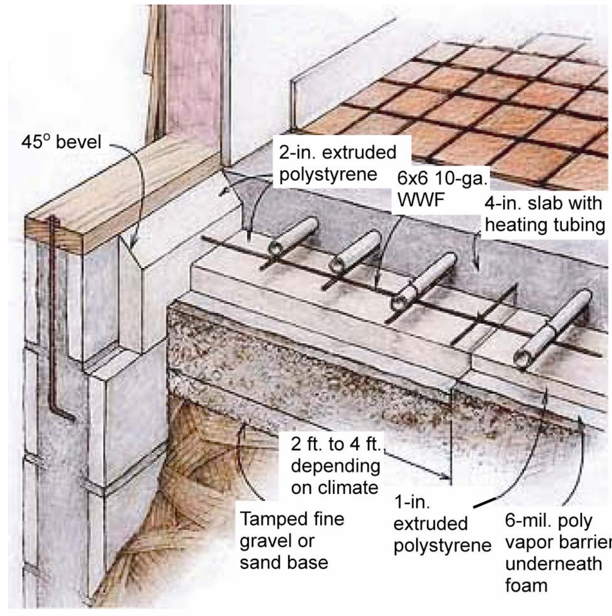


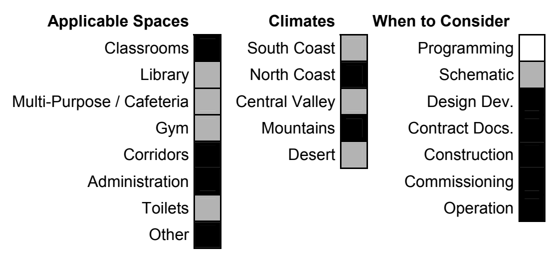
Figure 161—Radiant Slab

Description

A radiant slab heating system consists of the following:

- Hydronic distribution.
- Hot water source (boiler, solar, geothermal heat pump, etc.).
- Control system.

Like all radiant heating systems, radiant slab systems provide thermal comfort to building occupants predominantly through radiation heat transfer. In other words, the system heats or cools room objects and occupants, rather than the surrounding air. Two basic configurations exist for hydronic radiant slab heating and/or cooling. The first option involves the placement of pipes in the foundation slab itself, referred to as slab-on-grade. The second, called thin-slab, consists of piping placed in a thinner slab layer that is situated on top of the foundation slab or on suspended floors. Each consists of a loop of tubing (normally cross-linking polyethylene, PEX) that is imbedded in concrete or a similar material, such as gyp-crete. Hot water is passed through the tubing, which heats the slab, and in turn, the room.



Applicability

The use of radiant slabs for heating is applicable in all regions with a heating demand. However, due to the relatively slow response time of a radiant slab system, it is less useful in mild climates where heating is needed only for morning warmup.

Due to condensation concerns, the use of radiant slabs for cooling should be limited to areas with a low latent cooling load (i.e., low humidity).

Applicable Codes

There are no requirements specific to radiant slab systems in nonresidential sections of Title 24. (Residential code requires R-10 edge insulation.)

A supplemental ventilation system (mechanical or natural) must be used to meet indoor air quality standards.

Title 24 Section 123 details pipe insulation requirements.

Integrated Design Implications

In most cases, a mechanical ventilation system will be required in addition to the radiant heating system in order to meet air quality requirements. See the Overview section of this chapter for a discussion of ventilation for heating-only systems.

Choice of floor coverings affects system performance. For example, carpet reduces the heat rate. Therefore, non-insulating floor coverings are preferred, and an exposed concrete slab is typically best for heating effectiveness.

Choosing any hydronic heating system affects boiler decisions (heat pump, solar, etc.).

All radiant hydronic systems provide an alternative to large-scale air handling systems. This impacts many aspects of the building design including the required plenum sizing, boiler/chiller sizing, ducting, etc.

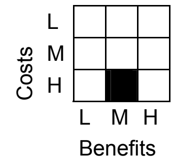
The slab system is a low temperature application and is complemented well by alternative water heating methods including geothermal heat pumps and solar thermal systems. Typical hydronic heating systems such as baseboard radiators use water temperatures of 140°F–200°F, whereas radiant floor heating uses temperatures 90°F–120°F.

Consider framing strength when installing suspended floor thin slab systems. It is much more cost effective to consider this during design rather than reinforcing the framing during construction.

This system can be integrated into a facility-wide hydronic heating and cooling system including baseboards and ceiling panels.

Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

Cost Effectiveness



The installed cost of a radiant floor system is in the range of $4–$6 per square foot.

PEX tubing costs around $0.65/lin ft retail.

Operation and maintenance costs are low. Fuel costs are lower due to increased efficiency compared to air handling systems.

The system is generally most cost effective when part of a facility-wide hydronic heating and cooling system.

Benefits

Advantages

- Hydronic systems can decrease or eliminate the need for mechanical air handling systems. This can provide a duct credit under Title 24.
- Quiet operation.
- Better perceived comfort. Radiant slabs heat occupants from the bottom up and may increase comfort. Allows for lower thermostat settings.
- Lower boiler temperatures of 90°F to 120°F compared to 140°F to 200°F for other heating systems. These temperatures can be accomplished by a geothermal heat pump or solar thermal system.
- Can provide fuel savings when compared to forced-air systems.
- Aesthetically pleasing; no heat registers or visible radiators.

Disadvantages

- Hard to set back temperatures because of slow response time.
- Ground losses can reduce efficiency if insulation is not properly installed.

Design Tools

Use of a CAD-based program to design the layout of the tubing is key to saving time, materials, and money.

Design Details

Install edge insulation around radiant slab.

Older installations used copper or other metal tubing, but these materials can react with the concrete and corrode if not properly treated. Copper has excellent heat transfer characteristics, but its short coil length and incomplete compatibility with concrete has caused a switch to polymer or synthetic rubber tubing. Most modern installations use cross-linked polyethylene (PEX) tubing. PEX tubing is usually layered with an oxygen diffusion barrier to extend the life of system components. Some installers use stainless steel components in lieu of the diffusion barrier. Another option is PEX-aluminum (PEX-Al-PEX) composite tubing, where the aluminum acts as a diffusion barrier. PEX-Al-PEX is also easier to bend than standard PEX.

Any PEX tubing outside of the slab should be protected from sunlight to prevent degradation.

Tubing must be routed through the sub-soil or in a protective sleeve when passing through expansion joints.

Before pouring the concrete, tubing should be laid out and pressurized to 100 psi for 24 hours to ensure no leakage. The tubing should remain pressurized throughout the pouring and curing process.

Water should be delivered to the slab at a temperature that can maintain surface temperatures between 80°F and 85ºF. The required inlet water temperature is dependent upon the thermal resistance of the slab and any floor finishing material.

Tubes should be spaced between 6 in. and 15 in. apart, depending on application.

Use tighter spacing for slabs with wood floor finishing. Even temperatures are critical in order to avoiding varying levels of expansion and contraction in wood floors.

Early planning, including an accurate estimate of the load requirements in the rooms to be heated and cooled, is key for these systems. Due to the nature of the system (in the foundation slab), the earlier the decision is made the better.

High quality control systems should be used that monitor both indoor and outdoor temperatures. The slab is a large thermal mass and care must be taken to avoid under or over shooting the prescribed temperature.

Operation and Maintenance Issues

The slab system consists of a large thermal mass and thus takes a significant amount of time to respond to changes in control settings. The response time of the system can be through proper operation and maintenance practices that serve to avoid severely over and/or under shooting the desired temperature.

Modern radiant slab systems require little maintenance and do not have the leakage concerns of earlier systems.

Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. Proper installation and management of the control system for a radiant slab are of particular importance. Be sure indoor and outdoor sensors are sited correctly and functioning properly.

References/Additional Information

Hydronic Specialties Company. Web site: www.h-s-c.com/.

Radiant Panel Association, www.radiantpanelassociation.org.

Warm Floors. Web site: www.warmfloors.com/.

Wirsbo Co. Web site: www.wirsbo.com/.

US Department of Energy, Radiant Floor Heating and Cooling Systems, October 2003, www.eere.energy.gov/consumerinfo/factsheets/bc2.html.

GUIDELINE TC21: BASEBOARD HEATING SYSTEM

Recommendation

Consider baseboard heating in areas experiencing periods of near-freezing temperatures.

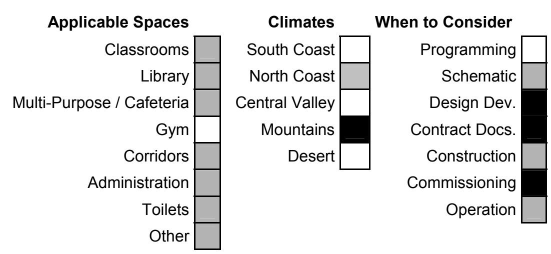
Description

Hydronic radiant baseboard heating is a common application that has been used for over 50 years in the U.S. The most common types are the finned-tube convector and radiant convector both of which heat cold air at the floor of the room and induce an upward convective current. This is extremely effective in reducing downdrafts at cold facades and under windows. These models provide heat through a combination of convection and radiation. Another model is the panel, or flat pipe, radiator. Panel radiators are common in Europe and provide thermal comfort predominately through radiation heat transfer. A baseboard heating system requires the following:

- Baseboard heaters (convector or panel).
- Hydronic distribution system (piping, pumps, valves, etc.).
- Control system (sensors, thermostats, etc.).
- Hot water source (boiler, solar thermal, recovered thermal energy, geothermal heat pump, etc.).

Figure 162— Baseboard Heater

Source: Embassy Industries Incorporated



Applicability

These systems are applicable in all areas experiencing extreme cold, and are especially effective in areas of significant heat loss, such as entryways or under windows.

Applicable Codes

There are no requirements specific to baseboard heaters in Title 24. A supplemental ventilation system (mechanical or natural) must be used to meet indoor air quality standards.

Title 24 Section 123 details pipe insulation requirements.

Integrated Design Implications

Baseboards are a good compliment for displacement ventilation systems in cool climates. They can operate independently to maintain space temperature and to recover from night cool down.

In many climates, it may be possible to avoid the need for a perimeter heating system such as a baseboard radiator if high performance windows are installed.

Space planning must allow for clear wall space at the perimeter.

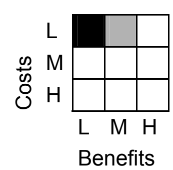
Choosing any hydronic heating system affects boiler decisions (heat pump, solar, etc.).

All radiant hydronic systems provide an alternative to large-scale air handling systems. This impacts many aspects of the building design including the required plenum sizing, boiler/chiller sizing, ducting, etc.

The systems can be integrated into a facility-wide hydronic heating and cooling system including radiant slabs and ceiling panels.

They can be the main heat source, or integrated with another system and used primarily to reduce downdrafts at cold walls or glass, and can provide off-hours heating without running fans.

Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early in order to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.



Cost Effectiveness

Baseboard heaters cost $10/lin ft to $25/lin ft.

Operation and maintenance costs are low. Fuel costs in a well-designed system are lower due to increased efficiency compared to air handling systems.

The system is generally most cost effective when part of a facility-wide hydronic heating and cooling system.

In buildings with air distribution systems, the extra cost of a baseboard heating system may not be justified if the air system can adequately meet heating needs.

Benefits

Hydronic systems can decrease or eliminate the need for mechanical air handling systems. This can provide a duct credit under Title 24.

These well-understood systems have been used for over 50 years.

The systems are low maintenance.

They can be more fuel-efficient than air systems and use less power to move heat through the facility.

Since they are quiet, these systems are good for classrooms.

Cold downdrafts at outside walls and windows are stopped.

Systems should be configured to allow for individual room control.

Design Tools

The *Advanced Installation Guide for Hydronic Heating Systems*, available from the Hydronics Institute, includes a design and sizing procedure for baseboard heating.

Hydronics Design Toolkit software is available from the Radiant Panel Association.

Design Details

Baseboard systems can use zone control or individual room control. Zone control uses one thermostat to regulate several spaces in a single hydronic loop. This system is simple and cheap, but often involves large temperature drops and can be difficult to balance. Individual room control uses thermostatic radiator valves (TRV) to independently control baseboard elements in each space. The TRV allows educators to control the thermal environment of their own classroom.

Flow rate must be controlled to ensure turbulent flow. If the flow rate is in the laminar regime (too low), the heat transfer rate will be dramatically lower and more sensitive to flow rate changes causing difficulties in maintaining intended thermal conditions. Too high a flow rate can cause pipe noise.

Increases in altitude can decrease the performance of finned-tube and radiant convectors.

Painting panel radiators can affect performance. Aluminum and bronze paint can reduce total heat output by up to 10%.

Make allowances for pipe expansion during installation in order to decrease audible disturbances.

Water should be delivered to baseboard radiators between 140ºF and 200ºF.

Care should be taken to ensure baseboard surface temperatures do not reach levels dangerous to young children.

Output ranges from 300 Btu/hr/ft to 800 Btu/hr/ft depending on inlet/outlet temp and flow rate.

Temperature drop across heater should not exceed 20ºF to insure uniform heating.

Be sure not to inhibit convective flow patterns when arranging furniture near baseboard heating elements.

"Quiet Type" baseboard heaters (ie., heaters designed to produce less operating noise) should be specified for occupied areas.

Operation and Maintenance Issues

Operation and maintenance issues for baseboard heating systems are minimal. Heat transfer surfaces should be kept clean and free of dust. If the system is open to the potable water supply some internal cleaning may be necessary to avoid fouling. Pipe fouling can lower efficiency by decreasing the heat transfer rate and increasing the pressure drop.

Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components.

References/Additional Information

"Advanced Installation Guide for Hydronic Heating Systems." Available from Hydronics Institute. Berkeley Heights, NJ 07922.

Radiant Panel Association, www.radiantpanelassociation.org.

GUIDELINE TC22: RADIANT COOLING

Recommendation

Consider the use of radiant cooling systems in applications with modest cooling loads to reduce the transport energy required to remove heat gain from the occupied space as compared to an air system.

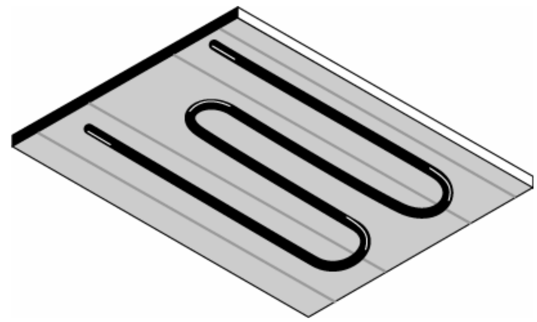
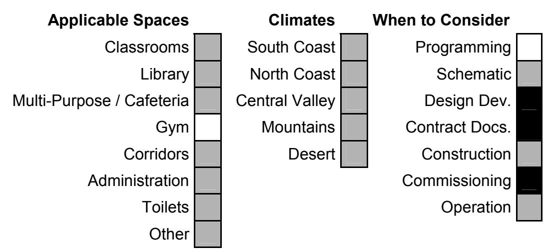


Figure 163—Radiant Cooling



Description

Radiant cooling offers a means of transporting cooling to occupied space with much less energy than conventional air circulation. The conventional practice for removing excess heat gain from an occupied space is to circulate air that has been cooled well below room temperature from a cooling source to the occupied space. The chilled air then absorbs heat from the space as it warms to room temperature. The air is then transported back to the cooling source where it is cooled again to repeat the cycle. With radiant cooling, the heat transport medium is liquid, usually water, and the transfer of heat from the room to the medium is by both radiant and convective means. Because of the higher mass and greater specific heat of the water, it conveys significantly greater heat per unit of energy required for circulation. Radiant cooling systems, furthermore, rely upon large surface areas for heat transfer, rather than large temperature differences between the space and the heat transport medium. As a result, temperature extremes within the space typically are reduced compared with spaces cooled by air circulation, which typically utilize large temperature differences to avoid excessive energy consumption for air circulation. A room radiant cooling source will typically operate at temperatures above 60°F in order to avoid condensation, while air cooling systems may well operate at temperatures as low as 50°F. Despite this decreased temperature difference with the space, transport energy for hydronic energy conveyance will typically be less than a quarter of that with air conveyance systems. The decrease in temperature difference, furthermore, between the space and the transport medium reduces the prevalence of discomfort brought about by imperfect mixing of the cold supply air and the warm room air. .Other characteristics of radiant cooling systems, including reduced noise levels, more gradual temperature transitions, and avoidance of drafts or sensible air currents results in more comfortable, less obtrusive conditioning of the space.

Radiant cooling systems are generally of two types, independent radiant panels, most commonly ceilings and integrated radiant building structure, most often floor slabs. Radiant panel systems are usually constructed of sheet metal plates with metal tubing mechanically attached to the backside of the panel. A popular European variation incorporates a standard lay-in perforated metal mesh acoustical ceiling tile incorporating a polypropylene capillary lattice backed by an acoustic glass fiber matt. Integrated radiant building structures are most commonly constructed using high density polyethylene tubing imbedded in concrete floor topping slabs or plaster walls. In both cases, warm water may be circulated through the tubing for heating or cool water for cooling.

Radiant cooling systems do not provide required ventilation air and do not assist in humidity control. These functions must be met by a separate and independent ventilation and dehumidification system. Sophisticated controls for the dedicated outside air system are necessary to insure that indoor air dewpoint temperature never approaches the radiant panel or slab temperature so that condensation may be avoided.

Applicability

Most applicable in areas with low latent heat load (dry), but can also work in more humid climates with a proper dehumidifying system. Panels can also be used for heating, generally as a substitution for radiators around building perimeter.

Applicable Codes

There are no requirements specific to hydronic ceiling panels in Title 24. A supplemental ventilation system (mechanical or natural) must be used to meet indoor air quality standards. Exposed piping must be insulated in accordance with Section 123 of Title 24. If the system is cooling-only, the insulation requirement will be minimal. Insulation is not required for water temperatures greater than 60°F, and inlet water temperatures for ceiling panel systems are typically between 58°F and 65°F.

Integrated Design Implications

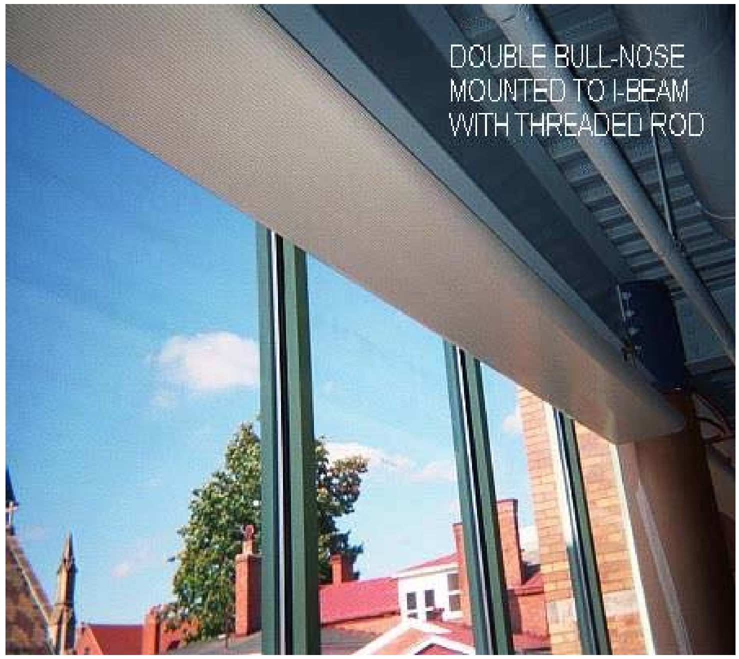


Figure 164—Extruded Aluminum Linear Panel

Source: Sun-El Corporation

Hydronic ceiling panel systems provide no outside air ventilation and thus fresh air must be supplied with either operable windows or an air handling system.Depending on regional weather characteristics and required panel water temperature, an air conditioning system may be required to remove excess latent heat load and avoid condensation.

Possibly integrate the system with building sprinkler systems to lower installation costs. Check with the fire marshal to ensure this does not violate fire code regulations.

Because radiant cooling systems rely upon low intensity conditioning applied over a wide area, the architecture of the building should be designed to moderate concentrated loads. Also, because radiant cooling systems may experience condensation when subject to high dewpoint temperatures, the airtight integrity of the building envelope is critical for controlling infiltration of humid air.

Radiant cooling systems require intensive integration with other building systems because they incorporate architectural components into the mechanical system. In the case of radiant ceiling panels, the ceiling finish becomes the primary delivery mechanism to the space for sensible cooling. Location and configuration of the radiant ceiling panels must be determined by space conditioning requirements even more than architectural considerations. Connection of the panels to the water circulation system and routing of the water piping becomes a major consideration of the ceiling design.

Radiant slab systems require similar integration with the architecture. The thermal conductivity of the floor finish is of utmost importance for radiant floor systems. Rugs and carpets reduce the cooling capacity of the floor to unacceptable levels. Wood flooring assemblies with high heat transfer coefficients, such as bamboo plywood bonded directly to the concrete slab are acceptable, but limit the capacity of the floor. The best floor finishes are stone or marble, masonry or terrazzo, with sheet flooring, such as linoleum a close second. The radiant floor system, by the mass of the floor itself, mitigates the intensity of cooling load variations.

Control location is another issue that must be integrated with other building systems. Radiant cooling floors are served by manifolds that must be located immediately adjacent to the area served. These manifolds, furthermore, must be located above the floor so that they can b e used to purge air bubbles from the system. Location of these manifolds is extremely important for the success of the system.

The vulnerability of radiant cooling systems to condensation requires careful planning around building entrances. Infiltration of humid air through entrances must be mitigated by locally intense supply of dehumidified air adjacent to the entrances. Dilution of the humid incoming air with this dehumidified supply air can avoid condensation on radiant surfaces adjacent to the entrance.

Consider using a heat pump or possibly a cooling tower to attain required water temperatures.

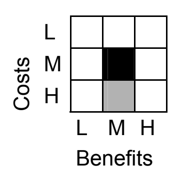
Acoustic properties of the panels need to be considered.

If the system is to be used for both heating and cooling, a choice between a two-pipe and four-pipe system must be made. This decision will affect the hydronic distribution system.

Use heavy-duty ceiling grid and provide space in plenum for hangar support.

System can be integrated into a facility-wide hydronic heating and cooling system, including baseboards and radiant slabs.

Effectiveness of panels relates to architectural and daylighting decisions regarding ceiling height. Performance of panel system degrades with increasing ceiling height.



Cost Effectiveness

Depending upon the application, radiant cooling systems are comparable in cost to conventional cooling systems. A recent cost comparison for a dormitory project showed that the radiant heating and cooling floor system designed for the project was approximately 10% lower in cost than a four-pipe fan coil system. Cost comparisons for other projects, particularly those that involve spaces with intense solar heat gain reveal that the radiant floor system is a less costly alternative for meeting these loads than would be an all-air system of comparable capacity.

Price for installed ceiling panels is roughly $\$18/\text{ft}^2$ of active ceiling area. This does not include costs for control system, hot/cold water supply, or hydronic distribution. Installed cost for modular and linear panels is roughly equal.

Benefits

Radiant cooling systems can provide enhanced comfort by controlling mean radiant temperature in the space. They provide increased energy efficiency by reducing the energy required to transport cooling capacity to the space. In addition, by separating the ventilation and dehumidification functions, from the sensible cooling function, the separate functions can be optimally controlled for both comfort and energy efficiency.

Hydronic systems can decrease or eliminate the need for mechanical air handling systems. This can provide a duct credit under Title 24.

Aluminum panels present the possibility for high recycled-content material use.

The system's low noise makes them good choices for classrooms.

Design Tools

Design tools for radiant cooling systems are very sophisticated because the heat transfer processes are very complex. Radiant floor slab systems are particularly complex, because heat conduction within the floor slab is complicated by floor finishes, incident solar radiation on the floor surface, in addition to the complex geometry of the tubing embedded in the topping slab. In addition, radiant cooling floors are not designed to provide a uniform air temperature distribution within the space; on the contrary, they are usually designed to create an envelope of occupant comfort immediately adjacent to the floor while allowing air high in the space to stratify to temperatures much higher than comfortable limits. The most frequently utilized tools are computational fluid dynamics simulation and three-dimensional finite element heat transfer modeling. Computational fluid dynamics simulation is particularly effective in determining the distribution of air temperatures within a stratified space. Typically this technique would be used to predict the resultant air temperature distributions for a variety of heat gain conditions, both for internal loads and for incident solar heat gain. The three dimensional heat transfer simulation may become necessary when the floor construction becomes complex and when floor finishes have an un usually high thermal resistance. For some projects, transient thermal simulation may be necessary to demonstrate the response off the system to rapidly varying thermal loads.

Some radiant tubing vendors offer design software, primarily aimed at radiant heating, for determining tubing diameter and spacing within the slab, but these suites do not address cooling. Radiant ceiling vendors provide charts of cooling capacity against air and water temperatures, but the actual calculation of cooling loads must be done in the conventional manner.

- Invensys/REDEC provides an AutoCAD-based program for layout design and Microsoft Excel-based spreadsheets for sizing calculations.
- RADCOOL is a software program developed by the Lawrence Berkeley National Laboratory for modeling buildings with radiant cooling systems.

- Design and sizing procedure is documented in Chapter 6 of the 2004 ASHRAE *Handbook—HVAC Systems and Equipment*.

Design Details

If the panels are to be used for heating and cooling, a two- or four-pipe system can be used. A two-pipe system is less expensive and will work for applications with infrequent changeover from one mode of operation to another. If frequent changeovers occur, it is best to use a four-pipe system.

Radiant cooling systems operate at higher cooling temperatures than conventional air cooling systems. Radiant ceiling systems rarely operate at lower than 64°F while radiant floor systems operate no lower than 68°F. These temperature limitations are a function of condensation avoidance, and in the case of the floor, avoidance of cold feet. Heating water temperatures are usually between 120°F and 180°F.

Ceiling radiant panel systems have a limited cooling capacity, on the order of 18 Btu/ft^2 to 20 Btu/ft^2, and must be supplemented with air supply or additional convective systems if higher cooling loads are to be met.

Floor radiant cooling systems have an even smaller cooling capacity than radiant ceiling panels, except when used for direct solar heat gain removal where capacity can be as high as 30 Btu/ft^2.

When floor radiant systems are utilized for direct solar heat gain removal, the use of a high heat transfer floor finish material is especially important.

For heating systems, panels located above occupants should not exceed a 95°F surface temperature for comfort reasons. Higher temperatures may be used for panels that do not extend more than 3 ft into the room. These high temperature panels can be used in lieu of baseboard radiators to heat glass surfaces and exterior walls to decrease downdrafts.

Water temperature should be kept at least 1°F higher than the dewpoint temperature at all times.

Temperature rise for cooling systems should be less than 5°F and temperature drop for heating systems less than 20°F.

Be sure the water flow rate is in the proper range. Rates too high can cause noise and those too low can result in a significant decrease in heat transfer rate due to laminar flow.

Panels can be perforated and installed with a special inlay material to improve acoustical properties.

In order to avoid condensation, a control system must be used. The system can either use flow control or temperature control. A flow control system uses humidity sensors, temperature sensors, and control valves. It is an on-off system; as soon as the water temperature reaches the dew point temperature, the control valve closes. This system is cheap and simple, but can make the system useless for extended periods. A temperature control system uses similar sensors and a two- or three-way valve to adjust water temperature and avoid condensation. This system is more complex, but it allows for system operation when humid conditions exist.

Precisely coordinate the location of the radiant cooling floor tubing with interior partitions to avoid puncturing the tubing when anchors for stud wall floor runners are driven into the slab.

Operation and Maintenance Issues

Normal hydronic operation and maintenance issues include checking pumps, valves, pipe leaks, chemical water treatment, and water quality/pipe fouling (important for sustaining maximum heat transfer and minimum pressure drop in open systems). Significant maintenance does not appear to be an issue. The ceiling panels have a life expectancy in excess of 30 years.

In many climates, the radiant ceiling system is used in concert with a dedicated outside air system to provide sensible and latent cooling and ventilation. Improper operation of the outside air system to allow excessive humidity into the space almost certainly will result in condensation and water damage to the building along with indoor air quality problems associated with mold and mildew growth. Because a portion of the building finish is part of the conditioning system, that component must be maintained in a way that preserves it function. For example, throw rugs would adversely affect the functioning of a radiant floor system.

Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. The ceiling panel array(s) should be documented with an infrared camera during testing, adjusting, and balancing work to guarantee even cooling and/or heating. Another important consideration in the commissioning process is verification of the control sequences for the system. Because of the thermal mass of the radiant system, both in the mass of the circulating water and, with radiant floors, the mass of the concrete floor, the system should not change over rapidly from heating to cooling.

References/Additional Information

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Feustel, Helmut. Radiant Cooling, A Literature Survey., Johnston City, TN: The Hydronics Foundation, Inc. 2002. www.hydronics.org/articles/Radiantcooling/radiant_cooling1.htm.

Mumma, S.A. and Conroy, C.L. Ceiling Radiant Cooling Panels as a Viable Sensible Parallel Cooling Technology Integrated with Dedicated Outside Air Systems. ASHRAE Transactions. Vol. 107. Atlanta. June 2001.REDEC. Web site: www.redec.com/.

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Watson, R.D. and Chapman, K.S. Radiant Heating and Cooling Handbook. NY: McGraw-Hill. 2002.

WIRSBO Radiant Design Guide

GUIDELINE TC23: GAS-FIRED RADIANT HEATING SYSTEM

Recommendation

Consider gas-fired radiant heating for spaces with high ceilings and potentially high infiltration, or in large spaces with spot heating needs such as workshops or gymnasiums.

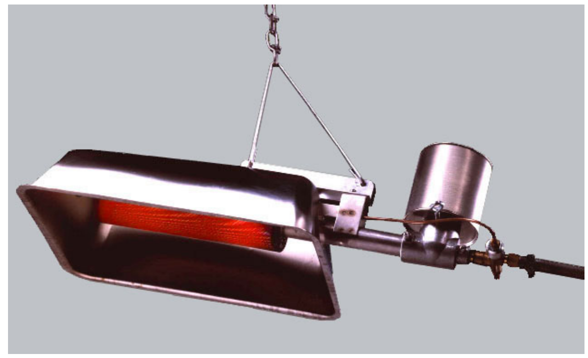


Figure 165— Radiant Heater

Courtesy: Gasolec

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	□
Library	□	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	□
Gym	■	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	□
Administration	□			Commissioning	□
Toilets	□			Operation	□
Other	■				

Description

This class of radiant heaters burns gas to heat a steel tube or a ceramic surface. The heated surface emits infrared radiation that is absorbed by occupants, furniture, floor, and elements of the building in view of the heating element. Those objects then heat the air in the space through convection. An advantage to this type of radiant heating in high traffic areas is that the objects in the space remain warm even if cool air is introduced.

Variations and Options

Several configurations of gas-fired radiant heaters are available. Some are linear units consisting of a long steel pipe with a reflector above. Another option is a smaller unit with heated ceramic surface design to cover a rectangular area of floor.

Applicability

Radiant heating is appropriate in spaces with high ceilings because it helps to overcome thermal stratification. Much of the heat is delivered directly to objects and occupants at floor level.

As mentioned earlier, radiant heating is also useful in areas with high traffic where infiltration can be a problem.

Appropriate spaces include gyms, shops, greenhouses, and high-traffic entrances or lobbies.

Radiant heaters can provide spot heating in large open spaces such as workshops or warehouses.

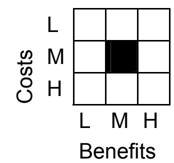
Applicable Codes

Codes may require an outdoor source for combustion air and/or venting for the products of combustion.

Integrated Design Implications

Consider the need for combustion air and flue gas venting when choosing the location for a gas-fired radiant heater. Also allow for adequate clearance around the unit, as recommended by the manufacturer.

Cost Effectiveness



Gas-fired radiant heaters are usually a cost-effective choice for spot heating in large open spaces. They may also be cost effective for general heating in spaces like gymnasiums when energy savings are considered.

Benefits

Advantages

Equal comfort with lower indoor air temperatures results in lower heating energy consumption.

Fan energy and/or pumping energy required for heating distribution is eliminated.

Disadvantages

Occupants may experience some discomfort due to warm heads and cool feet.

Design Tools

None.

Design Details

Provide protection for units installed in gymnasiums to prevent contact with sports equipment.

Follow the manufacturers guidelines for clearance above and to sides.

Provide an outdoor combustion air source and vent flue gas to outdoors.

“Quiet Type” unit should be specified.

Operation and Maintenance Issues

Gas-fired radiant heaters are relatively low maintenance systems.

Commissioning

Ensure that controls are installed as intended.

References/Additional Information

None.

GUIDELINE TC24: CHILLED WATER PLANTS

Recommendation

Use high-efficiency, water-cooled, variable speed chillers. Use chiller heat recovery if there is a reliable hot water demand. Install oversized induced draft cooling towers with axial propeller fans. Use low cooling tower approach temperatures and variable speed fan control.

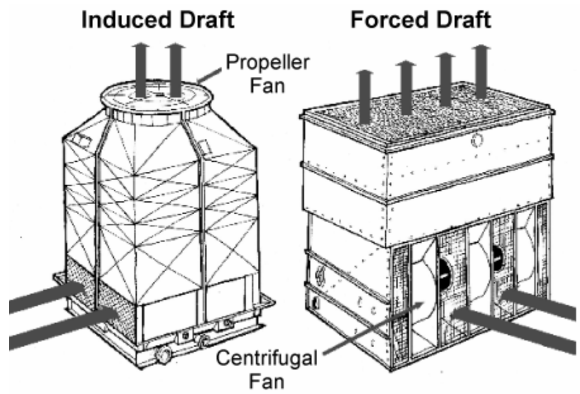
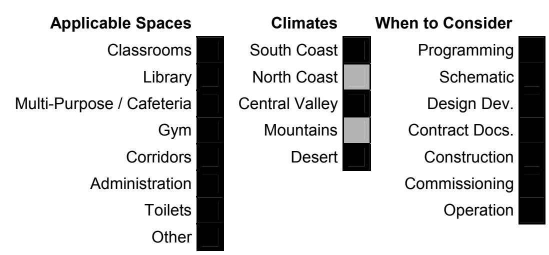


Figure 166—Cooling Towers



Description

Chillers

There are two basic chiller classifications, air-cooled and water-cooled. Water-cooled cost more (when considering the cooling tower and condenser water loop), but are more energy efficient. Several chiller types exist within the classifications, including electric (centrifugal, reciprocating, screw or scroll), gas-fired (engine-driven or double effect absorption), and steam absorption.

Towers

The purpose of a cooling tower is to provide heat rejection for a water-cooled chiller by exposing as much water surface area to air as possible to promote the evaporation of the water and thus cooling. Cooling towers come in a variety of shapes and configurations. A “direct” tower, also known as an “open” tower, is one in which the fluid being cooled is in direct contact with the air. An “indirect” tower, or “closed-circuit fluid cooler,” is one in which the fluid being cooled is contained within a heat exchanger or coil, and the evaporating water cascades over the outside of the tubes. The tower airflow can be driven by a fan (mechanical draft) or can be induced by a high-pressure water spray. The mechanical draft units can blow the air through the tower (forced draft) or can pull the air through the tower (induced draft). The water invariably flows vertically from the top down, but the air can be moved horizontally through the water (cross flow) or can be drawn vertically upward against the flow (counter flow).

Applicability

Chilled water plants are applicable for larger schools in areas needing significant amounts of chilled water and space cooling.

Applicable Codes

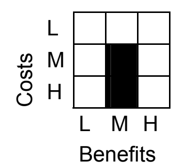
Title 24 sets efficiency requirements for chillers, cooling towers, and distribution systems for chilled water and condenser water. In addition, Title 24 requires that central plants with cooling capacity of 300 tons or greater may have no more than 100 tons of air-cooled chiller capacity.

Integrated Design Implications

Chiller and tower decisions are related to many aspects of building design and construction including space considerations, cooling/heating choices, and the hydronic distribution system layout. Tower performance is related to facility layout and orientation. The tower should be sited properly to minimize recirculation of saturated air and avoid noise problems.

The placement of chilled water plant components affects requirements of the hydronic distribution system. Try to make these decisions early to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

Cost Effectiveness



Installed estimates for chillers fall between $580/ton and $780/ton, depending on efficiency and drive choice. Installed tower cost estimates are between $130/ton and $180/ton.

As a general rule, air-cooled chillers are more cost effective if the chiller plant is smaller than 150 tons. Water-cooled are more cost effective above 150 tons. However, many factors affect operating costs for a chilled water plant, and the best choice of type, size, efficiency, and controls is difficult to generalize. Most California facilities experience varying cooling loads over the course of the year, and a variable-speed chiller will be cost effective. First cost premium when improving from an efficiency of 0.7 kW/ton to 0.6 kW/ton is $70/ton. This number increases to $136/ton for variable speed chillers. Simple payback periods vary from three to 11 years.

Increasing size and efficiency of cooling tower is generally cost effective with a four to seven year payback. Annual energy savings are between $\$0.01/\text{ft}^2$ and $\$0.04/\text{ft}^2$. Incremental costs are between $\$0.08/\text{ft}^2$ and $\$0.12/\text{ft}^2$, depending upon climate.

Design Tools

CoolTools: Chilled Water Plant Design Guide available from Pacific Gas and Electric.

Gas Cooling Guide available from InterEnergy Software.

The use of chillers with various efficiencies can be modeled using DOE-2 and VisualDOE.

Design Details

Vibration Isolation

Refer to 2003 ASHRAE Handbook Chapter 43 for recommended chiller and cooling tower vibration isolation.

Chiller Type

The best choice among electric, gas, and steam chillers (or some combination thereof) is largely site specific. If a reliable source of free or very low cost steam is available on-site, then steam absorption may make the most sense.

Gas versus electric or hybrid gas/electric will depend on utility rates. Gas-fired chillers can cost two times more than electrically-driven machines and will require a larger cooling tower and condenser water pump. Gas engine chillers are more energy efficient than absorption machines and have high temperature heat readily available for recovery but are more maintenance intensive than absorption machines.

Chiller type has a significant impact on the level and quality of noise produced. Historically, rotary screw compressors produce very high levels of noise, which typically contains an annoying tonal component. Centrifugal compressors are usually quieter than screw chillers and do not contain a tonal component. Scroll compressors are the most quiet of the three, but are usually air-cooled. The predominant source of noise from air-cooled scroll compressor chillers is the generated by the cooling fans. Variable-speed drives (VSD) can reduce the amount of noise being generated by slowing the flow of refrigerant through the compressor.

The most cost effective type of electric chiller is primarily a function of chiller size. General decision guidelines are listed in Table 48.

Table 48 -- Recommended Electric Chiller Types

Chiller Size	Recommendation
<= 100 tons	scroll or screw
100–300 tons	screw or centrifugal
> 300 tons	1st choice: centrifugal

Number of Chillers

As a general rule:

- If the peak chilled water load is less than 300 tons, then a single chiller is usually most economical.

- If the load is greater than 300 tons, use two chillers. This offers better low load capability and operating efficiency, and offers some redundancy should one of the chillers fail.

Having one smaller or pony chiller (as opposed to two or more equally-sized chillers) can improve part-load efficiency of the plant. However, some operators prefer if all the machines are the same size due to familiarity and parts interchangeability.

Unloading Mechanism

Centrifugal chillers typically use inlet vanes to control the chiller output at part-load. The use of hot gas bypass as a means to control the chiller at very low loads should be avoided, if at all feasible, as this strategy results in significant energy penalties. Using a VSD instead of inlet vanes allows the compressor to run at lower speed at part-load conditions, thereby reducing the chiller kW/ton more than inlet vanes. The energy savings from a VSD chiller can be quite significant if the chiller operates many hours at low load. In order to capture the potential savings of VSD chillers, it is important that the condenser water temperature is reset when ambient conditions are below design conditions. This can be accomplished either by using a fixed setpoint (e.g., 70°F) that is below the design condenser water temperature (e.g., 85°F) or using wet bulb reset control, which produces the coldest condenser water the tower is capable of producing at a particular time. A gas engine chiller is also capable of unloading by decreasing engine speed.

Chiller Efficiency

The ratings in Table 49 should be considered as upper bounds. Lower efficiencies are available and are often the lowest lifecycle cost option.

Table 49—Title 24-2005 Minimum and Recommended Chiller Rated Efficiency

Condenser Type	Compressor Type	Min Tons	Max Tons	T24-2005 Min./ Recommended kW/Ton	T24-2005 Min./ Recommended IPLV	T24-2005 Min./ Recommended C.O.P.
Water-Cooled	Scroll	1	80	0.79/0.79	0.68/0.68	
Water-Cooled	Screw	1	150	0.79/0.76	0.68/0.68	
Water-Cooled	Screw	151	300	0.72/0.72	0.63/0.63	
Water-Cooled	Screw	301	& up	0.64/0.64	0.57/0.57	
Water-Cooled	Reciprocating	1	80	0.84/0.84	0.70/0.70	
Water-Cooled	Reciprocating	81	& up	0.84/0.82	0.70/0.70	
Water-Cooled	Gas Engine	501	2000			1.20/1.80
Water-Cooled	Absorption (SE)	150	1000			0.70/0.70
Water-Cooled	Absorption (DE)	150	1000			1.00/1.00
Water-Cooled	Centrifugal	1	150	0.70/0.62	0.67/0.62	
Water-Cooled	Centrifugal	151	300	0.63/0.60	0.60/0.60	
Water-Cooled	Centrifugal	301	& up	0.58/0.56	0.55/0.55	
Air-Cooled	Scroll	1	80	1.26/1.25	1.15/1.10	
Air-Cooled	Absorption (SE)	1	& up			0.60/0.60
Air-Cooled	Screw	1	& up	1.26/1.21	1.15/1.00	
Air-Cooled	Reciprocating	1	& up	1.26/1.15	1.15/1.15	
Air-Cooled	Centrifugal	1	& up	1.26/1.26	1.15/1.15	

Heat Recovery Chiller

Heat rejected from the condenser of a chiller can be recovered and used to drive a desiccant system or for preheating domestic hot water by routing the condenser water through a double-wall heat exchanger that is either an integral part of a storage tank or is remotely located with a circulation pump to the storage tank. Heat recovery chillers are typically used only for a portion of the total cooling load, because of the need to match hot water load and cooling load and because of the lower efficiency of heat recovery chillers. Heat recovery chillers are not typically piped in parallel with other chillers but rather are either piped for “preferential” loading or in series with other chillers, allowing the cooling load on the heat recovery chiller to be matched to the hot water load. Waste heat can also be recovered from the engine jacket and exhaust of gas engine driven chillers.

The energy savings from chiller heat recovery are reduced when using economizers (air-side or water-side) because chillers are often not needed when the weather is mild or cold. Chiller heat recovery cannot eliminate the need for a DHW boiler but it can eliminate the need for some of the cooling towers at a site.

Chiller Staging

For a plant composed of single-speed chillers, control systems should be designed to operate no more chillers than required to meet the load. A plant composed of variable-speed chillers should attempt to keep as many chillers running as possible, provided they are all operating at above approximately 20% to 35% load. For example, for the typical variable-speed chiller plant, it is more efficient to run three chillers at 30% load than to run one chiller at 90% load. The use of hot gas bypass at very low loads should be avoided, if at all feasible, as this strategy results in significant energy penalties.

Tower Fan Speed Control

Two-speed (1,800 rpm/900 rpm) or variable-speed fan control is always more cost effective than single-speed fan control. For plants with multiple towers or multiple cells, provide two- or variable-speed control on all cells, not just the “lead” cells. The towers are most efficient when all cells are running at low speed rather than some at full speed and some off. For instance, two cells operating at half speed will use about 15% of full power compared to 50% of full power when one cell is on and the other is off.

Tower Oversizing

The tower and fill can be oversized to reduce pressure drop, thereby allowing the fan to be slowed down, which reduces motor power and noise. Tower heat transfer area should be oversized to improve efficiency to at least 60 gpm/hp to 80 gpm/hp at CTI conditions.[54] The energy savings should outweigh the added cost to oversize the tower and to accommodate the larger tower footprint and weight.

A larger tower can also produce cooler water, allowing chillers to run more efficiently. Selecting towers for a 4° or 5° approach will generally be cost effective relative to a more typical 10°. Cooling towers are available with as low as 3° approach temperature, but the tower cost increases as the degree of approach drops. A life-cycle cost analysis should be performed to compare the extra cost to the energy impact on the tower, chiller, and pumps.

Tower Performance

The performance of a cooling tower is a function of the ambient wet bulb temperature, entering water temperature, airflow and water flow. The dry bulb temperature has an insignificant effect on the performance of a cooling tower. “Nominal” cooling tower tons are the capacity based on a 3 gpm flow, 95°F entering water temperature, 85°F leaving water temperature, and 78°F entering wet bulb temperature. For these conditions, the range is 10°F (95°F–85°F) and the approach is 7°F (85°F–78°F).

[54] Tower efficiency (as defined in ANSI/ASHRAE/IESNA Standard 90.1-2001) is the ratio of the maximum tower flow rate (gpm) to the fan motor horsepower (hp) at standard CTI rating conditions (95°F to 85°F at 78°F wet bulb). Standard efficiency is about 35 gpm/hp to 40 gpm/hp efficiency.

Table 50—Cooling Tower Design Considerations

	Energy	Noise	Height	Chiller Fouling	Cost	Application
Packaged Induced Draft, Axial Fan	Lower	Higher	Higher	Higher	Medium	Best for most plants.
Field-Erected Induced Draft, Axial Fan	Lowest	Higher	Higher	Higher	Higher	Very large plants.
Forced Draft, Centrifugal Fan	Higher	Lower	Lower	Higher	Lower	Best if noise or height constrained or large external static pressure (e.g., tower located indoors).
Closed Circuit Evaporative Cooler, Axial Fan	Higher	Higher	Higher	Lower	Highest	Appropriate for heat pumps, not most chillers.
Closed Circuit Evaporative Cooler, Centrifugal Fan	Highest	Lower	Lower	Lower	Highest	Appropriate for heat pumps, not most chillers.
Spray Towers	Lowest	Lowest	Higher	Higher	Lowest	Seldom used due to high maintenance and variable condenser water flow.

Operation and Maintenance Issues

Chillers require periodic maintenance. See Volume IV Maintenance & Operations for details.

Periodic blow downs and scrubbing of cooling towers must be performed to avoid scaling of internal systems and biological growth. The condition of cooling tower fill is critical to performance. It should be inspected every year and the chemistry of the tower water should be maintained to minimize fouling.

Commissioning

In order for chillers to operate efficiently, they must be properly commissioned. Part of this process is making sure that sensors (such as chilled water flow, chilled water supply and return temperatures, and chiller electric demand), are specified and properly calibrated. Sensor data should be permanently stored by the energy management system and easily visualized graphically. Not only is this data valuable for insuring that the design intent is met in the construction process, but also for maintaining energy efficiency over the life of the chiller. For example, by monitoring the approach temperatures in the condenser and evaporator heat exchangers (as the heat exchanger surface becomes fouled, the approach temperature increases) maintenance can be scheduled when needed, as opposed to too often, which wastes maintenance resources, or too infrequently, which wastes energy. A detailed account of commissioning issues specific to chilled water plants can be found in the *CoolTools: Chilled Water Plant Design Guide* (see the References section below).

References/Additional Information

CoolTools: Chilled Water Plant Design Guide. Available from Pacific Gas and Electric, www.hvacexchange.com.

Energy Design Resources, *Design Brief Chiller Plant Efficiency.* www.energydesignresources.com.

STD-201 (September 2004) Standard for the Certification of Water Cooling Tower Performance. Available from Cooling Tower Institute, www.cti.org.

GUIDELINE TC25: EVAPORATIVE COOLING SYSTEM

Recommendation

Consider evaporative cooling for spaces with high outside air ventilation requirements and dry outdoor conditions.

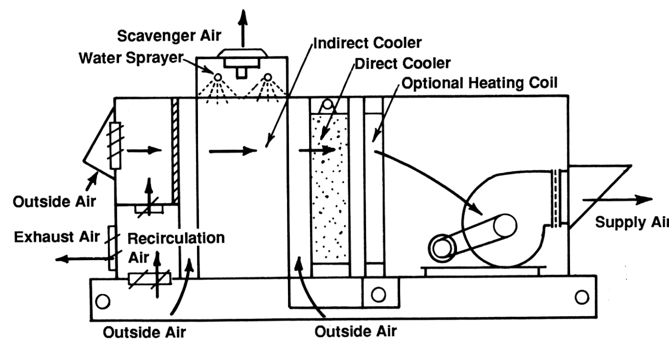


Figure 167—Evaporative Cooling System

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	■
Library	□	North Coast	□	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	□
Gym	■	Mountains	■	Contract Docs.	□
Corridors	■	Desert	■	Construction	□
Administration	■			Commissioning	□
Toilets	□			Operation	□
Other	□				

Description

Evaporative cooling is an alternative way to provide air conditioning. Lower energy costs result because no compressor is needed, only a fan and pump.

Evaporative cooling can be "direct" or "indirect." In a direct evaporative cooling system the water is exposed to the supply air stream. Usually the water flows over a special medium designed to maximize the surface area of water in contact with air, and the air is cooled by the evaporation. The effectiveness can reach 80% to 90%, meaning that the drybulb temperature drops 80%–90% of the difference between the drybulb and wetbulb temperature of the entering air. For example, if entering air temperature is 80°F drybulb and 50°F wetbulb, then the leaving air is cooled to 53°F–56°F drybulb.

Indirect evaporative cooling is not as effective as direct evaporative cooling, but adds no moisture to the supply air. In some systems, the air passes through a heat exchanger that is wetted on the outside, where cooling takes place in a secondary air stream. In other systems, air passes through a cooling coil supplied with water from a remote cooling tower. Indirect evaporative cooling can be approximately 60% effective in reducing the dry bulb temperature of the entering air to its wet bulb temperature. While direct cooling provides 53°F to 56°F air in the example above, indirect cooling could provide 62°F air.

Combining indirect and direct evaporative cooling (as shown in the figure above) further reduces the supply air temperature. When air passes through the indirect cooler first, then drybulb and wetbulb temperature is reduced through sensible cooling. Due to the lower wetbulb temperature, the direct cooler can achieve even cooler temperature for the supply air.

Variations and Options

Packaged evaporative coolers are available in a wide range of sizes, approximately 3,000 cfm to 20,000 cfm. They are typically roof mounted for easy access to outside air for the indirect cooling stage.

Packaged air handlers are available that incorporate both indirect and direct evaporative cooling. The evaporative cooling system should have an economizer that uses 100% outside airflow during cooling mode, and minimum outside airflow during heating mode. This allows the use of return air during the heating season to keep heating costs equivalent to a standard system. These package units can have hot water coils or duct furnaces installed to provide heating.

If evaporative cooling alone does not satisfy cooling loads, then it can be combined with packaged rooftop cooling by adding direct and/or indirect coolers onto the outside air intake of the packaged unit or it can be integrated directly into the mixed air stream (outside + return) of the packaged unit. Evaporative cooling reduces the load on the direct expansion (DX) cooling coil, allowing the compressor size to be reduced, and peak power to be reduced.

Alternatively, a combination of cooling tower and heat exchanger could be used with cooling coils and standard air handlers.

Some indirect evaporative cooling systems are designed to use exhaust air rather than outside air as the secondary air stream, providing heat recovery.

Other systems combine evaporative cooling with a desiccant wheel and/or enthalpy wheel as a method of precooling the outdoor air and increasing cooling capacity.

Applicability

Evaporative cooling is most effective in hot, dry climates but it can also be used to completely replace compressor cooling in cold and coastal areas. For areas with higher design wet bulb temperatures, such as Sacramento, CA (100°F/70°F), evaporative cooling can produce most of the space cooling needs. However, if evaporative cooling is used exclusively, space temperatures may rise above 80°F during design conditions.

Evaporative cooling is especially appropriate for spaces with high outside air ventilation requirements such as showers, locker rooms, kitchens, or shops. Compressor cooling is often too expensive to operate for these applications.

Combination evaporative and DX cooling only makes economic sense in certain climates and for packaged units over a certain size. Direct and/or indirect evaporative cooling should be considered for packaged units over:

- 20 tons in South Coast (Climate Zones 6 through 10).
- 15 tons in Central Valley (Climate Zones 11 through 13).
- 10 tons in Desert (Climate Zones 14, 15).

Applicable Codes

Evaporative cooling systems face no efficiency requirement except for fan system efficiency and heating efficiency.

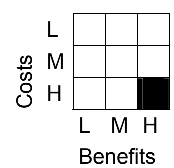
Integrated Design Implications

Evaporative cooling is a good match for displacement ventilation systems, which are designed for higher supply air temperature than a typical overhead air distribution system. However, the design may need to accommodate higher airflow than a DX system, and the higher airflow could disrupt stratification. Therefore, careful attention is necessary in locating and sizing supply outlets.

Larger ducts are required compared to a typical compressor cooling system, and duct size may be a consideration in the architectural and structural design.

Direct evaporative cooling may not be appropriate for spaces with materials such as wood floors that might be damaged by high humidity.

Cost Effectiveness



Installed costs are typically somewhat greater than for typical packaged air conditioning equipment.

Evaporative cooling is usually cost effective in warm and dry climates as long as somewhat higher indoor temperatures are acceptable during hot periods.

Benefits

Advantages

- Lower electricity consumption and lower peak electric demand result.
- Systems typically use 100% outside air in cooling mode, providing better air quality.
- Smaller electrical supply.

Disadvantages

- Regular maintenance is more critical than for compressor cooling systems.
- Higher airflow requirements lead to increased fan energy.
- Cooling unit requires water supply.
- On-site water consumption increases.
- Cooling requirements in some climates may not be completely satisfied.

- Direct evaporative cooling increases space humidity.
- First cost is higher.

Design Details

An evaporative cooling system requires higher airflow due to higher supply air temperature. Therefore, special attention to duct design and sizing is required to avoid high fan energy costs. The appropriate airflow depends on design conditions for the school's location.

A variable-speed or two-speed fan is a good idea to allow lower airflow in heating mode.

In warm climates, try to use exhaust air as the secondary air stream for indirect evaporative cooling systems.

Operation and Maintenance Issues

Evaporative coolers demand more maintenance than a typical compressor-based system, so they should be specified only for facilities with qualified maintenance staff or with a qualified outside service company.

To minimize maintenance requirements, specify adequate bleed-off rates to prevent mineral buildup (without causing excessive water consumption). Also specify controls that periodically flush the evaporative medium with water to remove dirt and scale. Finally, specify materials to minimize potential for corrosion.

Commissioning

Check for correct airflow.

Check for correct water flow rate over the evaporative media.

Check the bleed-off rate of water from the evaporative system to ensure that it is adequate to prevent mineral buildup but not too large to cause excessive water consumption.

Verify all modes of operation.

References/Additional Information

None.

Other Equipment and Systems

OVERVIEW

This chapter discusses systems that significantly improve the resource efficiency and performance of existing services, mechanisms, and equipment. These systems also improve energy management by reducing energy use and peak loads, as well as using abundantly available solar radiation. In particular, this chapter provides technical guidelines for the use of renewable energy technologies, power transmission, water conservation and heating technologies and techniques, information on high performance relocatable classrooms, kitchens, and other equipment and systems that make schools high performance.

- Guideline OS1: Photovoltaics
- Guideline OS2: Wind Power
- Guideline OS3: Solar Swimming Pools
- Guideline OS4: Timers for Recirculating Hot Water Systems
- Guideline OS5: Efficient Terminal Devices
- Guideline OS6: Zero-water Consumption Urinals
- Guideline OS7: Kitchen Area Ventilation
- Guideline OS8: Energy Efficient Transformers
- Guideline OS9: Networked Computer Monitor Control
- Guideline OS10: Efficient Vending Machines

The equipment and systems described in this chapter can all be used to emphasize that high performance schools are “buildings that teach.” Some of these systems are highly visible, making them ideal teaching tools. A PV array on a school building, for example, lends itself more readily to teaching opportunities than a remote power station does. Teachers can show students how photovoltaics produce on-site electricity, and can encourage students to think about the energy source that powers the systems that keep them comfortable. Such systems also require a higher level of involvement from the people who benefit from them, as their maintenance and functioning is the direct responsibility of the school staff.

Introducing these systems in schools promotes their acceptance on a broader community level. For instance, some people who are not familiar with zero-water consumption urinals may be concerned about unpleasant odors or unhygienic conditions. But, special liquids used in the traps for these urinals do not allow odors to escape the trap. And the no-touch system actually enhances hygiene and prevents overflow. Getting used to the system is the key to acceptance.

The main characteristics of many of the equipment and systems described here are that they use sustainable practices and require little or no fossil fuel-generated energy to operate. Photovoltaics and pool heaters, for example, use radiant and thermal energy from the sun. Zero-water consumption urinals conserve clean water and reduce the load on water treatment plants.

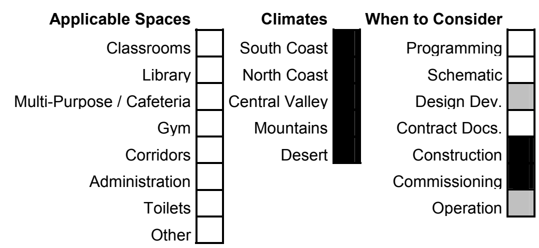
Due to the way energy cost is typically defined, many of these systems tend to have long payback periods. But the price in dollars and cents for 1 kWh of electricity does not include many environmental costs, such as adding greenhouse gases to the atmosphere, using fuels that are not abundantly available or not replenished, or damaging ecosystems or human health. Only an environmentally balanced life-cycle cost assessment will ascertain the real payback period for these systems. Such systems may also have high first costs because they do not benefit from the economies of scale that mass-produced systems do. Using these systems in high performance schools will make valuable contributions toward their gaining greater market share and acceptance.

GUIDELINE OS1: PHOTOVOLTAICS

Recommendation

Install photovoltaic (PV) arrays to convert radiant energy from the sun to electricity. PV is ideal for isolated or stand-alone tasks, and it can serve as an excellent teaching tool.

Photovoltaics are most cost effective in remote locations that are a distance from an electrical grid, but they have zero environmental costs. NREL/PIX07631.



Description

PV converts radiant energy from the sun into direct current electricity, without the environmental costs (greenhouse or acid gas emissions) associated with other methods of electricity generation.

PV produces electricity from an abundant, reliable, and clean source. In fact, the amount of solar energy striking the earth is greater than the worldwide energy demand each year.

The basic component of a PV system is a solar cell. Most solar cells are made of specially treated silicon semiconductor materials. Sunlight striking the cells generates a flow of electrons. This flow is directly proportional to the surface area of the cells and the intensity of the radiation (a cell of area 6.25 in^2 will produce 3.5 amperes in bright sunlight). Each solar cell produces approximately 0.5 volts. Higher voltages are obtained by connecting the solar cells in series. Solar cells are laminated; most have a tempered glass cover and a soft plastic backing sheet. This sealing protects the lodged electrical circuits from the outside elements and makes solar cells durable. Modules may be connected in series for higher voltages and in parallel for higher currents. The typical photovoltaic module uses 36 silicon solar cells, connected in series to provide enough voltage to charge a 12-volt battery. However, most buildings do not require battery storage and can use grid-tied PV systems. A grid-tied system can provide electricity savings as well as provide additional shading or cooling benefit. Most buildings can switch to a net metering rate schedule where utilities give credit for surplus electricity produced by PV systems.

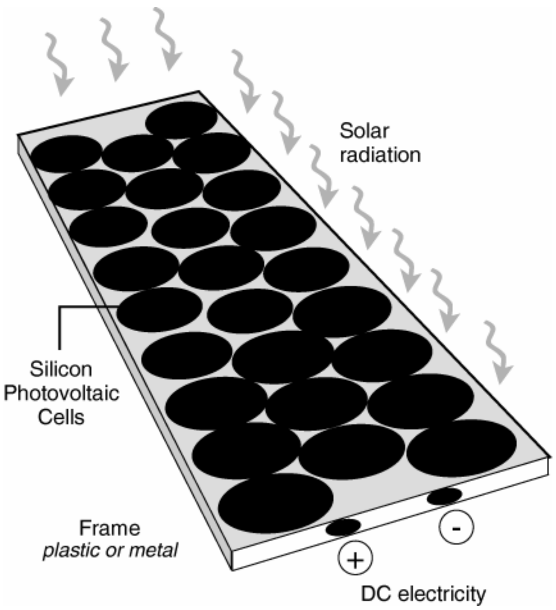


Figure 168—Photovoltaic Module

Individual modules may be further combined into panels, sub arrays, and arrays. PV arrays with storage batteries are sources for uninterrupted power supply. Buildings requiring emergency backup for communications systems in the case of an earthquake or rolling blackout can use this type of stand-alone system with batteries. Batteries store energy collected during the day for nighttime use. A battery charger controller may be included to avoid overcharging the battery. In addition, all systems include wire, connectors, switches, and electrical protective components. If the load requires alternating current (AC), an inverter is used to convert the direct current (DC) power to AC power. The energy collected during the day is stored for use during the night.

Applicable Codes

Each state has different laws regarding the connection of renewable electric systems to the grid. Twenty-three states have adopted net metering, which allows "extra" electricity produced at a site to be absorbed back by the utility at market or a set price to the turbine owner. More information about net metering can be found at DOE's State Energy Alternatives Web site:
www.eere.energy.gov/states/alternatives/net_metering.cfm.

Many states have enacted laws to protect and maintain a property owner's proper access to wind and/or sunlight. Some states allow for the creation of easements. A wind or solar easement is a privilege to have access to wind or sunlight even though another person's property may be affected; i.e., a property owner cannot restrict any other property owner's access to wind or sunlight. Other states may have laws that prohibit neighborhood covenants from explicitly restricting the installation or use of solar equipment. While solar and wind access is not considered an automatic right, the laws are meant to prohibit unreasonable infringement on access. More information on wind easements can be found on the State Energy Alternatives Web site:
www.eere.energy.gov/states/alternatives/wind.cfm.

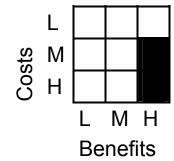
Integrated Design Implications

Before selecting a PV system for a building or facility, design the building to be as energy efficient as possible. Reducing energy consumption will reduce the size and cost of the PV array needed.

Building aesthetics. In the early design state, consider mounting PV on rooftops for best results.

System integration. Since PV is most likely to be used in hybrid systems, the mechanical engineer needs to perform detailed planning in the early design stages.

Costs



According to DOE's State Energy Alternatives Web Site www.eere.energy.gov/states/alternatives/walls_roofs.cfm, the same values that drive the PV system market also set the wide range of PV costs. Capital costs range $5–$12 per watt, but because there are no operation or fuel costs, the 20-year life-cycle cost ranges from 20–50 cents per kilowatt-hour. Because battery systems are so expensive and have shorter life spans, grid-tied PV is much more cost efficient in areas that have access to the power grid.

Benefits

Though PV is typically three to six times more expensive than utility-supplied electricity, the "real" or environmental cost of utility-generated electricity makes clean power, such as PV, more affordable in the long term. In addition, local rebates can substantially reduce the installed cost of PV.

PV is environmentally benign during use and does not produce any greenhouse gases or acid gas emissions associated with other methods of generating electricity. It has zero environmental costs.

PV produces electricity from an abundant and reliable "fuel"—sunlight. Coupled with storage batteries, PV is capable of supplying uninterrupted power.

PV is available in modular building blocks; more arrays may be added as the demand for power increases.

Wear and tear is minimized for PV, since it has no moving parts and produces power silently.

Although PV may be combined with other power sources in hybrid systems to increase system reliability, PV itself requires no connection to an existing power source or fuel supply.

For grid-tied PV systems, net metering allows buildings to receive utility credits for the surplus electricity generated by PV systems.

PV can withstand severe weather conditions including snow and ice.

PV can be combined with other types of electric generators (wind, hydropower, and diesel, for example) to charge batteries and provide power on demand.

By putting power back into the electrical grid and shaving peak loads, PV can have far-reaching implications.

Design Tools

Most PV dealers will work with designers to engineer the best-customized system. System requirements are determined by:

Estimating the daily load demand.

Determining the solar resource in the location.

Calculating the battery size.

Calculating the number of PV modules required.

For first estimates of the array size needed, consider the following variables that effect the production of power in an array:

Outside air temperature. Use average annual temperatures.

Amount of sunlight received, or Incident Solar Radiation, which depends on latitude, cloud cover, and angle of the array.

Efficiency of the photovoltaic cells. This information should be available from the manufacturer and is typically around 13% at field conditions to 30% under lab conditions.

$$P = (Sol_{ins} + \Delta t) \times A \times Eff$$

where,

P	=	Power generated, Watts (W)
Sol_{ins}	=	Incident solar radiation, Wh/ft^2
Δt	=	Difference between the control and design temperatures (use zero if the design temperature is between 50°F and 60°F; for control temperature, use 50°F for colder weather and 60°F for warm weather)
A	=	Area of the array, ft^2
Eff	=	Efficiency of the system (multiply cell efficiency by efficiency of the storage unit)

A Macintosh software program is available for PV design and sizing, wherein designers can specify appliances and AC/DC loads, inverter efficiency, and site location. Based on these variables, the software recommends the number of solar modules and batteries. The software costs about $15.

PVWatts is another PV software program. Researchers at the National Renewable Energy Laboratory developed PVWatts to allow non-experts to quickly obtain performance estimates for grid-connected PV systems at no cost.

Trnsys, a program developed at the University of Wisconsin, also helps size and locate PV systems. See the References section at the end of this guideline for more information.

Clean Power Estimator, an economic evaluation software program available for use by retailers and potential customers of photovoltaics and small wind generating systems can de downloaded at: www.consumerenergycenter.org/renewable/estimator/.

Design Details

The most important aspect of installing PVs is siting. Shading can significantly reduce the output of solar cells. Mount PV arrays at an elevation or on rooftops. Consider both summer and winter sun paths and ensure that trees, neighboring buildings, or other obstructions do not shade any portion of the array between 10:00 AM and 3:00 PM.

Mount the system for maximum southern exposure. The exact mounting angle will differ from site to site.

Flat, grassy sites work better than steep, rocky sites.

Use arrays as building components to economize to building materials and for unobtrusive design solutions. Arrays can be used as a finishing material on structures to create attractive roofs or skylights. Arrays can be used to break up and add interest to a large, uniform roof surface. They can double as shading devices, which not only block the sun but also capture it. Transparent arrays can be used as structural glazing instead of glass. Arrays can also be part of a curtain wall system.

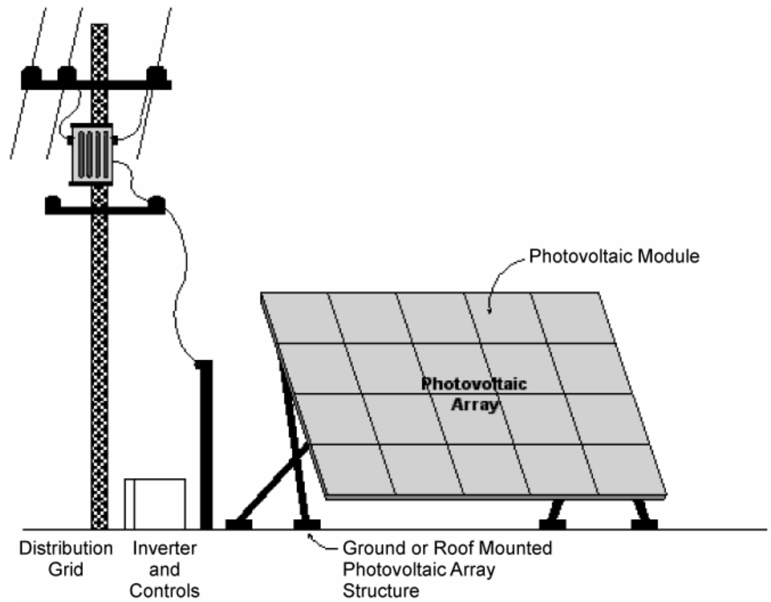


Figure 169—PV Siting, Elevated

Source: Renewable Energy Project Analysis Software

Operation and Maintenance Issues

PV systems require occasional cleaning to remove dust and debris. In cold, snowy climates, care must be taken to keep the array surface clear of snow.

Some PV systems contain storage batteries that may require some watering and maintenance similar to that required by batteries in automobiles.

PV modules are the longest living components of a PV system (20–30 years) and will likely outlive the batteries. Batteries may need replacement every 6 or 7 years.

No PV system is maintenance-free. Schedule regular inspections of the system to ensure that the wiring and contacts are free from corrosion, the modules are clear of debris, and the mounting equipment has tight fasteners. Roof-integrated systems should be designed to facilitate regular inspection and maintenance.

Monitor the power output of PV modules, the state-of-charge and electrolyte level of the batteries, and the actual amount of power that building loads use. Writing this information in a notebook helps to track the system's performance and determine whether the system is operating as designed. Monitoring will also help understand the relationships between the system's power production, storage capability, and load requirements.

Roof-integrated systems should be designed to allow easy removal if roof replacement is required.

Commissioning

Do not compromise on the initial module cost of PV systems. Skimping on first costs results in having to pay later, in terms of higher operation ($/kWh) costs that amount to a much higher figure over the lifespan of a system.

Purchase PV systems from established and knowledgeable dealers who can help determine requirements specific to the site. Look for warranties of 20 years or more. Thoroughly check the rating system that the dealer/manufacturer is using for reliability.

Always engage a professional to design and install PV systems. A preliminary design is a necessity to determine the size, layout, and potential energy output of the PV modules. This design can be performed with computer simulation tools using estimated hourly weather, solar resource, and load data. The time required preparing the preliminary design and detailed cost estimate typically falls between 30 and 60 hours, with fees ranging from $40/hour to $100/hour. Smaller scale projects with simple structural requirements fall at the low end of this time range. Larger scale projects requiring more difficult structural integration into existing buildings will be at the high end of this time range.

Fully commission panels and the entire array to confirm rated power is achieved.

References / Additional Information

U.S. Department of Energy. State Energy Alternatives. www.eren.doe.gov/state_energy/.

Solar Engineering Laboratory. University of Wisconsin-Madison. http://sel.me.wisc.edu/trnsys.

Sandia National Laboratory. Stand-Alone Photovoltaic Systems. *Handbook of Recommended Design Practices.*

GUIDELINE OS2: WIND POWER

Recommendation

Consider on-site wind power, if the site permits, to offset energy use, create funds to use elsewhere, and teach children about renewable energy.

Figure 170—Wind Turbine at School

This turbine is on of the two operating at an elementary school in Spirit Lake, Iowa, to produce 10,000 kW per year. NREL/PIX 09043

Applicable Spaces	Climates	When to Consider
Classrooms	South Coast	Programming
Library	North Coast	Schematic
Multi-Purpose / Cafeteria	Central Valley	Design Dev.
Gym	Mountains	Contract Docs.
Corridors	Desert	Construction
Administration		Commissioning
Toilets		Operation
Other		

Description

Wind turbines convert the kinetic energy in wind into mechanical energy that powers a generator to produce clean electricity. Turbine blades are aerodynamically designed to capture the maximum energy from the wind. The wind turns the blades, which then spin a shaft connected to a generator that makes electricity.

Many states use wind power in their utility power mix already, but small turbines are available and relatively affordable to provide on-site renewable energy for businesses, schools, and homes. The American Wind Energy Association (AWEA) defines a “small” wind system as one that has less than 100 kilowatts of generating capacity. A small wind electric system may be an appropriate technology to provide renewable power for many building and facilities if the following conditions are met:

There is enough wind where the school is located (usually average wind speeds of 14 mph or greater are needed for cost effectiveness).

Tall towers are allowed in the area (or consider a horizontal axis turbine if appropriate).

Enough space exists on the site.

It makes financial sense.

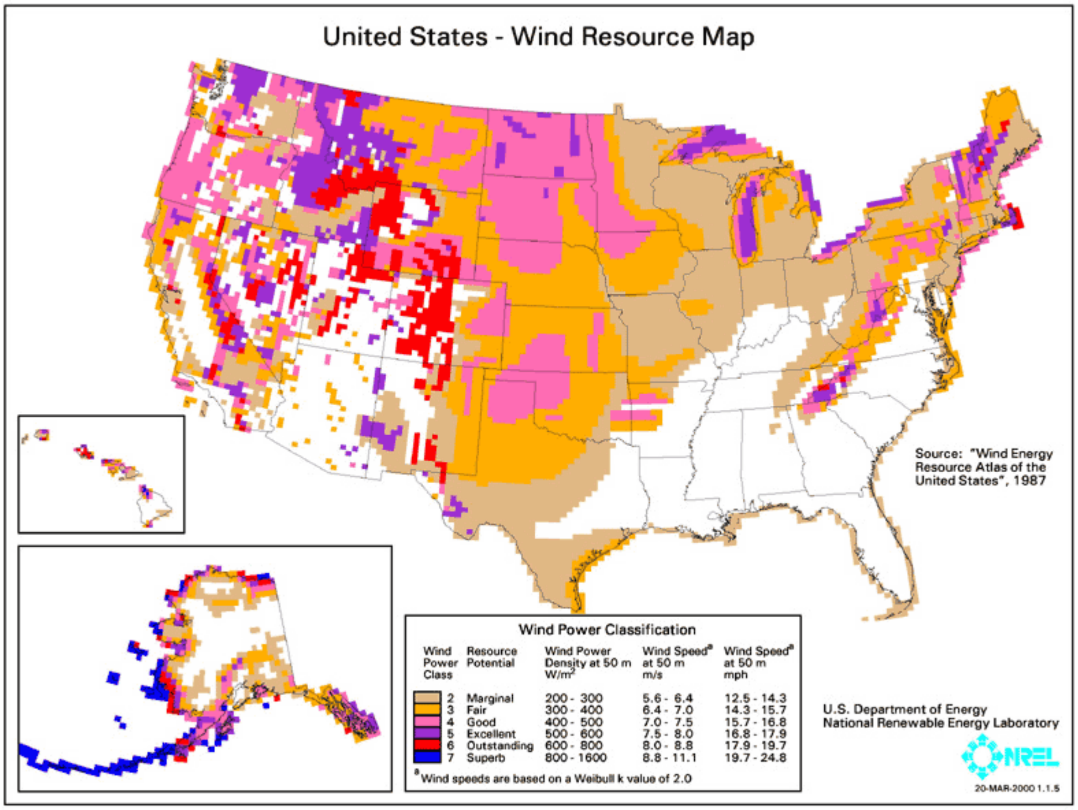


Figure 171—Wind Resource Map

Source: US DOE Energy Efficiency and Renewable Energy,
www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps_none.asp

Applicable Codes

Each state has different laws regarding the connection of renewable electric systems to the grid. As of 2003, 23 states had adopted net metering, including California, which allows “extra” electricity produced at a site to be absorbed back by the utility at market or a set price to the turbine owner. More information about net metering can be found at the State Energy Alternatives Web site: www.eere.energy.gov/states/alternatives/net_metering.cfm.

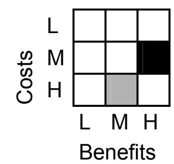
Many states have enacted laws to protect and maintain a property owner's proper access to wind and/or sunlight. Some states allow for the creation of easements. A wind or solar easement is a privilege to have access to wind or sunlight even though another person's property may be affected; i.e., a property owner cannot restrict any other property owner's access to wind or sunlight. Other states may have laws that prohibit neighborhood covenants from explicitly restricting the installation or use of solar equipment. While solar and wind access is not considered an automatic right, the laws are meant to prohibit unreasonable infringement on access. More information on wind easements can be found on the State Energy Alternatives Web site: www.eere.energy.gov/states/alternatives/wind.cfm.

As outlined on DOE’s State Energy Alternative Web site above, California's access laws involve both easement and covenant provisions. These laws appear in the California Civil, Government, and Natural

Resources Codes. The civil code allows the creation of solar easements to ensure access to proper sunlight for solar energy systems, including passive solar design. It also prohibits language in covenants and other home sale documents that explicitly restrict installation and use of solar energy systems. The government code allows subdivisions to include solar easements that apply to all properties within the subdivision. The natural resources code includes the Solar Shade Control Act. This act states that trees and other natural means of shading should be used except where it interferes with the use of solar systems.

Regarding installation, the U.S. National Electric Code (NEC), published by the National Fire Protection Association, has specific requirements for the installation of electrical equipment and wiring. Other local and state codes may apply to the installation of renewable energy systems. Renewable energy systems should be installed according to these codes by a licensed and knowledgeable professional.

Integrated Design Implications



Before selecting a small electric wind system for a building or facility, design the building to be as energy efficient as possible. Reducing energy consumption will reduce the size of the wind energy system needed.

Costs

A small wind turbine can cost anywhere from $3,000 to $35,000 installed, depending on size, application, and service agreements with the manufacturer. According to AWEA, an average 10 kW system costs approximately $32,000. A general rule of thumb for estimating the size of a small wind system is $1,000/kilowatt to $3,000/kilowatt.

Wind energy becomes more cost effective as the size of the turbine's rotor increases. Although smaller turbines cost less in initial outlay, they are proportionally more expensive; that is, they cost more per kilowatt produced.

Obviously, an energy efficient building design will allow for a smaller wind system, providing significant initial savings–the more energy efficient the design for the building, the smaller the wind turbine needed.

Wind energy systems involve a significant investment, but they can be competitive with conventional energy sources when accounting for a lifetime of reduced or avoided utility costs. The length of the payback period depends on the system chosen, available wind resources, electricity costs, and how the wind system is used. In some states, power generated over the amount needed by the building or facility can be sold back to the utility, further lowering operating costs and decreasing the payback period.

Benefits

Depending on the wind resource, a small wind electric system can lower electricity bills by 50%–90% and prevent power interruptions. Wind systems also provide clean power, with no emissions to cause pollution. A wind energy system can be a marketing draw for business, and a good teaching tool in schools.

The economics are best when:

There is a good wind resource (frequent local wind speeds in excess of 10mph).

There is net billing with 50 kilowatts cap or higher, preferably annual over monthly netting period.

Electric rates are above average.

Large kilowatt-hour usage allows larger wind turbines, which improves payback due to economies of scale.

Design Tools

The formula for calculating the power from a wind turbine is:

$$\text{Power} = C_P \tfrac{1}{2} \rho A V^3$$

Where:

C_P	=	Power coefficient, ranging from 0.2–0.4, dimensionless (theoretical max = 0.59)
ρ	=	air density, lb/ft^3
A	=	rotor swept area, or π D^2/4 (D is the rotor diameter in ft, π = 3.1416)
V	=	wind speed, mph

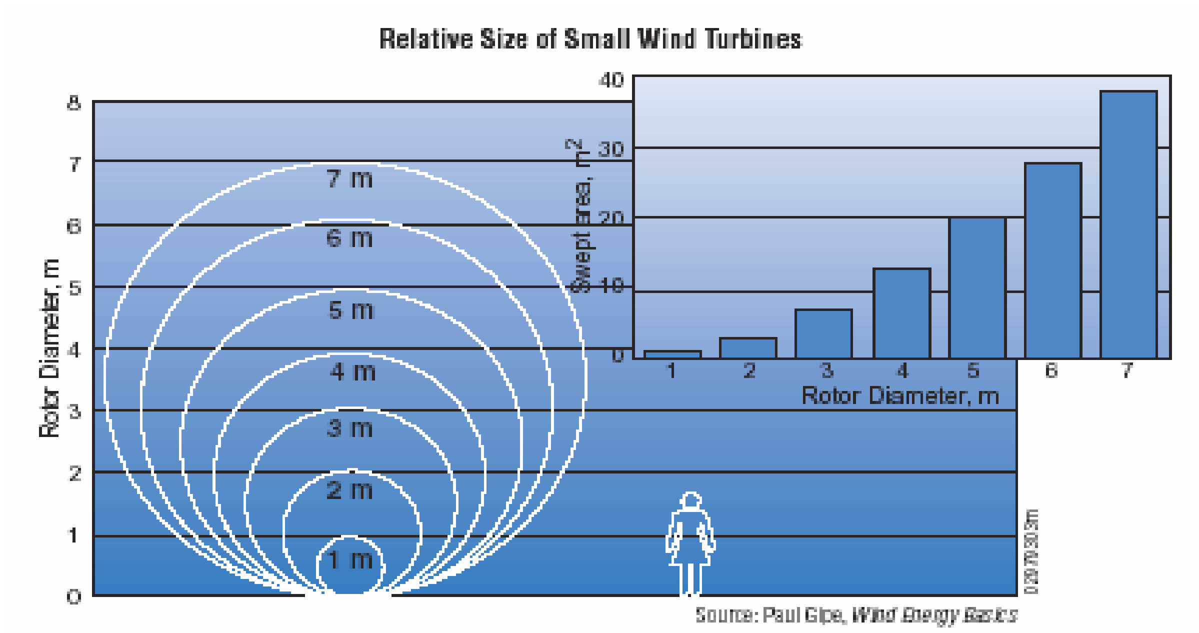


Figure 172—Relative Size of Small Wind Turbines

Figure 172 above shows the actual size of rotor diameters in relation to the size of an average person. This can help when examining the view of the turbine on a landscape.

The Wind Energy Design Payback Period Workbook is a spreadsheet tool that can help analyze the economics of small wind electric systems (www.nrel.gov/wind/docs/spread_sheet_final.xls).

Design Details

Mounting turbines on rooftops is not recommended. All wind turbines vibrate and transmit the vibration to the structure on which they are mounted. This can lead to noise and structural problems with the building.

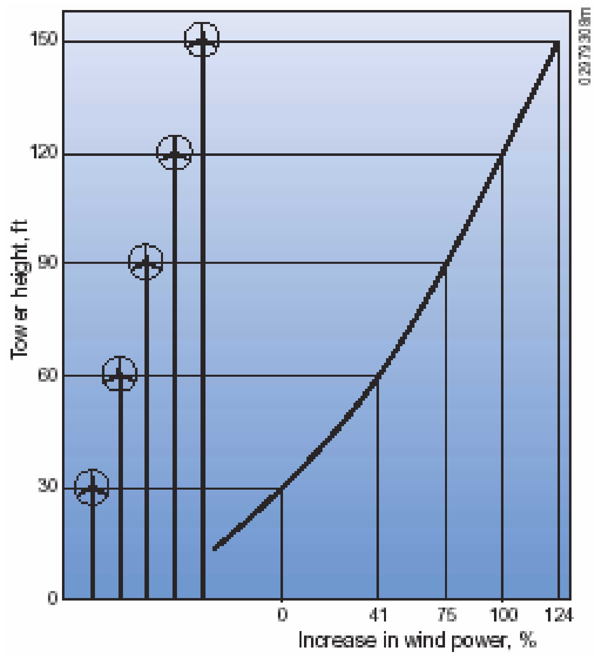


Figure 173—Wind Speeds Increase with Height

Average wind speeds increase with height and may be 15%–25% greater at a typical wind turbine hub height of 80 ft than at a typical airport anemometer height. This extra wind speed equals a power increase of 50% to 70% because power increases proportional to wind speed to the third power.

Operation and Maintenance Issues

Although small wind turbines are sturdy machines, they do require some annual maintenance. Bolts and electrical connections should be checked and tightened. The machines should be checked for corrosion and the guy wires for proper tension. After 10 years, the blades or bearings may need to be replaced, but with proper installation and maintenance, the turbine should last 20 years or more.

Tilt-down towers provide easy maintenance for turbines.

Commissioning

Wind turbine manufacturers and dealers should be able to help size and install the system. A credible installer will provide many services, including permitting. State energy offices or local utilities can provide a list of local wind system installers. Short-term monitoring should be performed to confirm that expected power output is achieved.

References / Additional Information

More detailed wind resource information, including the Wind Energy Resource Atlas of the United States, published by the U.S. Department of Energy at the following sites. These sites also contain information on educational curriculum for teachers and students.

National Wind Technology Center. www.nrel.gov/wind.

WindPowering America. www.eren.doe.gov/windpoweringamerica.

U.S. Department of Energy. State Energy Alternatives. www.eren.doe.gov/state_energy/.

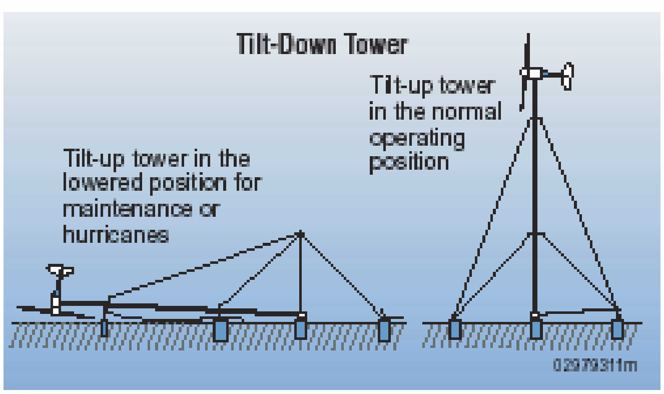
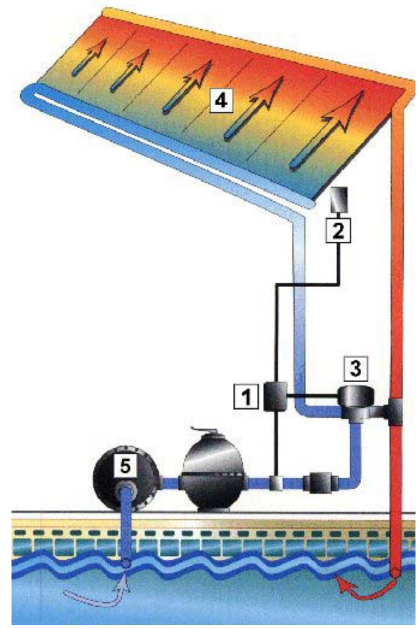


Figure 174—Tilt-Down Towers

GUIDELINE OS3: SOLAR SWIMMING POOLS

Recommendation

Use efficient pool heaters, and consider solar heaters for swimming pools as an environmentally friendly and cost-effective solution to pool heating requirements. Use pool covers at night and during unoccupied periods to limit heat losses.



Source: Solar-Tec Systems Solar Pool Heating

With an automatic system, simply set the desired temperature on the control panel (1). When the solar sensor (2) finds that there is enough solar energy to heat the pool, water is automatically sent to the solar collectors (4) by the valve (3). The pump (5) sends pool water to the solar collectors. As the water flows through the many tubes in each solar collector, the sun's energy heats it. The solar-heated water then flows back to the pool. This simple cycle continues until the pool reaches the desired temperature.

Applicable Spaces		Climates		When to Consider	
Classrooms		South Coast	■	Programming	
Library		North Coast	■	Schematic	
Multi-Purpose / Cafeteria		Central Valley	■	Design Dev.	▒
Gym		Mountains	■	Contract Docs.	
Corridors		Desert	■	Construction	■
Administration				Commissioning	■
Toilets				Operation	▒
Other	■ (green)				

Description

Most solar pool heating systems consist of three basic components: a collector, a pump, and a controller. Unlike domestic solar water heating systems, which raise a small amount of water to a high temperature of about 140°F, pool heaters raise the temperature of several thousand gallons of water to about 80°F by circulating the water at a relatively fast rate through the collectors. This circulation allows most of the solar energy falling on the collectors to transfer to the pool water.

The collector consists of a large area of pipes that absorb solar energy in the form of heat. They are made from plastic or rubber compounds that can withstand continuous exposure to sunlight. The collector is positioned for maximum access to sunlight. The pump circulates water through the collector to continually absorb heat. The hot water is then pumped back into the pool. This pump may be separate (especially in retrofit situations) from the regular pool pump that circulates pool water through a filter. The pump is automatically switched off when the temperatures of the water in the pool and the collector approach each other. The controller regulates the flow of water within the collector based on the temperature of the outgoing water using a diverting valve, the only moving part in a solar pool heating system. This valve controls whether or not the water circulates through the collector loop. When the collector temperature is sufficiently greater than the pool temperature, the water is diverted from the filter systems through the collector loop. The water bypasses the solar collectors during nighttime or cloudy periods. Some smaller systems are operated manually or with timers, but larger systems may be operated through electronic sensors.

Strip, panel, and tube systems are the three major types of solar collectors available. All three perform to a more or less equal standard, although strip systems are the most commonly used type.

Applicability

Solar heating for swimming pools is feasible for all climate types, even those that experience sub-freezing temperatures. Waterways on strip systems can expand to accommodate the increased volume of frozen water.

Most sloping roofs can be fitted with solar collectors. Relatively lightweight strip systems are suitable for sloping roofs. Strip collectors can be fitted to follow the roof contours and can be curved around obstructions, such as chimneys and skylights. Panel collectors are limited by their rigid sheet design and can be applied to flat or plane roofs only.

Applicable Codes

Title 24 allows for exceptions to Section 114 (a) 4 (that prohibits electric resistance heating) and Section 114 (b) 2 (that requires pool covers) for pools deriving at least 60% of the annual heating energy from site solar energy. Other codes may apply.

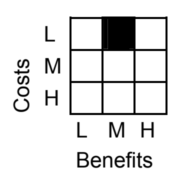
Integrated Design Implications

Although solar heated swimming pools can easily be accommodated later in the design or construction phases, the following issues should be considered beforehand:

Building aesthetics. Installation of solar collectors on rooftops may conflict with building aesthetics. Consider placement and orientation of the collectors early in the design phase to avoid this conflict.

Space availability. Solar collectors may occupy an area equivalent to 75% of the pool's surface area. This roof area must be available near the location of the swimming pool for unobstructed access to sunlight (although it's possible to mount the collectors at ground level).

Cost Effectiveness



Collectors made of copper are more expensive than those made of plastic, although they last longer. Plastic collectors are less conductive than copper, but are inert to chemicals and have about a 10-20 year lifespan. On average, total installed costs for unglazed solar heating systems for pools are about $\$14/ft^2$ –$\$20/ft^2$ (of collector area). Unglazed collectors alone cost about $\$8/ft^2$.

Below is an example of the typical costs of an unglazed system at a year-round school.

Pool Area	2,000ft^2
Collector Area	75% (2,000) = 1,500ft^2
Output	2therm/ft^2/year x 1,500ft^2 = 3,000therm
Savings	3,000therm/year x $1.00/therm = $3,000
System Cost	$21,000 - $30,000
Payback	7 – 10 years

Pool covers for an average size 600 ft^2 pool costs around $400 to $500 (not including the roller, which has a starting cost of around $300). Using the above figures for the cost of running a gas heater, heating the pool with solar energy can save from 3.8 tons to 5.1 tons of greenhouse gas emissions (CO_2) per year.

Benefits

Since solar pool heating collectors operate just slightly above the ambient air temperature (80°F), such systems typically use inexpensive, unglazed, low temperature collectors made from especially formulated plastic materials.

The solar heating system can save a significant amount of heating energy. A typical system will meet about 50% of the annual heating load. The existing pool heater can be used as a backup.

Solar pool heating systems have relatively low maintenance, and can last from 10 to 20 years.

A good solar pool heating system can generally be expected to increase pool water temperature by 9°F–18°F above the unheated water temperature from October through March. However, temperatures will vary depending on local climate conditions. A typical unglazed pool heating system will provide about 2 to 2.5 therms of heating energy per ft^2 of collector annually. Year-round schools or pools jointly used by the community during the summer months will benefit most from solar heating.

Collectors mounted on the roof can lower air conditioning costs for that space.

Design Tools

Use the following simplified algorithm for arriving at a rough estimate the required collector area:

$$A = A_p \times O \times S \times Sol_{ins}$$

where,

A = Area of solar collector, ft^2

A_p = Effective area of pool (multiply the surface area of the pool with the shape multiplier from Table 51), ft^2

O = Orientation multiplier (from Table 52)

S = Shading multiplier (from Table 53)

Sol_{ins} = Solar insolation (from figure below)

Table 51—Shape Multiplier

Shape	Multiplier
Rectangle	1.00
Kidney/Freeform	0.85
Oval	0.90
Round	0.79

Table 52—Orientation Multiplier

Orientation	Multiplier
South facing	1.00
East or west facing	1.25
Flat	1.10

Table 53—Shading Multiplier

Shading (from 9 a.m. to 5 p.m.)	Multiplier
No shade	1.00
25% shade	1.10
50% shade	1.25
75% shade	1.50
100% shade	1.75

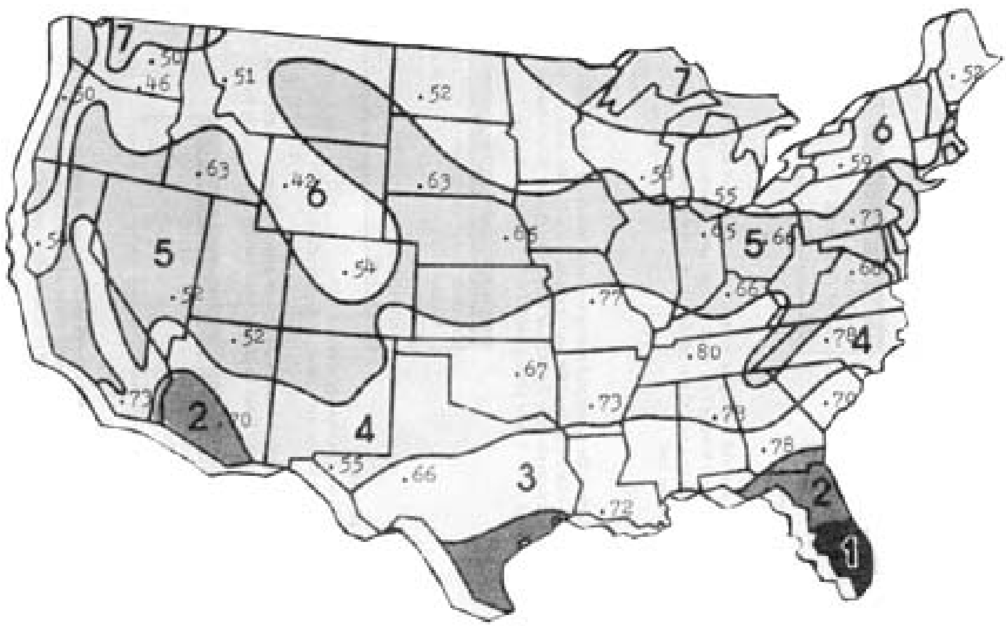


Figure 175—Solar Insolation Levels in the U.S.

Free software is available from DOE to analyze current energy consumption and project savings when implementing a variety of energy management systems from pool covers to solar systems. The *Energy Smart Pools* software uses hourly temperature and humidity data along with solar data to provide an accurate simulation of the heat losses and gains of a pool. More than 50 U.S. weather sites are currently available in the software. The program is intended to provide annualized simulation of annual energy costs, other costs, savings, and payback of adding a pool cover system, as well as costs, savings, and payback of adding a solar heating system.

Another free tool is the RETScreen International Clean Energy Project Analysis Software. This tool evaluates the economic feasibility of solar pool heating projects and other renewable energy technologies. This tool can be used to more accurately estimate required collector area for a particular pool. Information is available at www.retscreen.net.

Design Details

As in all solar heating, the primary factor in determining the effectiveness of the system is exposure to the sun. The size and the location of the collector, collector efficiency, local climate, wind protection, and roof orientation all influence the performance of solar pool heating systems.

Use a minimum collector area that is 60% of the pool's surface area. This applies only for ideal conditions (see the Design Tools section for more on sizing). Whenever conditions are unfavorable, for example in colder climates, the size of the collector will need to be increased, with a minimum area of 80% recommended for such installations. Increase collector area to 75% of the pool surface area if collectors are laid flat or if collectors face west. Other orientations are not recommended. In general, for every increase in collector area equal to 20% of the pool surface area, a 3°F rise in water temperature can be expected (based on collector rating at 1,000 Btu/ft^2 of collector area).

A south-facing roof is the best location for these systems. Use a west orientation or a flat roof if south orientation is unavailable.

Ideally, tilt the south-facing collectors by 30°–32°. A good rule of thumb is to orient collectors with a tilt equal to the latitude. Tilts of 0°F (flat) up to 40°F are acceptable, however.

Consider installing pool covers. They are the most cost effective measure for reducing heat loss, water evaporation, and chemical use. Pool heating requirements can be reduced by 50% with the use of a pool cover.

Unglazed collectors will typically use a flow rate of 3-6 gpm per collector, for a typical 40 ft^2 panel. Other flow rates may impact collector efficiency. It may be possible to use existing pumps used for filtration to circulate pool water through the collectors. However, the increased pressure drop will affect pump operating conditions.

The flow to solar collector manifold piping is normally limited to 40 gpm. This effectively limits the number of collectors that can be connected in series to 10 collectors.

Glazed collectors provide significantly higher heating output during the winter months. They are a viable option for year-round pool heating in colder climates, but are more commonly used with service water heating applications, which require a delivery temperature of 110°F or higher. Glazed collectors will also carry a much higher cost than unglazed systems. Glazed collectors typically have copper tubing, so freeze protection, typically a propylene glycol solution, is required in climates that experience freezing conditions.

Indoor pools that are used year round can benefit from glazed flat plate collectors, which should slope between 25° and 45°. For pools that operate throughout the winter, a tilt equal to latitude +10° will ensure good output in the winter, when gas rates are highest.

Operation and Maintenance Issues

Ensure that pools are manually and seasonally drained. In areas subject to winter freezing, the collectors and plumbing should be installed to allow all water to drain when the system is off. Pool filters will need to be cleaned periodically to maintain proper pump operation.

Paint all exposed PVC plumbing to protect it from damage due to UV radiation.

Commissioning

Carefully check how long the manufacturer has been in business and what warranty services are available. Use the Florida Solar Energy Center rating system (see References for more information).

References / Additional Information

American Solar Energy Society, Inc. (ASES). 2400 Central Avenue, G-1, Boulder, CO 80301. Phone: (303) 443-3130; Fax: (303) 443-3212, Email: ases@ases.org. Web site: www.ases.org.

National Spa & Pool Institute (NSPI). Phone: (800) 323-3996. Web site: www.nspi.org/.

The Energy Efficiency and Renewable Energy Clearinghouse (EREC).. P.O. Box 3048, Merrifield, VA 22116. Phone: (800) DOE-EREC (800-363-3732). Email: doe.erec@nciinc.com. Florida Solar Energy Center. 1679 Clearlake Rd., Cocoa, FL 32922. Phone: (407) 638-1000, Fax: (407) 638-1010, Pamphlets available by mail—call for costs, Collector Thermal Performance Ratings (publication FSEC-GP-16), Design and Installation Manual (publication FSEC-IN-21-82), System Sizing (publication FSEC GP-13). Web site: www.eren.doe.gov/consumerinfo.

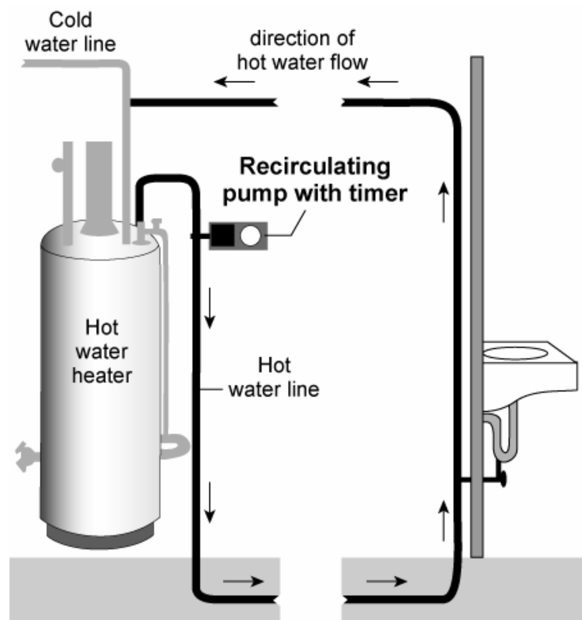
Solar Energy Industries Association (SEIA). 1616 H Street, NW, 8th Floor, Washington, DC 20006. Phone: (202) 628-7979, Fax: (202) 628-7779. www.seia.org/.

RETScreen International Clean Energy Project Analysis Software. www.retsreen.net.

GUIDELINE OS4: TIMERS FOR RECIRCULATING HOT WATER SYSTEMS

Recommendation

Use recirculation timers to control circulation of hot water based on demand. Use separate hot water systems for areas with significantly different demand patterns.

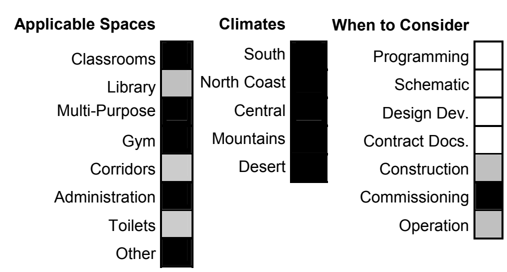


Description

Recirculating hot water systems connect to the hot water pipe and constantly circulate hot water through the pipes, from the heater to the furthest fixture and then back to the heater, making warm water immediately available upon turning the tap. Large facilities use recirculating hot water systems, which result in heat losses through the distribution piping. Installing timers ensures that hot water circulates only during times of need, which greatly reduces the heat loss through the distribution piping as well as the daily pumping load.

Applicability

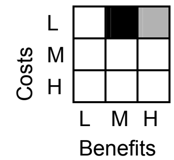
Timers are applicable for large facilities where hot water is recirculated. Timers will work effectively only when the hot water demand for a facility can be predicted accurately, as in the case of classrooms and school administrative areas.



Applicable Codes

The service hot water system should meet all the requirements of Title 24 Section 113—Mandatory Requirements for Service Water Heating Systems and Equipment. Section 113 (b) 2 also states that all pumps for circulating systems should have a control capable of automatically turning off the circulating pump when hot water is not required, with the exception of residential occupancies.

Cost Effectiveness



Timers are very cost effective and have a two to five year payback period.

Prices for recirculating system timers range between $40 and $50.

Benefits

Timers greatly reduce heat losses through distribution piping. Daily pumping loads are also reduced considerably.

Design Tools

None.

Design Details

Most schools are ideal candidates for using timers because of the predictability of classroom schedules. Set the system to operate only between classes, just before and after the school day, and during lunch periods.

Administrative areas, locker rooms, and other areas may have a demand schedule different from that of the classroom facility. Separate hot water systems or gas-powered, instantaneous water heaters can be used to accommodate these areas. Avoid using timers for areas with random and intermittent schedules.

Consider using thermostats connected in series with the timers. The thermostat turns off the pump when the water in the pipes reaches a certain temperature. Once the water in the pipe is hot, the pump turns off. If the timer and thermostatic controls are installed together in series, the circulator operates only at the preset clock times and only when the temperature conditions of the thermostat are met. That is, if either the timer control or the thermostatic control switch is open (off), the circulator will not operate, which results in additional savings.

Operation and Maintenance Issues

Adjust the initial timer schedule based on observed or monitored demand data. Schedules may vary from school to school, and it is important to fine-tune the timer settings based on specific demand patterns.

Check the hot water supply every six months to ensure that the timer is functioning as expected.

Always set the timer switch to the actual time by turning the programming ring in the direction of the arrow until the timing arrow points to the actual time on the ring.

In a power outage, the timer will not keep time. After power has been restored, the correct time of day must be reset by rotating the programming ring in the direction of the arrow until the timing arrow points to the actual time on the ring.

Commissioning

If installing a thermostat along with the timer, ensure that the two devices are installed in series.

After wiring is completed and checked, install the timer control unit onto the terminal box bracket of the pump and reinsert the terminal box screw. Be careful not to bind or leave any terminal box wires exposed.

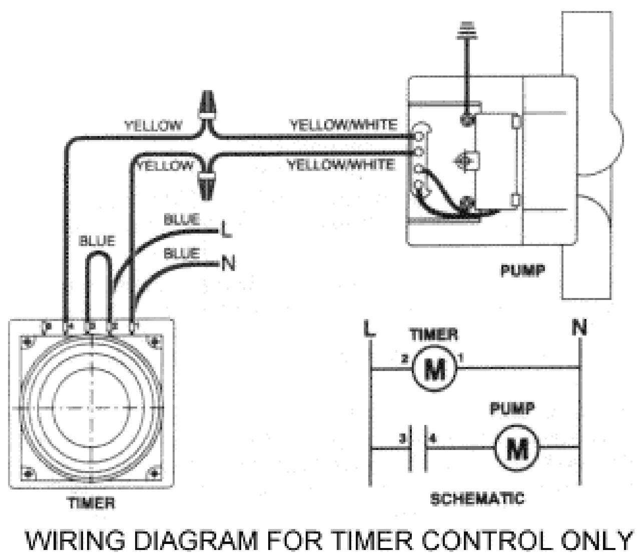


Figure 176—Wiring Diagram

Source: www.plumbingsupply.com/grundtimer.html

References/Additional Information

www.eren.doe.gov/buildings/consumer_information/water/waterques.html#13.

www.lainginc.com/instant.htm.

www.plumbingstore.com/circpump.html - faq.

GUIDELINE OS5: EFFICIENT TERMINAL DEVICES

Recommendation

Use low-flow toilets and low-flow devices on all terminals like faucets and showerheads. Use automatic faucets for controlling wastage of clean water.

Low-flow devices will reduce water consumption by 15% to 20% resulting in lower environmental costs and reduced load on wastewater treatment plants. NREL/PIX00653

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	□
Library	□	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	□
Gym	□	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	■
Administration	□			Commissioning	□
Toilets	■			Operation	□
Other	■				

Description

Installing low-flow devices is simple and cost effective. In 1995, the National Energy Policy Act mandated the use of toilets that use no more than 1.6 gallons of water per flush (gpf), reduced from 3.5 gpf. Low-flow toilets use various technologies like large drain passages, redesigned bowls, and tanks for increased functionality and easier wash-downs.

Older showerheads typically deliver 4 to 5 gallons per minute (gpm) of water. Newer showerheads are more efficient and follow the National Energy Policy Act of 1992 that allows a maximum water flow rate of 2.5 gpm (at standard water pressure of 80 lb/in^2). Showerheads should use aerator technology and multiple flow settings to save water. Conventional bathroom faucets use 3 gpm to 7 gpm. New faucets, designed to meet federal codes, use a maximum of 2.5 gpm (at 80 psi), although some are being designed to use 1.5 gpm or less.

The new low-flow faucets essentially operate in one of two ways: aeration or laminar flow. In laminar flow faucets, the water travels in parallel streams producing a clear flow of water without being mixed with air (as in aeration) that produces superior wetting ability over aerating faucets. Laminar flow faucets are somewhat more expensive than aerating types. Conventional faucet aerators do not compensate for changes in inlet pressure, so with greater water pressure, more water is used. New technology compensates for this occurrence and provides the same flow regardless of pressure. Aerators are also available that allow water to be turned off at the aerator itself.

Some low-flow faucets are metered-valve type; they deliver a fixed quantity of water and then shut off automatically. Other automatic faucets include self-closing and sensored. Sensored faucets, either infrared or ultrasonic, are designed to turn on when a user's hands are placed under the faucet, and turn off when the hands are removed.

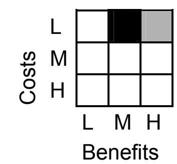
Applicability

Low-flow technology is applicable to all terminal devices that deliver water.

Applicable Codes

Low-flow plumbing fixtures must meet the appropriate American National Standards Institute (ANSI) standards listed by the International Association of Plumbing and Mechanical Officials (IAPMO).

Cost Effectiveness



A good quality, low-flow showerhead will cost $10–$20. Low-flow faucet aerators cost $4.50 to $8. A sensored faucet is expensive and may cost up to $160 per fixture more than the regular faucets.

Benefits

A low-flow device will pay for itself in energy saved within four to eight months.

Installing low-flow showerheads and faucet aerators can save significant amounts of hot water. Low-flow showerheads can reduce hot-water consumption for bathing by 30% while still providing a strong, invigorating spray.

Water consumption is reduced by 15%–20%, resulting in lower environmental costs and reduced load on wastewater plants. Easy installation procedures make low-flow plumbing fixtures feasible for retrofitting. It is estimated that low-flow toilets alone could save up to 2,000 gallons of water per person.

Design Tools

None.

Design Details

Use aerators that deliver 0.5 gpm–1 gpm of water for bathroom faucets.

Use aerators with higher flow rates (2 gpm–3 gpm) for sink faucets that will be used for intensive washing purposes.

Operation and Maintenance Issues

Faucets should be periodically checked for leaks and repaired as needed. Leaky faucets can waste enormous amounts of water (up to tens of gallons in a single day).

Faucet aerators need to be checked periodically for clogging, some models clog more easily than others and may need to be cleaned too often to be effective. Some aerators may cause unacceptable performance or the perception of poor performance, resulting in an increase in water use.

Commissioning

Installation of low-flow plumbing fixtures is similar to that of conventional fixtures. Most of these fixtures require no special connections or fittings. Low quality showerheads may simply restrict water flow, which often results in poor performance.

References/Additional Information

American Water Works Association. 1401 New York Ave. NW, Suite 640, Washington, DC 20005. Phone: (202) 628-8303. Web site: www.awwa.org.

Plumbing Manufacturers Institute (PMI). 800 Roosevelt Road, Building C, Suite 20, Glen Ellyn, IL, 60137. Phone: (708) 858-9172. Web site: www.pmihome.org.

GUIDELINE OS6: ZERO-WATER CONSUMPTION URINALS

Recommendation

Install zero-water consumption urinals wherever applicable.

Source: Waterless Co.

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	□
Library	□	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	□	Central Valley	■	Design Dev.	□
Gym	□	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	■
Administration	□			Commissioning	□
Toilets	■			Operation	□
Other	□				

Description

Zero-water consumption urinal systems have been used in schools since 1993, and have some innovative features that distinguish the product from the conventional urinal systems available today. The products look, feel, and work like a conventional urinal system except for one difference: they do not require water to operate.

The system has three main components: a polypropylene trap insert, a sealant liquid, and a reinforced fiberglass urinal body.

The primary component of the product is the trap cartridge. This cartridge ”traps” the biodegradable sealant liquid, which is lighter than other liquids. It floats on and seals the contents from the atmosphere. This special liquid allows urine to sink through its layer, creating a pleasant and odor-free environment. Since urine is 90% water, it readily flows down and falls through the trap. This trap design allows immersed urine to be discharged into the drain without using any mechanical parts.

The system requires only about three ounces of sealant liquid per charge to operate and will last for about 1,500 sanitary uses. Then, the liquid is simply replenished. The trap needs to be replaced three to four times a year, depending on frequency of use.

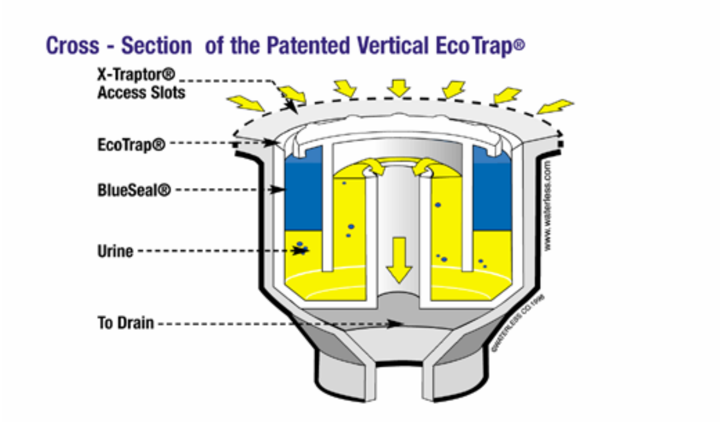


Figure 177—Cross-section of Zero-Water Urinal

Source: Waterless Co.

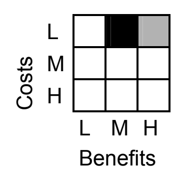
Applicability

Zero-water consumption urinals are applicable to all restroom modernizations and new construction.

Applicable Codes

American National Standards Institute (ANSI) Z124.9, UPC®, CSA®

Cost Effectiveness



Costs for zero-water consumption urinals are comparable to regular manual flushed urinals, but are less than automatic-sensor flushed urinals.

The payback period for the system is one to four years. Savings due to zero-water consumption urinals are estimated between $150/urinal/year and $330/urinal/year depending on factors like number of users, cost of water, cost of sewer, volume of water use, and maintenance.

Benefits

Some benefits of zero-water consumption urinals include:

Easy maintenance since it has durable, break-resistant fiberglass construction with no moving parts. This reduces operating costs by eliminating the problem of broken flush valves.

Flushometer and valve replacements are common problems for flush urinals. Such repairs are not an issue for zero-water consumption urinals.

Zero-water consumption urinals are simple to install and use. Replacing existing conventional urinals with zero-water consumption products is also relatively simple to accomplish, since they easily adapt to existing two-inch plumbing waste lines.

They have a short payback period of one to four years.

Fresh water supply will be preserved and can be applied in a more effective and meaningful way. In addition to saving water, they reduce the amount of water needing to be treated. Less water released into the treatment process lowers pollution and benefits the environment.

Zero-water consumption urinals significantly reduce clogging and prevent overflows.

Design Tools

None.

Design Details

None.

Operation and Maintenance Issues

The smooth, simple design of the zero-water consumption system is easy to clean and maintain. Also, there are no costly repairs usually associated with the mechanical components of flush valves.

The trap cartridge should be replaced two or four times per year, depending on the frequency of use.

The sealant liquid is biodegradable and the trap cartridge should be recycled.

Commissioning

The drain line should be clear before installation, which may require snaking the drain line.

References/Additional Information

Falcon Waterfree Technologies, 10900 Wilshire Blvd., 15th Floor, Los Angeles, CA 90024. Web site: www.waterlessurinals.com/.

Waterless Co., 1223 Camino Del Mar, Del Mar, CA 92014. E-mail: klaus@waterless.com, Web site: www.waterless.com/.

School districts using waterless urinals include:

San Dieguito Unified High School District, Encinitas, CA.

San Diego City Schools, San Diego, CA.

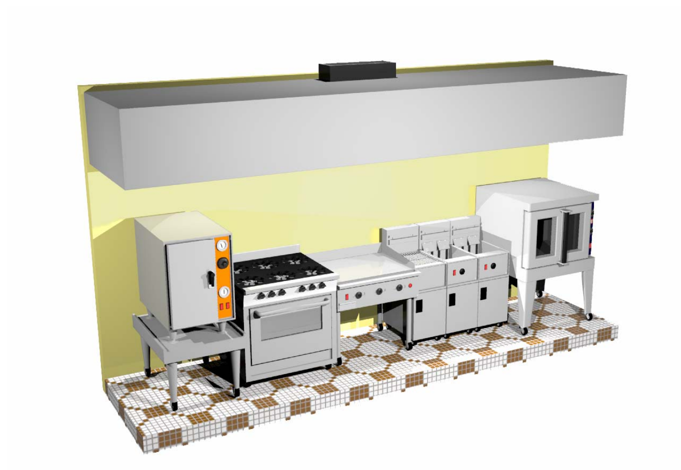
Carlsbad Unified School District, Carlsbad, CA.

Alameda Unified School District, Alameda, CA.

GUIDELINE OS7: KITCHEN AREA VENTILATION

Recommendation

Select and install kitchen exhaust hoods that minimize the amount of net exhaust air based on the appliances to be ventilated. Select and install makeup air diffusers that minimize interference with proper capture and containment by the exhaust hoods.



Design Kitchen Ventilation Systems to Improve both Energy Efficiency and IAQ. Source: PG&E Food Service Technology Center.

Applicable Spaces		Climates		When to Consider	
Classrooms	□	South Coast	■	Programming	■
Library	□	North Coast	■	Schematic	■
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	■
Corridors	□	Desert	■	Construction	■
Administration	□			Commissioning	■
Toilets	□			Operation	■
Other	□				

Description

Commercial kitchen ventilation systems account for upward of 20% of the total energy consumed in a cafeteria. Unfortunately, these systems are generally designed with only indoor air quality in mind. Several measures can be taken to conserve energy while maintaining proper indoor air quality, in commercial applications or schools.

Common kitchen exhaust systems include wall-mounted canopy hoods, island (single or double) canopy hoods, and proximity (backshelf, pass-over, or eyebrow) hoods. Each hood type has a different capture area and is mounted at a different height relative to the cooking equipment. The more open the capture area is and the greater the distance from the hood capture area from the appliance, the greater the amount of exhaust air required to have effective capture and containment. For example, for certain appliances, a properly designed and installed proximity hood will perform as well as a canopy hood with significantly less exhaust. See ASHRAE Handbook of HVAC Applications and resources listed below for specific guidance on selecting the appropriate style of hood.

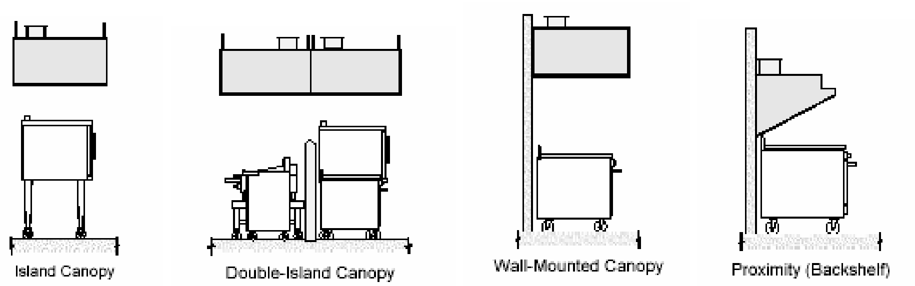


Figure 178—Kitchen Exhaust Hood Configurations

Source: California Energy Commission

Replacement Air Design Considerations

There are also several options for delivery of replacement air. Replacement air consists of dedicated makeup air and transfer air (from other adjacent spaces).

The strategy used to introduce replacement (makeup) air can significantly impact hood performance and should be a key factor in the design of kitchen ventilation systems. Makeup air introduced close to the hood's capture zone may create local air velocities and turbulence that result in periodic or sustained failures in thermal plume capture and containment. Furthermore, the more makeup air supplied (expressed as a percentage of the total replacement air requirement), the more dramatic the negative effect. The advantages and disadvantages of different methods of introducing replacement are discussed below.

Backwall Supply (Rear Discharge)

Lab testing has shown that the backwall supply can be an effective strategy for introducing makeup air. However, the discharge area of the backwall supply should be at least 12 inches below the cooking surfaces of the appliances to prevent the relative high velocity introduction of makeup air from interfering with gas burners and pilot lights. As with other local makeup air strategies, the quantity of air introduced through the backwall supply should be no more than 60% of the hood's exhaust flow.

Short-Circuit Supply (Internal Makeup Air)

These internal makeup air hoods were developed as a strategy to reduce the amount of conditioned air required by an exhaust system. By introducing a portion of the required makeup air in an untempered condition directly into the exhaust hood reservoir, the net amount of conditioned air exhausted from the kitchen is reduced. Research has shown however, that in the cases tested, internal makeup air cannot be introduced at a rate that is more than 15% of the threshold exhaust rate without causing spillage. Short-circuit supply is not recommended.

Air Curtain Supply

Introducing makeup air through an air curtain is a risky design option and most hood manufacturers recommend limiting the percentage of makeup air supplied through an air-curtain to less than 20% of the hood's exhaust flow. An air curtain (by itself, or in combination with another pathway) is not recommended, unless velocities are kept to a minimum. It is too easy for the as-installed system to oversupply, creating higher discharge velocities that cause cooking effluent to spill into the kitchen.

Front Face Supply

Supplying air through the front face of the hood is a configuration that has been recommended by many hood manufacturers. However, a front face discharge, with louvers or perforated face, can perform poorly if its design does not consider discharge air velocity and direction. Not all face discharge systems share the same design; internal baffling and/or a double layer of perforated plates improve the uniformity of flow. Face discharge velocities should not exceed 150 fpm and should exit the front face in a horizontal direction. Greater distance between the lower capture edge of the hood and the bottom of the face discharge area may decrease the tendency of the makeup air supply to interfere with hood capture and containment.

Perforated Perimeter Supply

Perforated supply plenums (with perforated face diffuser) are similar to a front face supply, but the air is directed downward toward the hood capture area. This may be advantageous under some conditions, since the air is directed downward into the hood capture zone. Face discharge velocities should not exceed 150 fpm from any section of the diffuser and the distance to lower edge of the hood should be no less than 18 inches (or the system begins to act like an air curtain). Widening the plenum will lower the discharge velocity for a given flow of makeup air and reduce the chance of the supply air affecting exhaust.

Four-Way Ceiling Diffusers

Four-way diffusers located close to kitchen exhaust hoods can have a detrimental affect on hood performance, particularly when the flow through the diffuser approaches its design limit. Air from a diffuser within the vicinity of the hood should not be directed toward the hood. Discharge velocity at the diffuser face should be set at a design value such that the terminal velocity does not exceed 50 fpm at the edge of the hood capture area. It is recommended that only perforated plate ceiling diffusers be used in the vicinity of the hood.

Displacement Diffusers

Supplying makeup air through displacement diffusers at a good distance away from the hood is an effective strategy for introducing replacement air. It is analogous to low-velocity "transfer air" from the dining room. However, the diffusers require floor or wall space that is usually a premium in the commercial kitchen. A couple of remote displacement diffusers (built into a corner) could help diversify the introduction of makeup air into the kitchen when transfer air is not viable.

Applicability

Applicable in all schools with commercial-style kitchen equipment.

Applicable Codes

ASTM Standard 1704-2004, Standard Test Method for the Performance of Commercial Kitchen Ventilation Systems. ASTM International. West Conshohocken, PA

UL Standard 710. UL 710, Exhaust Hoods for Commercial Cooking Equipment. Underwriters Laboratories

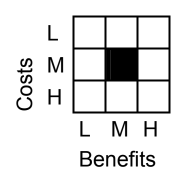
Integrated Design Implications

Kitchen hood systems should be installed with the makeup air system integrated with the exhaust hood operation. A portion of the makeup air may come from adjacent dining areas, and in those cases the control of the dining room ventilation system needs to be integrated with the kitchen system.

Efficient refrigeration: ENERGY STAR-labeled commercial solid door refrigerators and freezers are designed with components such as ECM evaporator and condenser fan motors, hot gas anti-sweat heaters, or high-efficiency compressors, which will significantly reduce energy consumption and utility bills. ENERGY STAR-labeled commercial solid door refrigerators and freezers can save as much as 46% compared to standard models with a 1.3-year payback. By buying commercial solid door refrigerators and freezers, purchasers can expect to save $140 annually per refrigerator and $100 per freezer.

Efficient kitchen appliances: general discussion here, with reference to fact sheets on www.fishnick.com/appliances/types/.

Cost Effectiveness



A well-designed kitchen exhaust system can reduce both fan energy and conditioned air, and thereby improve the efficiency of the kitchen ventilation system up to 50%. This translates into energy savings of $1,000–$2,000 per hood per year in any given kitchen. A typical payback ranges from one to three years. The exact savings depend on variables such as hours of operation, cost of energy, size of hood and fans, and nature of cooking load.

Benefits

Proper design of kitchen exhaust makeup can enhance indoor air quality and thermal comfort while also saving energy.

Design Tools

A public-domain software program described in the following ASHRAE paper provides engineers with a more sophisticated hour-by-hour simulation of commercial kitchen ventilation systems. The software illustrates the impact of makeup air set point and geographic location on outdoor air load.

Donald Fisher, P.Eng, Ferdinand Schmid and Anthony J. Spata. "Estimating the Energy-Saving Benefit of Reduced-Flow and/or Multi-Speed Commercial Kitchen Ventilation Systems," Publication. CH-99-20-3. Available from ASHRAE: www.ashrae.org.

The Food Service Technology Center has a variety of tools to help in designing efficient kitchens.

- Outdoor Air Load Calculator—Excellent tool for calculating fresh air heating and cooling loads. (Hosted by Architectural Energy Corporation) www.archenergy.com/oac/
- Pre-Rinse Spray Valve Calculator—Calculate total water, sewer and energy savings when installing low-flow pre-rinse spray valves. Works for other cost-saving water devices too. www.fishnick.com/tools/watercost/
- Life-Cycle and Energy Cost Calculators—Estimate energy savings from high-efficiency equipment. www.fishnick.com/tools/calculators/
- Design Guide 1: Improving Commercial Kitchen Ventilation System Performance Selecting and Sizing Exhaust Hoods Design guide 1 covers the fundamentals of kitchen exhaust, and provides design guidance and examples. This guide was made possible by the efforts and support of Southern California Edison. www.fishnick.com/ckv/designguide/
- Design Guide 2: Improving Commercial Kitchen Ventilation System Performance Optimizing Makeup Air Design Guide 2 augments Design Guide 1, with an emphasis on the makeup air side of the equation. This guide was previously published by the California Energy Commission under the title, Improving Commercial Kitchen Ventilation Performance, and was previously titled as Commercial Kitchen Ventilation Design Guide here. www.fishnick.com/ckv/designguide/

Design Details

The following design suggestions come from the California Energy Commission's Design Guide: *Improving Commercial Kitchen Ventilation System Performance* (see Resources) and can improve the energy efficiency and performance of commercial kitchen ventilation systems:

- Group appliances according to effluent production and associated ventilation requirements. Specify different ventilation rates for hoods or hood sections over the different duty classification of appliances. Where practical, place heavy-duty appliances such as charbroilers in the center of a hood section, rather than at the end.
- Use UL Listed proximity type hoods where applicable.

- Hood construction details (such as interior angles and flanges along the edge) or high-velocity jets can promote capture and containment at lower exhaust rates.
- Install side and/or back panels on canopy hoods to minimize cross drafts and reduce heat gain.
- Integrate the kitchen ventilation with the building HVAC system (i.e., use dining room outdoor air as makeup air for the hood).
- Maximize transfer air and minimize direct makeup air.
- Do not use short-circuit hoods. Use caution with air-curtain designs.
- Avoid 4-way or slot ceiling diffusers in the kitchen, especially near hoods.
- Diversify makeup air pathways (use combination of backwall supply, perforated perimeter supply, face supply, displacement diffusers, etc.).
- Minimize makeup air velocity near the hood; it should be less than 75 fpm.
- Consider variable or 2-speed exhaust fan control for operations with high diversity of appliances and/or schedule of use.
- Provide air balance requirements to avoid over- or under-supply of makeup air.
- Locate vent canopy on a wall to minimize the required air flow. Wall-mounted canopy hoods function effectively with a lower exhaust flow rate than the single-island hoods.
- If an island canopy is required, place a partition at the back of a row of cooking equipment or between a double row of equipment to improve efficiency.
- Locate kitchen exhaust away from the HVAC fresh air intake.
- Install spot cooling equipment (or radiant ceiling panels) to provide thermal comfort for the kitchen staff.

Operation and Maintenance Issues

Regularly clean filters and oil traps and check fan belts.

If the kitchen is closed off from other areas by doors, it is easy to check whether replacement air is available. Standing inside the kitchen with the exhaust hood system operating and all other doors are closed, open the door three or four inches: (1) if you feel an inward rush of air, the makeup air unit or transfer air sources (such as HVAC units serving adjacent areas) may be turned off, or (2) if you do not feel air movement then all replacement air sources are operating.

Check operation of the economizers (motorized outside air dampers) on HVAC units to assure that replacement air is available.

Commissioning

Building air balancing and kitchen system commissioning should be required as part of the construction requirements.

References/Additional Information

ASHRAE HVAC Applications Handbook, 2004, Chapter 30, Kitchen Ventilation.

California Energy Commission, *Design Guide: Improving Commercial Kitchen Ventilation System Performance*, publication # 500-03-034F. www.energy.ca.gov.

Fisher-Nickel. 2004. Food Service Technology Center. www.fishnick.com/.

U.S. Environmental Protection Agency (EPA). Energy Star Web site, commercial refrigeration. 2004. www.energystar.gov/index.cfm?c=commer_refrig.pr_commercial_refrigerators.

GUIDELINE OS8: ENERGY EFFICIENT TRANSFORMERS

Recommendation

Consider using energy efficient transformers at schools as part of a whole-building plan to minimize energy use.

Figure 179—ENERGY STAR-Qualified Transformer

These can save $100–$300 a year for each transformer (at an electricity rate of $0.075 cents per kWh). Source: Square D, www.squared.com

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	
Library	■	North Coast	■	Schematic	
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	■	Mountains	■	Contract Docs.	
Corridors	■	Desert	■	Construction	
Administration	■			Commissioning	
Toilets	■			Operation	
Other	■				

Description

Low-voltage transformers take building power, typically 480 volts (V), and convert it to 208/120 V to serve plug loads and some lighting systems (many lighting systems operate at 277 V). Typical transformer sizes range from 15–500 kilovolt-amperes (kVA). For reference, one kilovolt-ampere is equivalent to one kilowatt for loads with a power factor of 1.0. Otherwise, the volt-amperes required by a load is higher than the power consumed by the load (in watts) if the power factor is less than 1.0, which is the case with inductive loads (e.g., motors) or many electronic loads (e.g., electronic ballasts and computers).

Transformer efficiency drops off markedly when they are lightly loaded, and the vast majority of transformers in buildings run very lightly loaded compared to their rated capacity. Because they are common to all buildings and because they are continuously energized, inefficient transformers can be a constant drain on building energy.

The National Electrical Manufacturers Association (NEMA) has developed industry standards to define energy-efficient transformers. Products meeting NEMA TP 1-2002 reduce transformer losses by about 50%, yielding simple paybacks in 1–3 years. In fact, the United States would have saved more than 350 million kWh in the year 2000 if all low-voltage dry-type transformers sold in that year were TP 1 compliant. NEMA TP 1 applies to dry type transformers (the type used in most building applications) of 15 kVA and larger.

A "K"-rated transformer is designed to handle the harmonic currents created by some electronic equipment and other non-sinusoidal loads. The higher the "K-factor" the more harmonic current can be handled. These transformers are generally larger and more expensive than a standard transformer with the same power rating. They are also not necessarily energy efficient, which is the reason that K-rated transformers should also be TP 1-compliant.

NEMA TP 1 efficiency ratings are based on transformer loading of 35%. Studies suggest that typical loading in building distribution transformers is even lower in many cases. Figure 180 shows how transformer efficiency varies for three typical units, one that is TP 1-compliant and two standard efficiency transformers. This graph shows that the TP 1-compliant transformer is not the most efficient at 100% load, but it performs significantly better over the typical operating range of 35% or less.

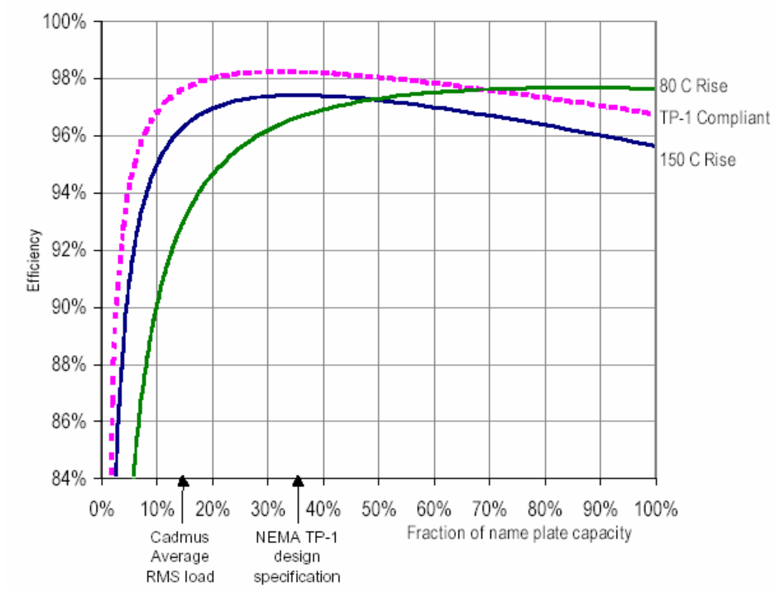


Figure 180—Efficiency of Typical TP 1-Compliant Transformer

Compared to Standard Efficiency Transformers Rated for 80C and 150C Temperature Rise
Image Source: CASE Study (see references)

Applicable Codes

Local codes, such as California's Title 20 appliance standards, may require TP 1-compliant transformers.

National Electric Code

National Electrical Manufacturers Association (NEMA). NEMA TP 1-2002: Guide for Determining Energy Efficiency for Distribution Transformers.

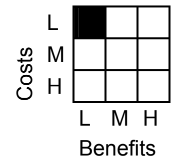
National Electrical Manufacturers Association (NEMA). NEMA TP 2-1998: Standard Test Method for Measuring the Energy Consumption of Distribution Transformers.

Underwriter's Laboratory. UL 1561 Dry Type General Purpose and Power Transformers.

Integrated Design Implications

Measures to improve the efficiency of lighting, mechanical and other building systems will reduce the electric demand and allow the selection of smaller transformers. In addition, measures to reduce the peak demand, such as demand-responsive controls, thermal energy storage, or daylighting controls will lead to a more constant demand over the course of the day. These measures should allow for steadier loading and more efficient transformer operation as long as the transformer is not oversized.

Costs



Incremental costs for efficient transformers can be considerable. For example, a 30-kVA efficient dry-type transformer can cost up to twice as much as a $600 base model. However, estimates show that the transformer will pay back in less than 5 years. The CASE report listed in the references section has more cost information on efficient transformers.

Benefits

Energy savings throughout the life of the transformer (usually about 30 years).

Design Tools

ENERGY STAR's transformer efficiency calculator may be used to calculate savings for any particular utility rates, product prices, or other variables. In just a few minutes, you can determine the per-transformer savings over time that you can gain for office, industrial, or customized commercial facilities. The calculator can be found at www.energystar.gov/index.cfm?c=ci_transformers.pr_ci_transformers.

Design Details

When selecting the transformer capacity, pay attention to efficiency measures and use realistic load estimates. Avoid significant oversizing.

Operation and Maintenance Issues

Transformers usually last more than 30 years and have negligible maintenance requirements due to their design and their lack of moving parts. Dry-type transformers are usually installed or replaced only during new construction or major renovations, or when the load increases dramatically.

Commissioning

Ensure that the transformers installed match the design soecifications.

References / Additional Information

Consortium for Energy Efficiency (CEE). www.cee1.org/ind/trnsfm/trnsfm-main.php3.

Eilert, Patrick. Dry-type Transformers. Codes and Standards Enhancement (CASE) Study. Pacific Gas & Electric Company. 2000. www.newbuildings.org/downloads/codes/Transformers.pdf

Energy Star. Commercial and Industrial Transformers. www.energystar.gov/index.cfm?c=ci_transformers.pr_ci_transformers.

National Electrical Manufacturers Association (NEMA). www.nema.org/.

GUIDELINE OS9: NETWORKED COMPUTER MONITOR CONTROL

Recommendation

Use network controls to enable "sleep" mode on computer monitors after 10 minutes of inactivity.

Figure 181—Networked Computer Monitor

Networked computer monitors controls turn off monitors when not being used and can save up to $1,700 annually for every 100 computers. Source: EPA Web site

Applicable Spaces		Climates		When to Consider	
Classrooms	■	South Coast	■	Programming	□
Library	■	North Coast	■	Schematic	□
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym	□	Mountains	■	Contract Docs.	□
Corridors	□	Desert	■	Construction	□
Administration	■			Commissioning	□
Toilets	□			Operation	■
Other	□				

Description

With schools and students having more access to and interaction with computers, the energy that they use is becoming an issue.

Free software is available to automatically put monitors to rest when not in use. The software also tracks power management and does not affect computer or network performance. A simple touch of the mouse of keyboard "wakes" the machine within seconds.

Applicable Codes

None.

Integrated Design Implications

Networked computer monitor control should be accompanied by other energy-efficient appliances and equipment.

Costs \ Benefits	L	M	H
L	□	□	■
M	□	□	□
H	□	□	□

Costs

None, except some staff time to install and/or activate the free software.

Benefits

Enabling monitor power management could save approximately 20,000 kWh per year for every 100 monitors. This amounts to $1,700 per year saved at 8.5 cents/kWh and enough energy to power 23 households for one month.

CO_2 reductions equivalent to preventing the emissions from three cars or planting 200,000 ft^2 of trees.

The software to enable these controls is often already located on computer systems and available from EPA for free.

Design Tools

The EPA and DOE have developed software tools and services that allow individuals to enable monitor power management quickly and easily. Organizations can activate monitor power management throughout their organization all at once through using EPA's EZ Save network software tool or by taking advantage of organization-wide migrations to Windows 2000 or XP. EZ Save software is available for free from the EPA's Web site: www.energystar.gov/index.cfm?c=power_mgt.pr_pm_easy_save

Network administrators at organizations using the latest Microsoft servers (Windows 2000 or Windows 2003 servers) and operating systems (Windows 2000 or XP) often use Group Policy Objects (GPOs) to manage their organization's desktops. ENERGY STAR's free EZ GPO tool allows a network administrator to centrally control power management settings using GPOs. In addition to setting monitor power management, EZ GPO can also activate "system standby," which places the PC box to sleep. This software can be downloaded at this EPA Web site: www.energystar.gov/index.cfm?c=power_mgt.pr_pm_ez_gpo

Design Details

Note that Windows NT 4.0 Workstation operating system does not support power management. The software tools will not set monitor power management on a computer running Windows NT. Solutions include migration to another operating system, and hardware monitor controls.

Operation and Maintenance Issues

Ensure that the power management control is not turned off.

Commissioning

None.

References / Additional Information

U.S. Environmental Protection Agency; Power Management. www.energystar.gov/powermanagement/index.asp

EZ-Conserve. www.ezconserve.com

GUIDELINE OS10: EFFICIENT VENDING MACHINES

Recommendation

Specify that beverage vending machine controls are installed to minimize energy used by vending machines, or request ENERGY STAR-qualified beverage vending machines. Turn off beverage and non-refrigerated snack vending machines during summer and other long breaks.

Figure 182—Efficient Vending Machine

Vending machines can cost up to $300 annually per machine to operate. Source: Enterprise Vending

Applicable Spaces		Climates		When to Consider	
Classrooms		South Coast	■	Programming	
Library		North Coast	■	Schematic	
Multi-Purpose / Cafeteria	■	Central Valley	■	Design Dev.	■
Gym		Mountains	■	Contract Docs.	
Corridors		Desert	■	Construction	
Administration	■			Commissioning	
Toilets				Operation	■
Other	■				

Description

Vending machines consume 7–14 kilowatt-hours/day of electricity, depending on size: that can be as much as $300 a year to operate each vending machine in a school district.

For new vending machines, request an ENERGY STAR-qualified beverage vending machine. The ENERGY STAR Web page has more information on where to purchase efficient vending machines at www.energystar.gov/index.cfm?c=vending_machines.pr_vending_machines.

For existing or older vending machines,
VendingMiser is a control that reduces the energy consumption of cold drink vending machines by using an occupancy sensor to power down the lights and compressor. A temperature sensor powers the machine back up as needed to keep drinks cold. The device is invisible to the user since the lights come on when an occupant is detected.

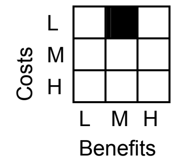
Applicable Codes

None.

Integrated Design Implications

Vending machine efficiency controls and options should be accompanied by other energy-efficient appliances, equipment, and technologies.

Costs



Minimal cost for controls: Vending Miser sells for about $200 for each machine. Some vending companies are now providing machines that have similar controls already built into the unit. Ask your vendor about these options. Some cities and/or states offer a rebate for purchasing vending machine controls.

Benefits

ENERGY STAR beverage vending machines and machines using VendingMiser have been shown to provide average energy savings of 35%–40%. This translates into a reduction of $55 to $130 in the annual electricity bill for each machine. For a district with 1,000 vending machines, that can be savings of $55,000–$130,000 annually. Turning off machines completely during the summer months or during breaks can save even more energy and dollars.

Design Tools

Land of Sky Regional Council's "Vending Machines: Utility Savings Initiative" fact sheet provides a tool to calculate potential savings: www.optimumenergy.com/management/miser.html

Design Details

None.

Operation and Maintenance Issues

Make sure that maintenance and custodial staff understand how vending machines are intended to be operated—with lights off and the control cycling the machine itself on and off as needed. Place stickers on the vending machines explaining to users that the machine is operational but that the lights are switched off to save energy. Unplug the vending machine over summer and other long breaks.

Commissioning

None.

References / Additional Information

Land of Sky Regional Council. "Vending Machines: Utility Savings Initiative Fact Sheet." www.p2pays.org/ref/32/31320.pdf

City of Seattle Energy Smart Services. "Vending Machine Energy Conservation" fact sheet. www.ci.seattle.wa.us/light/conserve/business/cv5_vm.htm

U.S. Environmental Protection Agency (EPA). ENERGY STAR Refrigerated Beverage Vending Machines. www.energystar.gov/index.cfm?c=vending_machines.pr_vending_machines