Advanced Energy Design Guide for K-12 School Buildings

Achieving 30% Energy Savings Toward a Net Zero Energy Building

Developed by:
American Society of Heating, Refrigerating, and Air-Conditioning Engineers
The American Institute of Architects
Illuminating Engineering Society of North America
U.S. Green Building Council
U.S. Department of Energy

Advanced Energy Design Guide for K-12 School Buildings

This is an ASHRAE Design Guide. Design Guides are developed under ASHRAE's Special Publication procedures and are not consensus documents. This document is an application manual that provides voluntary recommendations for consideration in achieving greater levels of energy savings relative to minimum standards.

This publication was developed under the auspices of ASHRAE Special Project 111.

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DOE

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Paul Torcellini
SP-111 Chair
December 2007

Abbreviations and Acronyms

A	=	area, ft^2
ACCA	=	Air Conditioning Contractors of America
AEDG-SR	=	*Advanced Energy Design Guide for Small Retail Buildings*
AFUE	=	annual fuel utilization efficiency, dimensionless
AHU	=	air-handling unit
AIA	=	American Institute of Architects
ANSI	=	American National Standards Institute
ASHRAE	=	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	=	American Society for Testing and Materials
AV	=	audiovisual
BAS	=	building automation system
BF	=	ballast factor
BPA	=	Bonneville Power Administration
Btu	=	British thermal unit
C-Factor	=	thermal conductance, $Btu/(h \cdot ft^2 \cdot °F)$
CA	=	census area
CD	=	construction documents
CFL	=	compact fluorescent lamp
cfm	=	cubic feet per minute
CHPS	=	Collaborative for High Performance Schools
CHW	=	chilled water
c.i.	=	continuous insulation
CM	=	construction manager
CMH	=	ceramic metal halide
CMU	=	concrete masonry unit
CO_2	=	carbon dioxide
COP	=	coefficient of performance, dimensionless
CPE	=	chlorinated polyethylene
CPSE	=	chlorosulfonated polyethylene
CRI	=	color-rendering index
CRRC	=	Cool Roof Rating Council
Cx	=	commissioning

CxA	=	commissioning authority
CU	=	coefficient of utilization, dimensionless
D	=	diameter, ft
DCV	=	demand-controlled ventilation
DL	=	Advanced Energy Design Guide code for “daylighting”
DOAS	=	dedicated outdoor air system
DOE	=	U.S. Department of Energy
DSP	=	daylighting saturation percent
DX	=	direct expansion
E_c	=	efficiency (combustion), dimensionless
E_t	=	efficiency (thermal), dimensionless
E	=	emittance
EER	=	energy efficiency ratio, Btu/W·h
E	=	efficiency
EF	=	energy factor
EIA	=	Energy Information Agency
EL	=	Advanced Energy Design Guide code for “electric lighting”
EMCS	=	energy management control systems
EN	=	Advanced Energy Design Guide code for “envelope”
EPA	=	U.S. Environmental Protection Agency
EPDM	=	ethylene propylene diene monomer
EPRI	=	Electric Power Research Institute
ERV	=	energy recovery ventilator
ESP	=	external static pressure, dimensionless
EX	=	Advanced Energy Design Guide code for “exterior lighting”
F-Factor	=	slab-edge heat loss coefficient per foot of perimeter, Btu/(h·ft·°F)
FFR	=	daylighting fenestration to floor area ratio, dimensionless
ft	=	feet
FWR	=	vertical fenestration to gross exterior wall area ratio, dimensionless
GC	=	general contractor
GSHP	=	ground-source heat pump
Guide	=	*Advanced Energy Design Guide for K-12 School Buildings*
HC	=	heat capacity, Btu/(ft^2·°F)
HID	=	high-intensity discharge
HO	=	high-output lighting
H_2O	=	water
HP	=	high performance
hp	=	horsepower
HSPF	=	heating season performance factor, Btu/Wh
HV	=	Advanced Energy Design Guide code for “HVAC systems and equipment”
HVAC	=	heating, ventilating, and air-conditioning
HW	=	hot water
IAQ	=	indoor air quality
IEEE	=	Institute of Electrical and Electronics Engineers
IESNA	=	Illuminating Engineering Society of North America
in.	=	inches
IPLV	=	integrated part-load value
IR	=	infrared
ISO	=	International Standards Organization
K	=	kindergarten
kBtuh	=	thousands of British thermal units per hour
kW	=	kilowatt

LBNL	=	Lawrence Berkeley National Laboratory
LCD	=	liquid crystal display
LED	=	light-emitting diode
LEED™	=	Leadership in Energy and Environmental Design
lm	=	lumens
LPD	=	lighting power density, W/ft^2
M	=	million
MERV	=	minimum efficiency reporting values
MLPW	=	mean lumens per watt
MPM	=	monitor power management
MTC	=	Massachusetts Technology Collaborative
MZS	=	multiple-zone recirculating ventilation system
N/A	=	not applicable
NBI	=	New Buildings Institute
NCEF	=	National Clearinghouse for Educational Facilities
NEMA	=	National Electrical Manufacturers Association
NFRC	=	National Fenestration Rating Council
NIBS	=	National Institute of Building Sciences
NREL	=	National Renewable Energy Laboratory
NZEB	=	net zero energy buildings
OA	=	outdoor air
O&M	=	operations and maintenance
OPR	=	owner's project requirements
PAR	=	parabolic aluminized reflector
PF	=	projection factor
PIR	=	passive infrared
PL	=	Advanced Energy Design Guide code for "plug loads"
ppm	=	parts per million
psf	=	pounds per square foot
PV	=	photovoltaic
PVC	=	polyvinyl chloride
QA	=	quality assurance
QMH	=	quartz metal halide
R-Value	=	thermal resistance, (h·ft^2·°F)/Btu
RCR	=	room-cavity ratio
RFP	=	request for proposal
RFQ	=	request for qualifications
RPI	=	Rensselear Polytechnic Institute
SBIC	=	Sustainable Buildings Industry Council
SEER	=	seasonal energy efficiency ratio, Btu/W·h
SHGC	=	solar heat gain coefficient, dimensionless
SP	=	standard series lamps
SPx	=	premium series lamps
sq	=	square
SRI	=	solar reflectance index, dimensionless
SSPC	=	standing standards project committee
SWH	=	service water heating
TC	=	technical committee
TDV	=	thermal displacement ventilation
TSO	=	thermoplastic polyolefin
TV	=	television
U-Factor	=	thermal transmittance, Btu/(h·ft^2·°F)

UPS	=	uninterruptible power supply
USGBC	=	U.S. Green Building Council
VAV	=	variable-air-volume
VFD	=	variable-frequency drives
VLT	=	visible light transmission
VSD	=	variable speed drive
W	=	watts
w.c.	=	water column
WH	=	Advanced Energy Design Guide code for “water heating systems and equipment”
WSHP	=	water source heat pump

Foreword: A Message to School Administrators and School Boards

The *Advanced Energy Design Guide for K-12 School Buildings* can help you use *ANSI/IESNA/ASHRAE Standard 90.1-1999, Energy Standard for Buildings Except Low-Rise Residential Buildings* as a benchmark to build new schools that are 30% more energy efficient than current industry standards. This saves energy and, perhaps more importantly, helps you enhance your school's educational mission.

IMPROVED LEARNING ENVIRONMENT

A better environment that includes favorable light, sound, and temperature can help students learn better. In many cases, improving these attributes can also reduce energy use. In *Greening America's Schools: Costs and Benefits*, Greg Kats provides 17 studies that demonstrate productivity increases of 2% to more than 25% from improved indoor air quality, acoustically designed indoor environments, and high-performance lighting systems.[1]

Some of these studies show that daylighting, which uses the sun to produce high-quality, glare-free lighting, can improve academic performance by as much as 20%. Because it requires little or no electrical lighting, which can increase cooling loads, daylighting is also a key strategy for achieving energy savings. Quality lighting systems include a combination of daylighting and energy-efficient electric lighting systems. These complement each other by reducing visual strain and providing better lighting quality.

Advanced energy-efficient heating and cooling systems provide thermal comfort and are quiet. This produces quieter, more comfortable, and more productive spaces. Various studies show that noise exposure—even modest levels of ambient noise—negatively affects educational outcomes. The impact on learning is magnified for younger children.

Advanced, energy-efficient heating and cooling systems create cleaner, healthier indoor environments that lower student and staff absentee rates and improve teacher retention. This translates into higher test scores and lower staff costs. For example, Ash Creek Intermediate School in Oregon has reduced absenteeism (compared to the previous facility) by 15%.

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1. Greening America's Schools Costs and Benefits, A Capital E Report, October 2006. Report prepared by Gregory Kats. Sponsoring organizations include American Federation of Teachers, American Institute of Architects, American Lung Association, Federation of American Scientists, and the U.S. Green Building Council. www.cap-e.com.

REDUCED OPERATING COSTS

Many schools spend more money on energy each year than on school supplies. By using energy efficiently and lowering a school's energy bills, millions of dollars each year can be redirected into facilities, teachers' salaries, computers, and textbooks. Strategic up-front investments in energy efficiency provide significant long-term savings. Durant Road Middle School in Raleigh, North Carolina, uses many of the recommendations in this Guide. The school saves thousands of dollars annually, and recouped its initial investment within two years. The total annual energy cost in 2006 was only $1.01/ft^2. Smart use of a site's climatic resources and more efficient envelope design are keys to reducing a building's overall energy requirements. Efficient equipment and energy management programs then help meet those requirements more cost effectively. Because of growing water demand and shrinking aquifers, the price of water is escalating at 10% per year or greater in some areas. Saving energy generally means saving water. Lower operating costs mean less fluctuation in budgets because of price instabilities of energy. Purchasing energy efficiency is buying into energy futures at a known fixed cost.

LOWER CONSTRUCTION COSTS/FASTER PAYBACK

Ideally, energy-efficient schools would cost the same or less to build than a typical school. We have been trained to think that energy efficiency must cost more; however, thoughtfully designed, energy-efficient schools can cost less to build. For example, optimizing the envelope to match the climate can substantially reduce the size of the mechanical systems. A school with properly designed north-south glazing will have lower mechanical costs than one with the same amount of glazing on an east-west orientation and will cost less to build. The heating systems at the Topham Elementary School in Langley, British Columbia, requires half as much heat as the next most efficient school in its district, costs half as much to maintain, and was less expensive to install. More efficient lighting means fewer lighting fixtures are needed. Better insulation and windows mean heating systems can be downsized. Likewise, cooling systems can often be downsized with a properly designed daylighting system and a better envelope.

Some strategies may cost more up front, but the energy they save means they often pay for themselves within a few years.

MORE SUPPORT FOR CONSTRUCTION FUNDING

Lower construction and operating costs also signify responsible stewardship of public funds. This translates into greater community support for school construction financing, whether through local district bonds or state legislative action.

ENHANCED ENVIRONMENTAL CURRICULUM

Schools that incorporate energy efficiency and renewable energy technologies make a strong statement about the importance of protecting the environment. They also provide hands-on opportunities for students and visitors to learn about these technologies and about the importance of energy conservation. Figure 1 shows a student at Desert Edge High School in Goodyear, Arizona, accessing information from an educational kiosk.

ENERGY SECURITY

Building an energy-conserving school reduces its vulnerability to volatile energy pricing. The price of natural gas increased more than 270% between 1994 and 2004. The price of oil continues to climb as part of an upward trend. Additionally, approximately 60% of US oil is now imported. The United States is also importing electricity and natural gas. Using less energy contributes to a more secure future for our country and our communities.

Photo courtesy of Agua Fria school district and Quality Attributes Software /Green Touchstone

Figure 1. A student at Desert Edge High School in Goodyear, Arizona, accesses information from an education kiosk.

WATER AS A RESOURCE

Water is a rapidly depleting natural resource. Though this Guide deals only with direct building-related energy conservation measures, water savings result in related energy savings. Water savings from low-flow fixtures and reduced water use from efficient landscaping result in related energy savings from pumping and waste disposal. Potable water savings also result in water supply and processing energy savings of 10–25 Btu per gallon of water saved.[2] Water is also used to produce electricity and to extract and process fossil fuels. Saving energy saves water.

REDUCED GREENHOUSE GAS EMISSIONS

According to the U.S. Environmental Protection Agency, buildings are responsible for almost half (48%) of all greenhouse gas emissions annually in the United States. Carbon dioxide, which is produced when fossil fuel is burned, is the primary contributor to greenhouse gas emissions. School districts can be a part of the solution when they reduce their consumption of fossil fuels for heating, cooling, and electricity. Students and their parents will appreciate this forward-thinking leadership.

ACHIEVING THE 30% ENERGY SAVINGS GOAL

Building a new school to meet or exceed a 30% energy savings goal is not difficult, but it does take some thought. First and foremost, it requires that the school system commit to the goal. A commitment that is incorporated in district policy is helpful. An individual from the school with decision-making power needs to act as a champion for the goal. The team must be willing and able to produce a design that meets the energy savings goals. It must also ensure that the building is constructed as designed and that school system staff is trained to operate the energy systems properly.

Design Team

To help optimize your design, reference your energy goal and this Guide in your request for qualifications/request for proposals (RFQ/RFP). Ideally, your prospective design team is already familiar with the Guide. Regardless, the team you select should have an established record of constructing buildings that operate with significant energy savings.

2. Energy Index Development for Benchmarking Water and Wastewater Utilities. Report prepared by Steven W. Carlson and Adam Walburger, CDH Energy Corp. Published by the AWWA Research Foundation, 2007.

Design firms that successfully coordinate project team members, bring in building users and facilities staff for input, and use an iterative process to test design concepts are more likely to achieve the 30% goal cost-effectively.

If you use the prescriptive measures recommended in this Guide, you can realize energy savings of at least 30% without computer building energy modeling. However, properly performed computer building energy modeling can help you optimize your design and will result in lower up-front construction costs and energy savings that often exceed 50%. Consider the design team's energy modeling capabilities during the architect/engineer selection process to achieve even greater savings.

Good daylighting can contribute to the 30% goal; however, it requires good technical daylighting design. If the design team does not have experience with a well-balanced daylighting design, a daylighting consultant should probably be added to the team. Some universities and utilities provide daylighting consulting at low or no cost.

Commissioning Authority (aka Commissioning Agent)

A building can have the best possible design for achieving energy savings, but unless it is constructed as designed and is operated according to the design intent, it will not realize energy savings. A commissioning authority (CxA) ensures that the energy- and water-saving methods and devices selected by the design team are incorporated in the building plans and specifications; that everything is built and tested accordingly; and that school personnel, including those occupying the building, are provided the necessary documentation and training to operate the building properly after it is occupied. The CxA can be an independent member of the design firm, the school's facility staff, or a third-party consultant. Some prefer to use third-party consultants for this role to ensure that the work is done independently of the design team and that the results are not biased. More information on commissioning is available in Chapter 5 and Appendix B.

School Personnel

Operations and maintenance personnel and teachers must be trained in the proper operation of a school's energy systems when the building is occupied. Initial training should be backed up by a long-term commitment to maintain an informed staff, including administrative, instructional, and facilities personnel, and to fund proper upkeep over the life of the installed systems. Scheduling and monitoring are important to ensure timely preventative maintenance. In addition, we recommend that any substantive changes made by facilities personnel be well documented and reviewed in the context of the original design.

A GOAL WITHIN REACH

Saving 30% or more on energy is within the reach of any school district with the will to do so. It is a good deal for students, teachers, administrators, and taxpayers. Join us in the goal to save energy, save money, protect the environment, and create a more secure energy future. We look forward to learning about your new energy-efficient schools through the case study database at www.ashrae.org/aedg.

1 Introduction

The *Advanced Energy Design Guide for K-12 School Buildings* was written to help owners and designers of elementary, middle, and high school buildings achieve energy savings of at least 30% compared to the minimum requirements of *ANSI/ASHRAE/IESNA Standard 90.1-1999, Energy Standard for Buildings Except Low-Rise Residential Buildings,* which serves as a baseline. This baseline is consistent with other Advanced Energy Design Guides in the series. One significant addition is the inclusion of daylighting options in the recommendations. This Guide contains recommendations only and is not a code or standard.

The Guide is intended to show that achieving the 30% target is not only possible, but easy. Case studies showcase schools around the country that have achieved or exceeded the target—the technologies are available to do the job.

By specifying a target goal and identifying paths for each climate zone to achieve the goal, the Guide provides some ways to meet the 30% target and build K-12 schools that use substantially less energy than those built to minimum energy-code requirements. This Guide provides *a* way, but not the *only* way to achieve the 30% energy savings target, and since there may be other ways of achieving this goal, we hope the Guide generates ideas for innovation.

The Guide was developed by a project committee that represents a diverse group of professionals. Guidance and support was provided through a collaboration of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IESNA), the U.S. Green Building Council (USGBC), and the U.S. Department of Energy (DOE). Members of the project committee come from these partner organizations: the ASHRAE Standing Standards Project Committee 90.1 (SSPC 90.1), the ASHRAE Technical Committee on Educational Facilities (TC 9.7), the Sustainable Building Industry Council (SBIC), the Collaborative for High Performance Schools Project (CHPS), and the National Clearinghouse for Educational Facilities (NCEF) at the National Institute of Building Sciences (NIBS).

The 30% energy savings target is the first step toward achieving *net zero energy schools*—schools that, on an annual basis, draw from outside sources less or equal energy than they generate on site from renewable energy sources. For more information on net zero energy buildings, see the references in Appendix E, "Additional Resources."

Other Guides in this series include the *Advanced Energy Design Guide for Small Office Buildings*, the *Advanced Energy Design Guide for Small Retail Buildings*, and the soon-to-be-pulished *Advanced Energy Design Guide for Small Warehouses and Self Storage Buildings* (www.ashrae.org/aedg).

SCOPE

This Guide applies to K-12 (classified as elementary, middle, and high schools) buildings with administrative and office areas, classrooms, hallways, restrooms, gymnasiums, assembly spaces, food preparation spaces, and dedicated spaces such as media centers and science labs. This Guide does not consider specialty spaces such as indoor pools, wet labs (e.g., chemistry), "dirty" dry labs (e.g., wood-working or auto shop), or other unique spaces with extraordinary heat or pollution generation. It is primarily intended for new construction, but it may be equally applicable to many school renovation, remodeling, and modernization projects.

Included in the Guide are recommendations for the design of the building envelope; fenestration; lighting systems (including electrical lights and daylighting); heating, ventilation, and air-conditioning (HVAC) systems; building automation and controls; outside air (OA) treatment; and service water heating (SWH). Additional savings recommendations are also included but are not necessary for 30% savings. Additional savings recommendations are provided for electrical distribution, plug loads, renewable energy systems, and using the building as a teaching tool.

The recommendation tables do not include all the components listed in, ASHRAE Standard 90.1-1999. Though this Guide focuses only on the primary energy systems within a building, the underlying energy analysis presumes that all the other components are built to the criteria in Standards 90.1 and 62.1.

Certain aspects of energy-efficient school design, including steam heat, modular classrooms, vehicle and maintenance areas, domestic water well piping, kitchen process loads (e.g., ovens, coolers, freezers), and sewage disposal are excluded from the Guide. Significant energy-efficiency opportunities may be available in these areas, and Guide users are encouraged to take advantage of these opportunities and treat them as bonuses beyond the 30% target. In addition, the Guide is not intended to substitute for rating systems or references that address the full range of sustainable issues in schools, such as acoustics, productivity, indoor air quality (IAQ), water efficiency, landscaping, and transportation, except as they relate to energy use. This Guide is not a design text; rather, it presumes good design skills and expertise in school design.

SCHOOL PROTOTYPES

To provide a baseline for this Guide, three school prototype designs with a variety of envelope, lighting, and HVAC configurations were developed and analyzed by using hourly building simulations in eight climate zones. The designs include a 74,500 ft^2 elementary school, an 112,000 ft^2 middle school, and a 205,000 ft^2 high school, each of which was carefully assembled to be representative of construction for schools of that class. Information was drawn from a number of sources and various school templates from around the country. The space types included in the prototype designs are shown in Table 1.1.

Two sets of hour-by-hour simulations were run for each prototype. The first set meets the minimum requirements of ASHRAE Standard 90.1-1999, and the second uses the recommendations in this Guide to achieve 30% energy savings. This process was repeated for all climate zones. All materials and equipment used in the simulations are commercially available from two or more manufacturers.

Energy savings for the recommendations vary depending on climate zones, daylighting options, HVAC system type, and school type, but in all cases are at least 30% when compared to ASHRAE 90.1-1999. The savings as compared to ASHRAE 90.1-1999 for

Table 1.1. Prototype Designs Space Types

Space Types	Elementary	Middle	High
Classrooms	×	×	×
Library	×	×	×
Media center	×	×	×
Computer lab	×	×	×
Science lab		×	×
Music	×	×	×
Arts/crafts	×	×	×
Multipurpose room	×		×
Auditorium/theater			×
Special ed/resource	×	×	×
Gymnasium		×	×
Auxiliary gymnasium			×
Offices	×	×	×
Infirmary/clinic	×	×	×
Cafeteria	×	×	×
Kitchen	×	×	×
Hall lockers		×	×

the options with daylighting but without high efficiency electrical lighting ranged from 34%–50%. The savings for the options without daylighting but with high efficiency electrical lighting, ranged from 32%–45%.

Analysis was also made to determine energy savings of at least 30% when compared to ASHRAE Standard 90.1-2004. The savings as compared to ASHRAE 90.1-2004 for the options with daylighting but without high efficiency electrical lighting ranged from 30%–45%. The savings for the options without daylighting but with high efficiency electrical lighting ranged from 24%–41%. Complete results of the prototype school simulations are presented in the *Technical Support Document: Development of the Advanced Energy Design Guide for K-12 School Buildings*, available at www.ashrae.org/aedg.

ACHIEVING 30% ENERGY SAVINGS

Meeting the 30% energy savings goal is not difficult, but it requires more than doing business as usual. Here are the essentials.

1. *Obtain school district buy-in.* There must be strong buy-in from the school district's leadership and staff. The more they know about and participate in the planning and design process, the better they will be able to help achieve the 30% goal after the school becomes operational. See the NCEF resource list, "School Energy Savings," at www.ncef.org for one source of information about obtaining support for building energy-efficient, high-performance schools. The building owner must decide on the goals and provide the leadership to make the goals reality.
2. *Assemble an experienced, innovative design team.* Interest and experience in designing energy-efficient buildings, innovative thinking, and the ability to work together as a team are all critical to meeting the 30% goal. The team achieves this goal by creating a school that maximizes daylighting, minimizes heating and cooling loads, and has highly efficient lighting and HVAC systems. Energy goals should be communicated in the RFP and design team selection based in part on the team's ability to meet the goals. The design team implements the goals for the owner.
3. *Adopt an integrated design approach.* Cost-effective, energy-efficient design requires trade-offs among potential energy-saving features. This requires an integrated approach

to school design. A highly efficient lighting system, for instance, may cost more than a conventional one, but because it produces less heat, the building's cooling system can often be downsized. The greater the energy savings, the more complicated the trade-offs become and the more design team members must work together to determine the optimal mix of energy-saving features. Because many options are available, the design team will have wide latitude in making energy-saving trade-offs. This Guide uses an integrated approach to achieve the energy savings by creating an envelope that can provide most of the heating, cooling, and lighting for the building.

4. *Consider a daylighting consultant.* Daylighting can be an important energy savings strategy that has additional academic benefits; however, it requires good technical daylighting design. If the design team does not have experience with a well-balanced daylighting design, it may need to add a daylighting consultant. Some universities and utilities provide daylighting consultations at low or no cost.
5. *Consider energy modeling.* This Guide is designed to help achieve energy savings of 30% without energy modeling, but energy modeling programs that simulate hourly operation of the building and provide annual energy usage data make evaluating energy-saving trade-offs faster and far more precise. These programs have learning curves of varying difficulty, but energy modeling for school design is highly encouraged and is considered necessary for achieving energy savings beyond 30%. See DOE's "Building Energy Software Tools Directory" at http://www.eere.energy.gov/buildings/tools_directory for links to energy modeling programs. Part of the key to energy savings is using the simulations to make envelope decisions first and then evaluating heating, cooling, and lighting systems. Developing HVAC load calculations is *not* energy modeling and is *not* a substitute for energy modeling.
6. *Use building commissioning.* Studies verify that building systems, no matter how carefully designed, are often improperly installed or set up and do not operate as efficiently as expected. The 30% goal can best be achieved through building commissioning (Cx), a systematic process of ensuring that all building systems—including envelope, lighting, and HVAC—perform as intended. The Cx process works because it integrates the traditionally separate functions of building design, system selection, equipment startup, system control calibration, testing, adjusting and balancing, documentation, and staff training.

   The more comprehensive the Cx process, the greater the likelihood of energy savings. A commissioning authority (CxA) should be appointed at the beginning of the project and work with the design team throughout the project. Solving problems in the design phase is more effective and less expensive than making changes or fixes during construction. See Appendix B and the "Commissioning" section of Chapter 5 of this Guide for more information, as well as Appendix E for additional resources.
7. *Train building users and operations staff.* Staff training can be part of the building Cx process, but a plan must be in place to train staff for the life of the building to meet energy savings goals. The building's designers and contractors normally are not responsible for the school after it becomes operational, so the school district must establish a continuous training program that helps occupants and operations and maintenance (O&M) staff maintain and operate the school for maximum energy efficiency. This training should include information about the impact of plug loads on energy use and the importance of using energy-efficient equipment and appliances. One source of information about staff training is the NCEF resource list "School Facilities Management" at www.ncef.com.
8. *Monitor the building.* A monitoring plan is necessary to ensure that energy goals are met over the life of the building. Even simple plans, such as recording and plotting monthly utility bills, can help ensure that the energy goals are met. Buildings that do not meet the design goals often have operational issues that should be corrected.

HOW TO USE THIS GUIDE

- Review Chapter 2 to understand how an integrated design approach is used to achieve 30% or greater energy savings. Checklists show how to establish and maintain the energy savings target throughout the project.
- Use Chapter 3 to select specific energy saving measures by climate zone. This chapter provides a prescriptive path that does not require modeling for energy savings. These measures also can be used to earn credits for CHPS, LEED®, and other building rating systems.
- Review the case studies in Chapter 4 to see how the 30% energy savings goal has been met in schools in climate zones across the country.
- Use Chapter 5 to apply the energy saving measures in Chapter 3. This chapter has suggestions about best design practices, how to avoid problems, and how to achieve additional savings with energy-efficient appliances, plug-in equipment, and other energy saving measures.

An Integrated Design Approach to Achieve Savings

2

The integrated design process strives to minimize the building loads by selecting an appropriate building site and increasing envelope thermal efficiency. This usually reduces the demand on subsystems such as HVAC, lighting, plumbing, and power. Integration encourages the right-sizing of building systems and components that allows for reduced first and life-cycle costs. A successful integrated design approach provides the best energy performance at the least cost and is characterized as follows:

- *It is resourceful.* Integrated design begins with site assessment and selection. Site selection is an opportunity to obtain free energy resources. Daylighting can provide most lighting needs in many locations, passive solar heat can reduce mechanical heating loads, external overhangs can reduce cooling loads, and photovoltaic (PV) panels can reduce the amount of electricity that needs to be produced by fossil fuels. Proper building orientation, form, and layout provide substantial energy savings.
- *It is multidisciplinary.* Integrated design goes beyond the conventional practice of a kick-off meeting with the designers and their consultants. Instead, it involves the owner, designers, technical consultants, construction manager (CM), CxA, facility staff, and end users in all phases of the project. The process requires cross-disciplinary design and validation at all phases of the process.
- *It is goal driven.* A goal-setting session early in the design process can identify strategies to meet energy-efficiency and other sustainable building goals in relation to the school's mission. Goals must be quantifiable and measurable. Insisting on a well-defined Basis of Design at the beginning of the project will help ensure that the energy goals and objectives are integrated into the design and considered throughout the project. By including school district representatives, parents, and, when appropriate, students in this session, the likelihood of generating integrated, creative solutions is greatly increased. Aligning design goals with learning and including those invested in the school's mission are key to a successful project.
- *It is iterative.* A goal-setting session is just the beginning. As the design concept takes shape, it needs to be tested to determine which strategies will result in desired energy performance, optimized maintenance requirements, and reduced life-cycle costs. Preferably, this takes the form of energy modeling at key points in the design process. It also requires that time be set aside during design reviews to discuss system-level energy use.

The CxA, who may be a member of the school district's facility staff, an independent staff member from the design firm, or an outside consultant, is an integral part of this iterative process. He or she validates that the design documents meet the energy savings goals, that the building is constructed as designed, and that the school staff knows how to use, operate, and maintain the building to achieve the energy savings goals.

The following presentation of an integrated process for achieving energy savings in new school buildings is valuable for designers and builders who want to augment and improve their practices so that energy efficiency is deliberately considered at each stage of the development process from project conception through building operation. The tasks to be completed in each design, construction, and operation phase are identified, and responsibilities are assigned in Tables 2.1–2.4.

PRE-DESIGN PHASE

Adopting measurable energy goals at the beginning of the project will guide the team and provide a benchmark throughout the project's life. General strategies that relate to these goals will be identified at this phase as part of the goal discussions. Strategies will be further refined and confirmed during the design phase. Because of the nature of school buildings, goal setting should include consideration of the community context and curriculum opportunities. One example is to prioritize an energy strategy that also teaches. Another example would be to identify synergies with other facility uses to avoid constructing unnecessary buildings. Daylighting, as an energy-saving strategy that is uniquely important to classroom design, needs to be decided on early in the process so it can be integrated into the whole building design.

Emphasize goals that relate to large energy uses and can produce the most savings. Priorities are likely to vary significantly from one climate zone to another and may vary between schools in the same climate zone. Site conditions can significantly affect energy performance. For example, differences in building application, climate, and orientation will affect the selection of various energy goals and strategies. Figure 2.1 shows the baseline energy use for a 74,500 ft^2 elementary school in the 15 climate zones. It demonstrates that cooling and lighting energy predominates in climate zone 1 (Miami is in 1A, a subset of climate zone 1), so the goals and strategies for cooling and lighting should

Table 2.1. Energy Goals in the Context of the Pre-Design Phase

Activities	Responsibilities
Select the core team • Include energy goals in the RFP • Designers (including project architect and engineer and other design consultants) • CxA • CM	Owner
Adopt energy goals	Owner and designers
Assess the site • Evaluate centrality to the community • Evaluate access to public transportation • Identify on-site energy opportunities • Identify best building orientation	Owner, designers, CM
Define functional and spatial requirements	Owner and designers
Define energy efficiency and budget benchmarks	Owner, designers, CM, estimator
Prepare the design and construction schedule	Owner, designers, CM
Determine building envelope and systems preferences	Owner, designers, CM
Perform cost/benefit analysis for energy strategies	Owner and designers
Identify applicable energy code requirements	Owner and designers

Table 2.2. Energy Goals in the Context of the Design Phase

Activities	Responsibilities
Prepare diagrammatic building plans that satisfy functional program requirements	Designers
Develop specific energy strategies	Owner, designers, CM, CxA
Develop the site plan to make best use of building orientation and daylighting strategies	Designers
Select building systems, taking into account their desired energy efficiency	Owner, designers, CM
Develop building plans, sections, and details incorporating the above strategies	Designers
Develop architectural and lighting details (for example, lighting, fenestration, exterior sun control, taking into account their energy implications)	Designers
Refine the design (for example, refine the building elevations to reflect the appropriate location and size of windows)	Designers
Perform design reviews at each phase of the project to verify that the project meets functional and energy goals	Owner, designers, CM, CxA
Calculate building HVAC loads AND run energy models to optimize design at each design stage (schematic, design development, and construction drawings) to ensure that energy goals are being met; use recommended loads for lighting power density from this Guide.	Designers
Match capacity of HVAC systems to design loads to avoid costly overdesign, specify equipment efficiency as recommended by this Guide	Designers
Perform final coordination and integration of architectural, mechanical, and electrical systems	Designers
Prepare specifications for all systems	Designers
Integrate Cx specifications into project manual	Designers and CxA
Prepare cost estimates at each phase of design	CM, CxA, estimator
Review and revise final design documents	Owner, designers, CxA

Table 2.3. Energy Goals in the Context of the Bidding and Construction Phase

Activities	Responsibilities
At the pre-bid conference, emphasize energy-efficiency measures and the Cx process	Owner, designers, CM, CxA
At all job meetings, review energy efficiency measures and Cx procedures	Owner, designers, CM, CxA
Verify that building envelope construction carefully follows the drawings and specifications	Designers, CxA
Verify that HVAC and electrical systems meet specifications	Designers, CxA

Table 2.4. Energy Goals in the Context of the Acceptance Phase

Activities	Responsibilities
Prepare pre-occupancy punch list	Owner, designers, CM, CxA
Conduct system performance tests	Designers, CM, CxA, general contractor, subcontractor
Submit completed O&M manuals	CxA, general contractor, subcontractor
Provide O&M training for school staff	CxA, general contractor, subcontractor
Establish building O&M program	CxA, general contractor, subcontractor, facility staff
Resolve any remaining Cx issues identified during the construction or occupancy phase	Owner, CM, CxA, general contractor, subcontractor
Certify building as substantially complete	Owner, designers, CM, CxA
Purchase computers and other energy using appliances that meet ENERGY STAR® efficiency to reduce plug loads	Owner, facility staff
Monitor post-occupancy performance for one year	CxA, facility staff
Create post-occupancy punch list	CxA, facility staff
Grant final acceptance	Owner, designers, CM, CxA

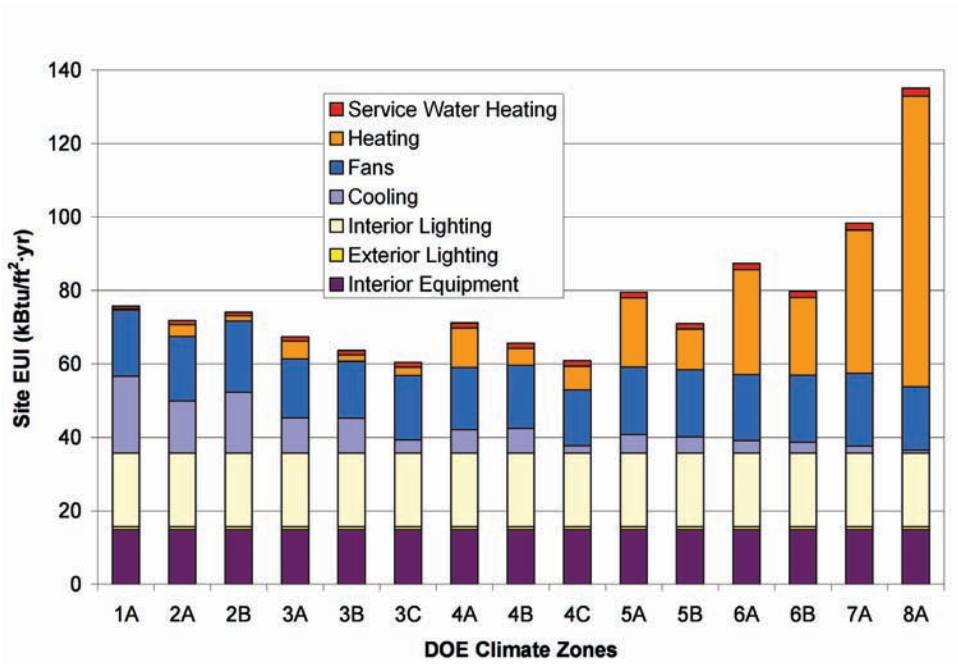


Figure 2.1. Elementary school annual baseline end uses across climate zone.

receive the highest priorities. In climate zone 8 (Fairbanks), the goals and strategies for heating and lighting should receive the highest priority. Table 2.1 lists strategies to follow to keep the pre-design phase in line with energy design goals.

DESIGN PHASE

In the design phase, the project team develops and incorporates energy strategies into building plans and specifications. This will have a major impact on the overall energy performance of the building as constructed. Design choices should be in order as follows:

1. Optimize on-site resources, especially daylighting
2. Reduce energy loads
3. Size systems properly
4. Incorporate efficient equipment

At each point, the decisions should take into account other priorities and systems decisions. For example, cooling system sizing should take into account daylighting measures, glazing sizes, and building orientation.

The CxA reviews the design to verify that the project goals are being met. The CxA should also verify that the assumptions for HVAC load calculations and other modeling assumptions are based on actual design parameters rather than on rule of thumb. Information about how to integrate the Cx process into your project is included in Chapter 5. Table 2.2 lists strategies to follow to keep the design phase in line with energy design goals.

BIDDING AND CONSTRUCTION

Even the best design will not yield the expected energy savings if the construction plans and specifications are not correctly executed. Table 2.3 lists strategies that the project team can use to keep the construction process in line with energy design goals.

OCCUPANCY: EVALUATE PERFORMANCE AND TRAIN USERS

Occupancy is a critical time in the process and is often neglected by the project teams. Energy savings are difficult to attain if the occupants and O&M staff do not know how to use, operate, and maintain the building. The CxA should ensure timely submittals of the O&M manuals through specifications and regular reminders at construction meetings, and ensure adequate and timely training of all school personnel.

A performance review should be conducted during the first year of building operation. The building operator should discuss any systems that are not performing as expected with the design and construction team so they can be resolved during the warranty period. Over time, the building's energy use, changes in operating hours, and any addition of energy-consuming equipment should be tracked and documented by school facilities staff. This information can be used to determine how well the building is performing and can provide lessons to take back to the design table for future projects. Performance evaluations should take place on a schedule specified in a maintenance manual provided to the owner as part of final project acceptance. Ongoing training of school personnel, including facilities staff, administrators, and instructional staff, should be provided to address changes and staff turnover. Table 2.4 lists strategies to help keep the acceptance phase in line with energy design goals. Additional information about energy-efficient operation and ongoing energy management is available in Appendix E.

Recommendations by Climate

3

This chapter contains a unique set of energy-efficiency recommendations for each climate zone. The recommendation tables represent some—but not all—ways to reach the 30% energy savings target over ASHRAE Standard 90.1. Other approaches may also save energy, but they are not part of the scope of this Guide; assurance of those savings is left to the user. The recommendation tables do not include all the components listed in ASHRAE Standard 90.1, since the Guide focuses only on primary energy systems. Future editions of energy codes may have more stringent values. In these cases, the more stringent values are recommended.

You should determine the recommendations for your construction project by first locating the correct climate zone. The U.S. DOE has identified eight climate zones for the United States. Each is defined by county borders, as shown in Figure 3.1 and as listed below the individual climate zone maps that follow. These climate zones are based on temperature and, in some cases, are divided into subzones based on humidity levels. Humid subzones are A zones, dry subzones are B zones, and marine subzones are C zones. This Guide uses these zones to define the energy recommendations. Tables with the climatic zones for locations in Mexico and Canada are in Appendix C.

Each climate zone recommendation table includes a set of common items arranged by building subsystem: envelope, daylighting, lighting, HVAC systems, and SWH. Recommendations are included for each item, or subsystem, by component within that subsystem. For some subsystems, recommendations depend on the construction type, HVAC system type, and daylighting type. For example, insulation values are given for mass, steel-framed, and wood-framed wall types. For others, recommendations are given for each attribute. For example, glass recommendations are given for size, thermal transmittance, solar heat gain coefficient (SHGC), and exterior sun control.

Electric lighting is one of the largest energy users in schools. Depending on climate, lighting energy use can be as high as 40% of the total energy use of a basic, energy code-compliant school. Because lighting-related improvements can be inexpensive and offer rapid payback, they top the list of recommendations for meeting an overall target of 30% energy savings. Lighting design also affects the HVAC system. Two distinctly different approaches, either of which can be used to meet the recommendations in this chapter, can be used to reduce lighting energy:

- *Design a daylighted school.* If carefully designed, vertical fenestration and skylights can provide interior illumination without excessive solar heat gain. Electric lighting systems can then be extinguished or dimmed for most school hours, saving significant energy and maintenance costs. The key to daylighting is an integrated design in which HVAC and electric lighting controls are optimized to take full advantage of and harvest energy savings, and added first costs of fenestration are offset by reduced costs in HVAC equipment. Because of daylighting's additional non-energy benefits (see Foreword), a design that uses daylighting should be pursued whenever possible. Proper daylighting design requires an integrated approach and good design skills. If these are possible, lighting and daylighting design can provide predictable and persisting lighting energy savings of up to 43%.

  For the daylighting options, recommendations are given for classrooms and gyms/multipurpose rooms. There are three classroom daylighting patterns: a toplighted pattern, a sidelighted pattern, and a combined toplighted and sidelighted pattern. For the gym/multipurpose rooms, there are a roof monitor pattern and a skylight pattern. Recommendations are provided for both north- and south-facing versions, and whichever are applicable to your design would apply. East- and west-facing daylighting systems are not recommended because solar gains and glare are difficult to manage. Recommended patterns are also provided by climate zone. See the daylighting recommendations for DL1–37 of Chapter 5, "How to Implement Recommendations."
- *Use efficient, state-of-the art products and techniques to design electric lighting.* Site constraints or program requirements may preclude daylighting solutions. Therefore, a nondaylighted path is provided to meet the recommendations in Chapter 3. The recommendations provided in this section include lighting systems that use the most current, energy-efficient lamps, ballasts, and integrated controls. Because lighting energy savings also produce cooling savings, HVAC energy savings of 10% to 15% are also possible in cooling-dominated climates. Moreover, even though the cost of high-performance lighting may be about the same or more than a basic solution, the cost of HVAC capacity can also be reduced. See the general lighting recommendations for EL1–16 in Chapter 5, "How to Implement Recommendations."

There are six possible HVAC system types from packaged direct expansion (DX) rooftops to water-source heat pumps to central variable-air-volume (VAV) air handlers with chillers and boilers (see HV1–6 in Chapter 5 for detailed descriptions). Some system types, however, are not recommended for certain humid climate zones because of the energy impact of humidity control. Unique recommendations are included for each HVAC system type based on practicality of implementation and the 30% energy reduction goal. For example, air-side economizers are recommended for packaged DX rooftops in many climate zones because they are easy to implement and they help achieve the desired energy savings. However, higher chiller and boiler efficiencies are recommended for fan-coil systems because air-side economizers are less practical for this system type. In some cases, recommended HVAC equipment efficiencies are based on system size (capacity). Because conditioning OA for ventilation is such a big contributor to energy use in a K-12 school building, either exhaust-air energy recovery or demand-controlled ventilation (DCV) is recommended.

Where "Comply with Standard 90.1" is indicated in the "Recommendation" column of the tables, you must meet at least the minimum requirements of the most current version of ASHRAE Standard 90.1 or the requirements of local codes whenever they exceed the requirements of ASHRAE Standard 90.1.

The fourth column in each table lists references to how-to tips for implementing the recommended criteria. The tips are found in Chapter 5 under separate sections coded for envelope (EN), daylighting (DL), electric lighting (EL), HVAC systems and equipment

(HV), and SWH systems and equipment (WH) suggestions. In addition to design and maintenance suggestions that represent good design practice, these tips include cautions for what to avoid. Each tip in Chapter 5 is tied to the applicable climate zones. The final column is provided as a simple checklist to identify the recommendations that are being used for a specific building design and construction.

Chapter 5 provides additional recommendations and strategies for energy savings over and above the 30% recommendations contained in the eight climate regions. These additional savings are in the areas of plug loads, alternative HVAC systems, renewable energy systems, and others.

The recommendations presented are either minimum or maximum values. Minimum values include the following:

- R-values
- mean lumens/watt (MLPW)
- seasonal energy efficiency ratio (SEER)
- solar reflectance index (SRI)
- energy efficiency ratio (EER)
- integrated part-load value (IPLV)
- annual fuel utilization efficiency (AFUE)
- heating season performance factor (HSPF)
- coefficient of performance (COP)
- efficiency (E_c and E_t)
- energy factor (EF)
- insulation thicknesses

Maximum values include the following:

- fenestration U-factors
- fenestration SHGC
- total fenestration to gross wall area ratio
- lighting power density (LPD)
- hp/1000 cfm
- external static pressure (ESP)
- friction rate

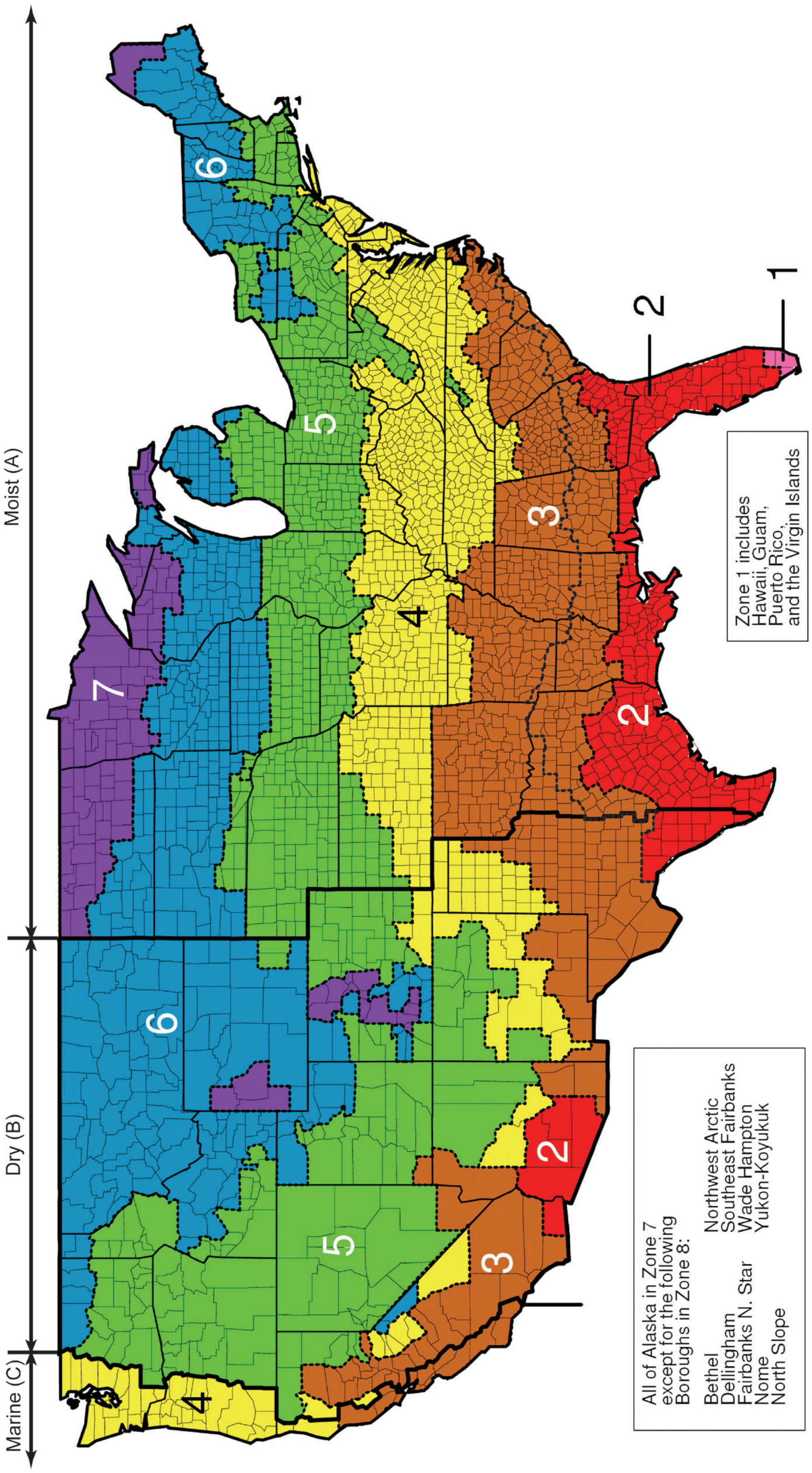
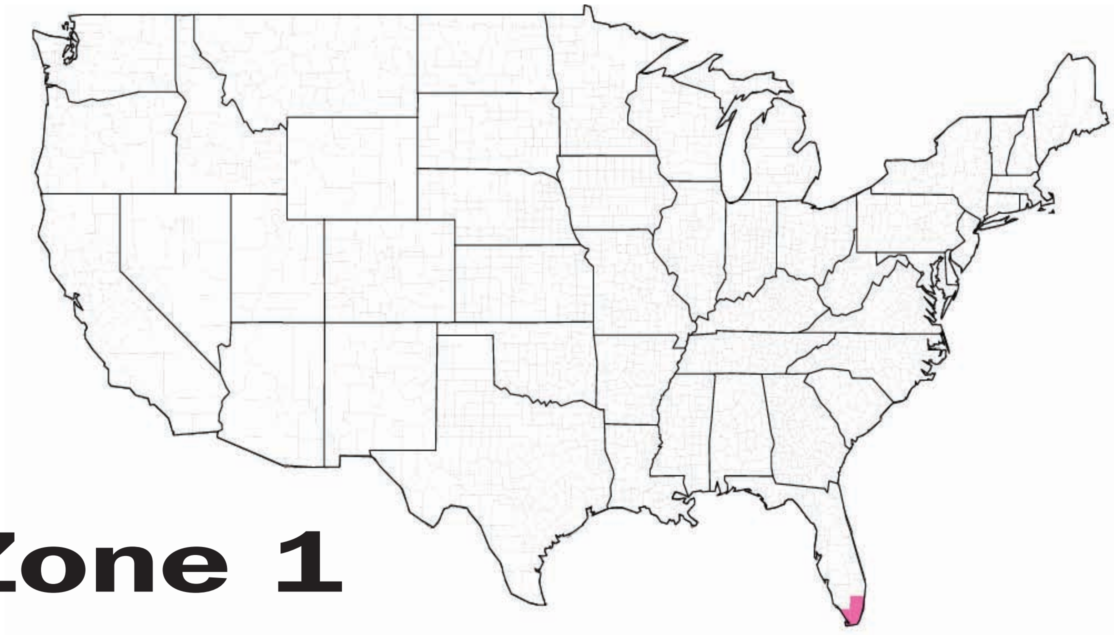


Figure 3.1. Climate zone map.



Zone 1

Florida

Broward
Miami Dade
Monroe

Guam

Hawaii

Puerto Rico

U.S. Virgin Islands

Climate Zone 1 Recommendation Table for K-12 Schools

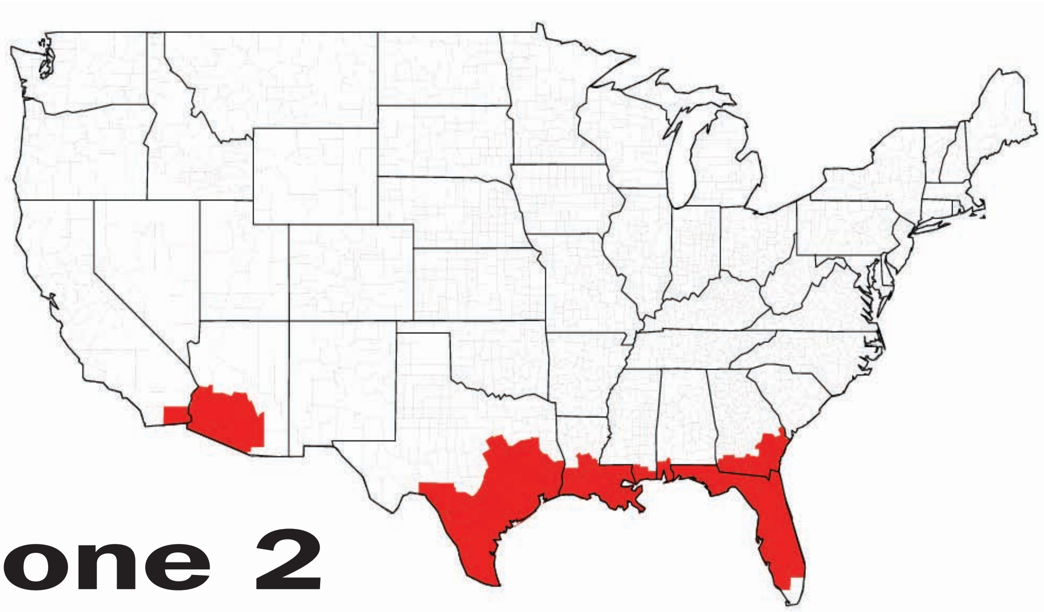
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-30	EN3, EN15–16, EN18	
		Metal building	R-19	EN3–4 EN15, EN18	
		SRI	0.78	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-5.7 c.i.	EN5, EN15, EN18	
		Steel framed	R-13	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-16	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-4.2 c.i.	EN9, EN15, EN18	
		Steel framed	R-19	EN10, EN15, EN18	
		Wood framed and other	R-19	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-7.5 for 12 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-1.45	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.56	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.25	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2, EL3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4, EL5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Non-Daylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2, EL3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4, EL5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135 and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 1 Recommendation Table for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER/11.5 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		Ground-source heat pump (GSHP) (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	System type not recommended	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency		HV3, HV7–8, HV10, HV25	
		Gas boiler		HV3, HV7, HV10, HV26	
		Economizer		HV13	
		Ventilation		HV9, HV11–12, HV14	
		Pressure drop		HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	80% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	80% E_c	HV5, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	80% E_c	HV6–7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × Volume	WH1–5	
		Pipe insulation (d < 1.5 in./d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the applicable version of ASHRAE Standard 90.1 or the local code requirements.



Zone 2

Alabama

Baldwin
Mobile

Arizona

La Paz
Maricopa
Pima
Pinal
Yuma

California

Imperial

Florida

Alachua
Baker
Bay
Bradford
Brevard
Calhoun
Charlotte
Citrus
Clay
Collier
Columbia
DeSoto
Dixie
Duval
Escambia
Flagler
Franklin
Gadsden
Gilchrist
Glades
Gulf
Hamilton
Hardee
Hendry
Hernando
Highlands
Hillsborough
Holmes
Indian River
Jackson
Jefferson
Lafayette
Lake
Lee
Leon
Levy
Liberty
Madison
Manatee
Marion
Martin
Nassau
Okaloosa
Okeechobee
Orange
Osceola
Palm Beach
Pasco
Pinellas
Polk
Putnam
Santa Rosa
Sarasota
Seminole
St. Johns
St. Lucie
Sumter
Suwannee
Taylor
Union
Volusia
Wakulla
Walton
Washington

Georgia

Appling
Atkinson
Bacon
Baker
Berrien
Brantley
Brooks
Bryan
Camden
Charlton
Chatham
Clinch
Colquitt
Cook
Decatur
Echols
Effingham
Evans
Glynn
Grady
Jeff Davis
Lanier
Liberty
Long
Lowndes
McIntosh
Miller
Mitchell
Pierce
Seminole
Tattnall
Thomas
Toombs
Ware
Wayne

Lousiana

Acadia
Allen
Ascension
Assumption
Avoyelles
Beauregard
Calcasieu
Cameron
East Baton Rouge
East Feliciana
Evangeline
Iberia
Iberville
Jefferson
Jefferson Davis
Lafayette
Lafourche
Livingston
Orleans
Plaquemines
Pointe Coupee
Rapides
St. Bernard
St. Charles
St. Helena
St. James
St. John the Baptist
St. Landry
St. Martin
St. Mary
St. Tammany
Tangipahoa
Terrebonne
Vermilion
Washington
West Baton Rouge
West Feliciana

Mississippi

Hancock
Harrison
Jackson
Pearl River
Stone

Texas

Anderson
Angelina
Aransas
Atascosa
Austin
Bandera
Bastrop
Bee
Bell
Bexar
Bosque
Brazoria
Brazos
Brooks
Burleson
Caldwell
Calhoun
Cameron
Chambers
Cherokee
Colorado
Comal
Coryell
DeWitt
Dimmit
Duval
Edwards
Falls
Fayette
Fort Bend
Freestone
Frio
Galveston
Goliad
Gonzales
Grimes
Guadalupe
Hardin
Harris
Hays
Hidalgo
Hill
Houston
Jackson
Jasper
Jefferson
Jim Hogg
Jim Wells
Karnes
Kenedy
Kinney
Kleberg
La Salle
Lavaca
Lee
Leon
Liberty
Limestone
Live Oak
Madison
Matagorda
Maverick
McLennan
McMullen
Medina
Milam
Montgomery
Newton
Nueces
Orange
Polk
Real
Refugio
Robertson
San Jacinto
San Patricio
Starr
Travis
Trinity
Tyler
Uvalde
Val Verde
Victoria
Walker
Waller
Washington
Webb
Wharton
Willacy
Williamson
Wilson
Zapata
Zavala

Climate Zone 2 Recommendation Table for K-12 Schools

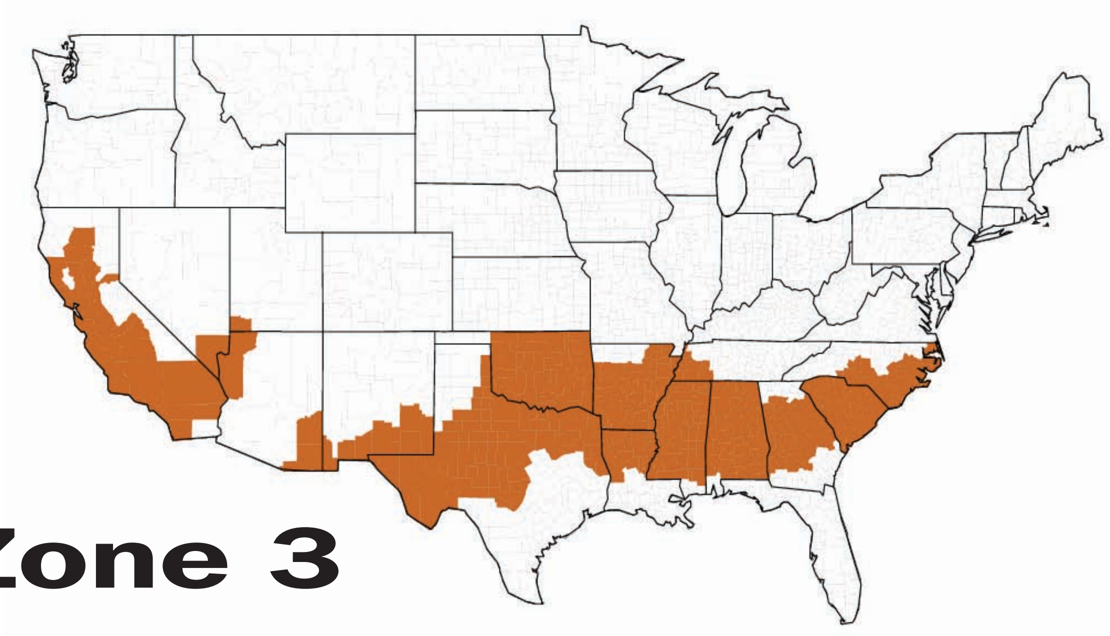
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1, EN2	
		Attic and other	R-38	EN3–4, EN15–16, EN18	
		Metal building	R-13 + R-13	EN3, EN15, EN18	
		SRI	0.78	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-7.6 c.i.	EN5, EN15, EN18	
		Steel framed	R-13	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-16	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-6.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-19	EN10, EN15, EN18	
		Wood framed and other	R-19	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-7.5 for 12 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-1.45	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.45	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.25	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2, EL 3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Non-Daylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135 and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 2 Recommendation Table for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER/11.5 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, V10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System		A (humid) zones: System not recommended B (dry) zones:		
		Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	No recommendation	HV3, HV7–8, HV10, HV25	
		Gas boiler	80% E_c	HV3, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_20	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	80% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	80% E_c	HV5, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	80% E_c	HV6–7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the applicable version of ASHRAE Standard 90.1 or the local code requirements.



Zone 3

Alabama
All counties except::
Baldwin
Mobile

Arizona
Cochise
Graham
Greenlee
Mohave
Santa Cruz

Arkansas
All counties except:
Baxter
Benton
Boone
Carroll
Fulton
Izard
Madison
Marion
Newton
Searcy
Stone
Washington

California
All counties except:
Alpine
Amador
Calaveras
Del Norte
El Dorado
Humboldt
Imperial
Inyo
Lake
Lassen
Mariposa
Modoc
Mono
Nevada
Plumas
Sierra
Siskiyou
Trinity
Tuolumne

Georgia
All counties except:
Appling
Atkinson
Bacon
Baker
Banks
Berrien
Brantley
Brooks
Bryan
Catoosa
Camden
Charlton
Chatham
Chattooga
Clinch
Colquitt
Cook
Dade
Dawson
Decatur
Echols
Effingham
Evans
Fannin
Floyd
Franklin
Gilmer
Glynn
Gordon
Grady
Habersham
Hall
Jeff Davis
Lanier
Liberty
Long
Lowndes
Lumpkin
McIntosh
Miller
Mitchell
Murray
Pickens
Pierce
Rabun
Seminole
Stephens
Tattnall
Thomas
Toombs
Towns
Union
Walker
Ware
Wayne
White
Whitfield

Louisiana
Bienville
Bossier
Caddo
Caldwell
Catahoula
Claiborne
Concordia
De Soto
East Carroll
Franklin
Grant
Jackson
La Salle
Lincoln
Madison
Morehouse
Natchitoches
Ouachita
Red River
Richland
Sabine
Tensas
Union
Vernon
Webster
West Carroll
Winn

Mississippi
All counties except:
Hancock
Harrison
Jackson
Pearl River
Stone

New Mexico
Chaves
Dona Ana
Eddy
Hidalgo
Lea
Luna
Otero

Nevada
Clark

Texas
Andrews
Archer
Baylor
Blanco
Borden
Bowie
Brewster
Brown
Burnet
Callahan
Camp
Cass
Childress
Clay
Coke
Coleman
Collingsworth
Collin
Comanche
Concho
Cottle
Cooke
Crane
Crockett
Crosby
Culberson
Dallas
Dawson
Delta
Denton
Dickens
Eastland
Ector
El Paso
Ellis
Erath
Fannin
Fisher
Foard
Franklin
Gaines
Garza
Gillespie
Glasscock
Grayson
Gregg
Hall
Hamilton
Hardeman
Harrison
Haskell
Hemphill
Henderson
Hood
Hopkins
Howard
Hudspeth
Hunt
Irion
Jack
Jeff Davis
Johnson
Jones
Kaufman
Kendall
Kent
Kerr
Kimble
King
Knox
Lamar
Lampasas
Llana
Loving
Lubbock
Lynn
Marion
Martin
Mason
McCulloch
Menard
Midland
Mills
Mitchell
Montague
Morris
Motley
Nacogdoches
Navarro
Nolan
Palo Pinto
Panola
Parker
Pecos
Presidio
Rains
Reagan
Reeves
Red River
Rockwall
Runnels
Rusk
Sabine
San Augustine
San Saba
Schleicher
Scurry
Shackelford
Shelby
Smith
Somervell
Stephens
Sterling
Stonewall
Sutton
Tarrant
Taylor
Terrell
Terry
Throckmorton
Titus
Tom Green
Upshur
Upton
Van Zandt
Ward
Wheeler
Wichita
Wilbarger
Winkler
Wise
Wood
Young

Utah
Washington

North Carolina
Anson
Beaufort
Bladen
Brunswick
Cabarrus
Camden
Careret
Chowan
Columbus
Craven
Cumberland
Currituck
Dare
Davidson
Duplin
Edgecombe
Gaston
Greene
Hoke
Hyde
Johnston
Jones
Lenoir
Martin
Mecklenburg
Montgomery
Moore
New Hanover
Onslow
Pamlico
Pasquotank
Pender
Perquimans
Pitt
Rnadolph
Richmond
Robeson
Rowan
Sampson
Scotland
Stanly
Yrrell
Union
Washington
Wayne
Wilson

Oklahoma
All counties except:
Beaver
Cimarron
Texas

South Carolina
All counties

Tennessee
Chester
Crockett
Dyer
Fayette
Hardemon
Hardin
Haywood
Henderson
Lake
Lauderdale
Madison
McNairy
Shelby
Tipton

Climate Zone 3 Recommendations for K-12 Schools

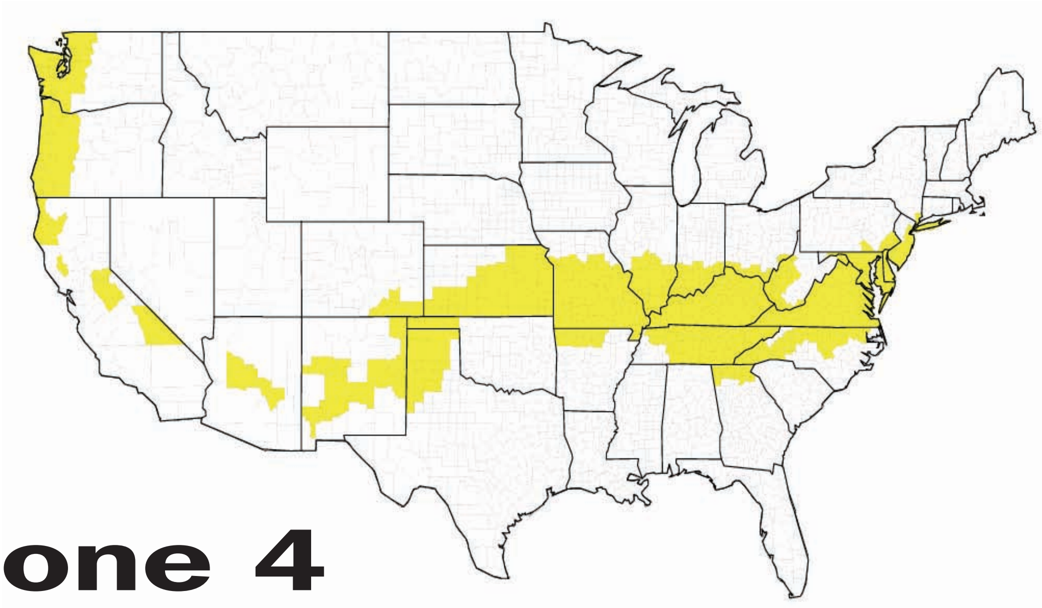
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-13	EN3–4, EN15, EN18	
		SRI	0.78	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-7.6 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-3.8 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-16	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-8.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-19	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-10 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-1.45	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.45	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.25	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10% Only skylights: 2%–4%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto-off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Non-Daylighted Option	LPD	0.9 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135) and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 3 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER/11.0 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System		A (Humid) Zones: System not recommended / B (Dry) and C (Marine) Zones:		
		Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_20	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99–0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 4

Arizona
- Gila
- Yavapai

Arkansas
- Baxter
- Benton
- Boone
- Carroll
- Fulton
- Izard
- Madison
- Marion
- Newton
- Searcy
- Stone
- Washington

California
- Amador
- Calaveras
- Del Norte
- El Dorado
- Humboldt
- Inyo
- Lake
- Mariposa
- Trinity
- Tuolumne

Colorado
- Baca
- Las Animas
- Otero

Delaware
- All counties

District of Columbia

Georgia
- Banks
- Catoosa
- Chattooga
- Dade
- Dawson
- Fannin
- Floyd
- Franklin
- Gilmer
- Gordon
- Habersham
- Hall
- Lumpkin
- Murray
- Pickens
- Rabun
- Stephens
- Towns
- Union
- Walker
- White
- Whitfield

Illinois
- Alexander
- Bond
- Brown
- Christian
- Clay
- Clinton
- Crawford
- Edwards
- Effingham
- Fayette
- Franklin
- Gallatin
- Hamilton
- Hardin
- Jackson
- Jasper
- Jefferson
- Johnson
- Lawrence
- Macoupin
- Madison
- Marion
- Massac
- Monroe
- Montgomery
- Perry
- Pope
- Pulaski
- Randolph
- Richland
- Saline
- Shelby
- St. Claire
- Union
- Wabash
- Washington
- Wayne
- White
- Williamson

Indiana
- Clark
- Crawford
- Daviess
- Dearborn
- Dubois
- Floyd
- Gibson
- Greene
- Harrison
- Jackson
- Jefferson
- Jennings
- Knox
- Lawrence
- Martin
- Monroe
- Ohio
- Orange
- Perry
- Pike
- Posey
- Ripley
- Scott
- Spencer
- Sullivan
- Switzerland
- Vanderburgh
- Warrick
- Washington

Kansas
All counties except:
- Cheyenne
- Cloud
- Decatur
- Ellis
- Gove
- Graham
- Greeley
- Hamilton
- Jewell
- Lane
- Logan
- Mitchell
- Ness
- Norton
- Osborne
- Phillips
- Rawlins
- Republic
- Rooks
- Scott
- Sheridan
- Sherman
- Smith
- Thomas
- Trego
- Wallace
- Wichita

Kentucky
- All counties

Maryland
All counties except:
- Garrett

Missouri
All counties except:
- Adair
- Andrew
- Atchison
- Buchanan
- Caldwell
- Chariton
- Clark
- Clinton
- Daviess
- DeKalb
- Gentry
- Grundy
- Harrison
- Holt
- Knox
- Lewis
- Linn
- Livingston
- Macon
- Marion
- Mercer
- Nodaway
- Pike
- Putnam
- Ralls
- Schuyler
- Scotland
- Shelby
- Sullivan
- Worth

New Jersey
All counties except:
- Bergen
- Hunterdon
- Mercer
- Morris
- Passaic
- Somerset
- Sussex
- Warren

New Mexico
- Bernalillo
- Cibola
- Curry
- DeBaca
- Grant
- Guadalupe
- Lincoln
- Quay
- Roosevelt
- Sierra
- Socorro
- Union
- Valencia

New York
- Bronx
- Kings
- Nassau
- New York
- Queens
- Richmond
- Suffolk
- Westchester

North Carolina
- Alamance
- Alexander
- Bertie
- Buncombe
- Burke
- Caldwell
- Caswell
- Catawba
- Chatham
- Cherokee
- Clay
- Cleveland
- Davie
- Durham
- Forsyth
- Franklin
- Gates
- Graham
- Granville
- Guilford
- Halifax
- Harnett
- Haywood
- Henderson
- Hertford
- Iredell
- Jackson
- Lee
- Lincoln
- Macon
- Madison
- McDowell
- Nash
- Northampton
- Orange
- Person
- Polk
- Rockingham
- Rutherford
- Stokes
- Surry
- Swain
- Transylvania
- Vance
- Wake
- Warren
- Wilkes
- Yadkin

Ohio
- Adams
- Brown
- Clermont
- Gallia
- Hamilton
- Lawrence
- Pike
- Scioto
- Washington

Oklahoma
- Beaver
- Cimarron
- Texas

Oregon
- Benton
- Clackamas
- Clatsop
- Columbia
- Coos
- Curry
- Douglas
- Jackson
- Josephine
- Lane
- Lincoln
- Linn
- Marion
- Multnomah
- Polk
- Tillamook
- Washington
- Yamhill

Pennsylvania
- Bucks
- Chester
- Delaware
- Montgomery
- Philadelphia
- York

Tennessee
All counties except:
- Chester
- Crockett
- Dyer
- Fayette
- Hardeman
- Hardin
- Haywood
- Henderson
- Lake
- Lauderdale
- Madison
- McNairy
- Shelby
- Tipton

Texas
- Armstrong
- Bailey
- Briscoe
- Carson
- Castro
- Cochran
- Dallam
- Deaf Smith
- Donley
- Floyd
- Gray
- Hale
- Hansford
- Hartley
- Hockley
- Hutchinson
- Lamb
- Lipscomb
- Moore
- Ochiltree
- Oldham
- Parmer
- Potter
- Randall
- Roberts
- Sherman
- Swisher
- Yoakum

Virginia
- All counties

Washington
- Clallam
- Clark
- Cowlitz
- Grays Harbor
- Island
- Jefferson
- King
- Kitsap
- Lewis
- Mason
- Pacific
- Pierce
- San Juan
- Skagit
- Snohomish
- Thurston
- Wahkiakum
- Whatcom

West Virginia
- Berkeley
- Boone
- Braxton
- Cabell
- Calhoun
- Clay
- Gilmer
- Jackson
- Jefferson
- Kanawha
- Lincoln
- Logan
- Mason
- McDowell
- Mercer
- Mingo
- Monroe
- Morgan
- Pleasants
- Putnam
- Ritchie
- Roane
- Tyler
- Wayne
- Wirt
- Wood
- Wyoming

Climate Zone 4 Recommendations for K-12 Schools

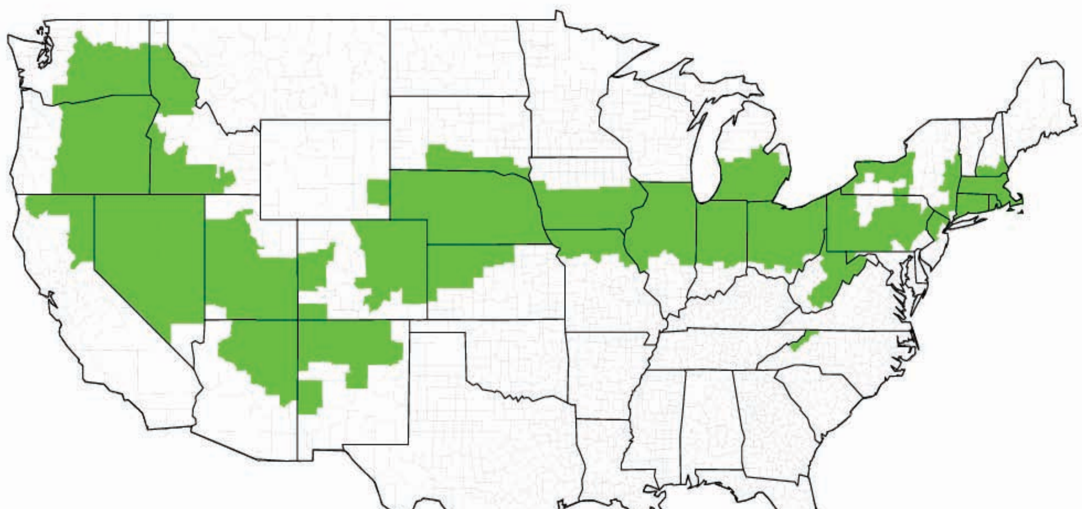
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft^2·°F)	R-9.5 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-19	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-8.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-30	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-15 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.42	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.40	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted—South-facing roof monitors: 8%–11%; North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted—South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10% Only skylights—3%–4%	DL1–19, DL36–37	
		LPD	1.2 W/ft^2 maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym, and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	0.9 W/ft^2	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135 and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 4 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER and 11.0 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, V10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV3, HV7–8, V10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. /d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 5

Arizona
Apache
Coconino
Navajo

California
Lassen
Modoc
Nevada
Plumas
Sierra
Siskiyou

Colorado
Adams
Arapahoe
Bent
Boulder
Cheyenne
Crowley
Delta
Denver
Douglas
Elbert
El Paso
Fremont
Garfield
Gilpin
Huerfano
Jefferson
Kiowa
Kit Carson
La Plata
Larimer
Lincoln
Logan
Mesa
Montezuma
Montrose
Morgan
Phillips
Prowers
Pueblo
Sedgwick
Teller
Washington
Weld
Yuma

Connecticut
All counties

Idaho
Ada
Benewah
Canyon
Cassia
Clearwater
Elmore
Gem
Gooding
Idaho
Jerome
Kootenai
Latah
Lewis
Lincoln
Minidoka
Nez Perce
Owyhee
Payette
Power
Shoshone
Twin Falls
Washington

Illinois
All counties except:
Alexander
Bond
Brown
Christian
Clay
Clinton
Crawford
Edwards
Effingham
Fayette
Franklin
Gallatin
Hamilton
Hardin
Jackson
Jasper
Jefferson
Johnson
Lawrence
Macoupin
Madison
Marion
Massac
Monroe
Montgomery
Perry
Pope
Pulaski
Randolph
Richland
Saline
Shelby
St. Clair
Union
Wabash
Washington
Wayne
White
Williamson

Indiana
All counties except:
Clark
Crawford
Daviess
Dearborn
Dubois
Floyd
Gibson
Greene
Harrison
Jackson
Jefferson
Jennings
Knox
Lawrence
Martin
Monroe
Ohio
Orange
Perry
Pike
Posey
Ripley
Scott
Spencer
Sullivan
Switzerland
Vanderburgh
Warrick
Washington

Iowa
All counties except:
Allamakee
Black Hawk
Bremer
Buchanan
Buena Vista
Butler
Calhoun
Cerro Gordo
Cherokee
Chickasaw
Clay
Clayton
Delaware
Dickinson
Emmet
Fayette
Floyd
Franklin
Grundy
Hamilton
Hancock
Hardin
Howard
Humboldt
Ida
Kossuth
Lyon
Mitchell
O'Brien
Osceola
Palo Alto
Plymouth
Pocahontas
Sac
Sioux
Webster
Winnebago
Winneshiek
Worth
Wright

Kansas
Cheyenne
Cloud
Decatur
Ellis
Gove
Graham
Greeley
Hamilton
Jewell
Lane
Logan
Mitchell
Ness
Norton
Osborne
Phillips
Rawlins
Republic
Rooks
Scott
Sheridan
Sherman
Smith
Thomas
Trego
Wallace
Wichita

Maryland
Garrett

Massachusetts
All counties

Michigan
Allegan
Barry
Bay
Berrien
Branch
Calhoun
Cass
Clinton
Eaton
Genesee
Gratiot
Hillsdale
Ingham
Ionia
Jackson
Kalamazoo
Kent
Lapeer
Lenawee
Livingston
Macomb
Midland
Monroe
Montcalm
Muskegon
Oakland
Ottawa
Saginaw
Shiawassee
St. Clair
St. Joseph
Tuscola
Van Buren
Washtenaw
Wayne

Missouri
Adair
Andrew
Atchison
Buchanan
Caldwell
Chariton
Clark
Clinton
Daviess
DeKalb
Gentry
Grundy
Harrison
Holt
Knox
Lewis
Linn
Livingston
Macon
Marion
Mercer
Nodaway
Pike
Putnam
Ralls
Schuyler
Scotland
Shelby
Sullivan
Worth

Nebraska
All counties

Nevada
All counties except:
Clark

New Hampshire
Cheshire
Hillsborough
Rockingham
Strafford

New Jersey
Bergen
Hunterdon
Mercer
Morris
Passaic
Somerset
Sussex
Warren

New Mexico
Catron
Colfax
Harding
Los Alamos
McKinley
Mora
Rio Arriba
Sandoval
San Juan
San Miguel
Santa Fe
Taos
Torrance

New York
Albany
Cayuga
Chautauqua
Chemung
Columbia
Cortland
Dutchess
Erie
Genesee
Greene
Livingston
Monroe
Niagara
Onondaga
Ontario
Orange
Orleans
Oswego
Putnam
Rensselaer
Rockland
Saratoga
Schenectady
Seneca
Tioga
Washington
Wayne
Yates

North Carolina
Alleghany
Ashe
Avery
Mitchell
Watauga
Yancey

Ohio
All counties except:
Adams
Brown
Clermont
Gallia
Hamilton
Lawrence
Pike
Scioto
Washington

Oregon
Baker
Crook
Deschutes
Gilliam
Grant
Harney
Hood River
Jefferson
Klamath
Lake
Malheur
Morrow
Sherman
Umatilla
Union
Wallowa
Wasco
Wheeler

Pennsylvania
All counties except:
Bucks
Cameron
Chester
Clearfield
Delaware
Elk
McKean
Montgomery
Philadelphia
Potter
Susquehanna
Tioga
Wayne
York

Rhode Island
All counties

South Dakota
Bennett
Bon Homme
Charles Mix
Clay
Douglas
Gregory
Hutchinson
Jackson
Mellette
Todd
Tripp
Union
Yankton

Utah
All counties except:
Box Elder
Cache
Carbon
Daggett
Duchesne
Morgan
Rich
Summit
Uintah
Wasatch
Washington

Washington
Adams
Asotin
Benton
Chelan
Columbia
Douglas
Franklin
Garfield
Grant
Kittitas
Klickitat
Lincoln
Skamania
Spokane
Walla Walla
Whitman
Yakima
Wyoming
Goshen
Platte

West Virginia
Barbour
Brooke
Doddridge
Fayette
Grant
Greenbrier
Hampshire
Hancock
Hardy
Harrison
Lewis
Marion
Marshall
Mineral
Monongalia
Nicholas
Ohio
Pendleton
Pocahontas
Preston
Raleigh
Randolph
Summers
Taylor
Tucker
Upshur
Webster
Wetzel

Climate Zone 5 Recommendations for K-12 Schools

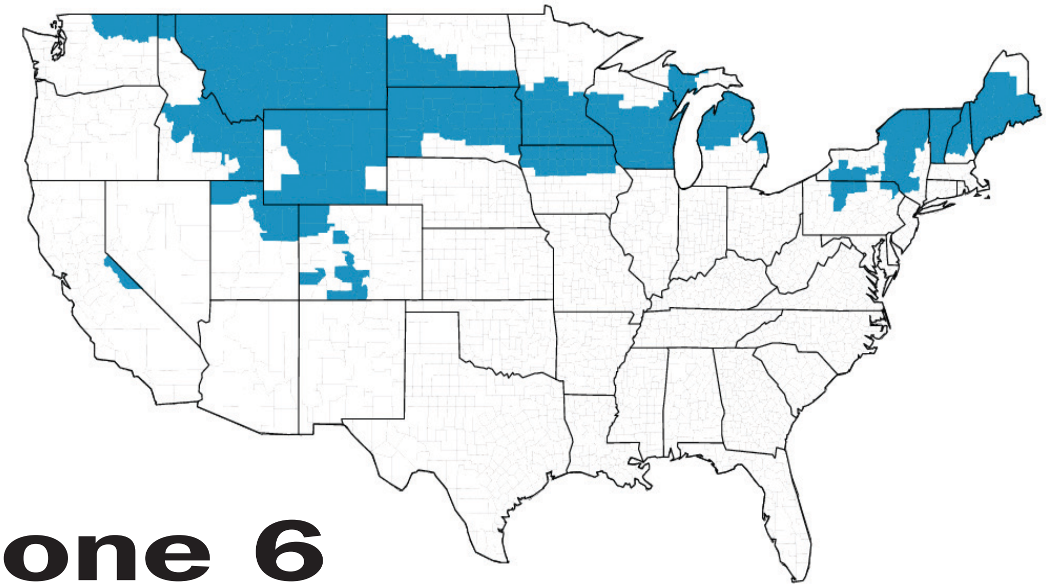
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-11.4 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-3.8 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-5.6 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-7.5 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-10.4 c.i.	EN9, EN15, EN18	
		Steel framed	R-30	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-15 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% Max	EN20	
		Thermal transmittance—all types and orientations	U-0.42	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.40	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.0 EER		
		Air conditioner (≥135 and <240 kBtu/h)	10.8 EER		
		Air conditioner (≥240 kBtu/h)	10.0 EER and 10.4 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 5 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER and 11.0 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86F Heating: 4.5 COP at 68F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86F Heating: 4.2 COP at 68F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.0 EER and 10.4 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	85% E_c	HV6–7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. /d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 6

California
- Alpine
- Mono
- Colorado
- Alamosa
- Archuleta
- Chaffee
- Conejos
- Costilla
- Custer
- Dolores
- Eagle
- Moffat
- Ouray
- Rio Blanco
- Saguache
- San Miguel

Idaho
- Adams
- Bannock
- Bear Lake
- Bingham
- Blaine
- Boise
- Bonner
- Bonneville
- Boundary
- Butte
- Camas
- Caribou
- Clark
- Custer
- Franklin
- Fremont
- Jefferson
- Lemhi
- Madison
- Oneida
- Teton
- Valley

Iowa
- Allamakee
- Black Hawk
- Bremer
- Buchanan
- Buena Vista
- Butler
- Calhoun
- Cerro Gordo
- Cherokee
- Chickasaw
- Clay
- Clayton

Delaware
- Dickinson
- Emmet
- Fayette
- Floyd
- Franklin
- Grundy
- Hamilton
- Hancock
- Hardin
- Howard
- Humboldt
- Ida
- Kossuth
- Lyon
- Mitchell
- O'Brien
- Osceola
- Palo Alto
- Plymouth
- Pocahontas
- Sac
- Sioux
- Webster
- Winnebago
- Winneshiek
- Worth
- Wright

Maine
All counties except:
- Aroostook

Michigan
- Alcona
- Alger
- Alpena
- Antrim
- Arenac
- Benzie
- Charlevoix
- Cheboygan
- Clare
- Crawford
- Delta
- Dickinson
- Emmet
- Gladwin
- Grand Traverse
- Huron
- Iosco
- Isabella
- Kalkaska
- Lake
- Leelanau
- Manistee
- Marquette
- Mason
- Mecosta
- Menominee
- Missaukee
- Montmorency
- Newaygo
- Oceana
- Ogemaw
- Osceola
- Oscoda
- Otsego
- Presque Isle
- Roscommon
- Sanilac
- Wexford

Minnesota
- Anoka
- Benton
- Big Stone
- Blue Earth
- Brown
- Carver
- Chippewa
- Chisago
- Cottonwood
- Dakota
- Dodge
- Douglas
- Faribault
- Fillmore
- Freeborn
- Goodhue
- Hennepin
- Houston
- Isanti
- Jackson
- Kandiyohi
- Lac qui Parle
- Le Sueur
- Lincoln
- Lyon
- Martin
- McLeod
- Meeker
- Morrison
- Mower
- Murray
- Nicollet
- Nobles
- Olmsted
- Pipestone
- Pope
- Ramsey
- Redwood
- Renville
- Rice
- Rock
- Scott
- Sherburne
- Sibley
- Stearns
- Steele
- Stevens
- Swift
- Todd
- Traverse
- Wabasha
- Waseca
- Washington
- Watonwan
- Winona
- Wright
- Yellow Medicine

Montana
- All counties

New Hampshire
- Belknap
- Carroll
- Coos
- Grafton
- Merrimack
- Sullivan

New York
- Allegany
- Broome
- Cattaraugus
- Chenango
- Clinton
- Delaware
- Essex
- Franklin
- Fulton
- Hamilton
- Herkimer
- Jefferson
- Lewis
- Madison
- Montgomery
- Oneida
- Otsego
- Schoharie
- Schuyler
- Steuben
- St. Lawrence
- Sullivan
- Tompkins
- Ulster
- Warren

Wyoming

North Dakota
- Adams
- Billings
- Bowman
- Burleigh
- Dickey
- Dunn
- Emmons
- Golden Valley
- Grant
- Hettinger
- LaMoure
- Logan
- McIntosh
- McKenzie
- Mercer
- Morton
- Oliver
- Ransom
- Richland
- Sargent
- Sioux
- Slope
- Stark

Pennsylvania
- Cameron
- Clearfield
- Elk
- McKean
- Potter
- Susquehanna
- Tioga
- Wayne

South Dakota
All counties except:
- Bennett
- Bon Homme
- Charles Mix
- Clay
- Douglas
- Gregory
- Hutchinson
- Jackson
- Mellette
- Todd
- Tripp
- Union
- Yankton

Utah
- Box Elder
- Cache
- Carbon
- Daggett
- Duchesne
- Morgan
- Rich
- Summit
- Uintah
- Wasatch

Vermont
All counties

Washington
- Ferry
- Okanogan
- Pend Oreille
- Stevens

Wisconsin
All counties except:
- Ashland
- Bayfield
- Burnett
- Douglas
- Florence
- Forest
- Iron
- Langlade
- Lincoln
- Oneida
- Price
- Sawyer
- Taylor
- Vilas
- Washburn

Wyoming
All counties except:
- Goshen
- Platte
- Lincoln
- Sublette
- Teton

Climate Zone 6 Recommendations for K-12 Schools

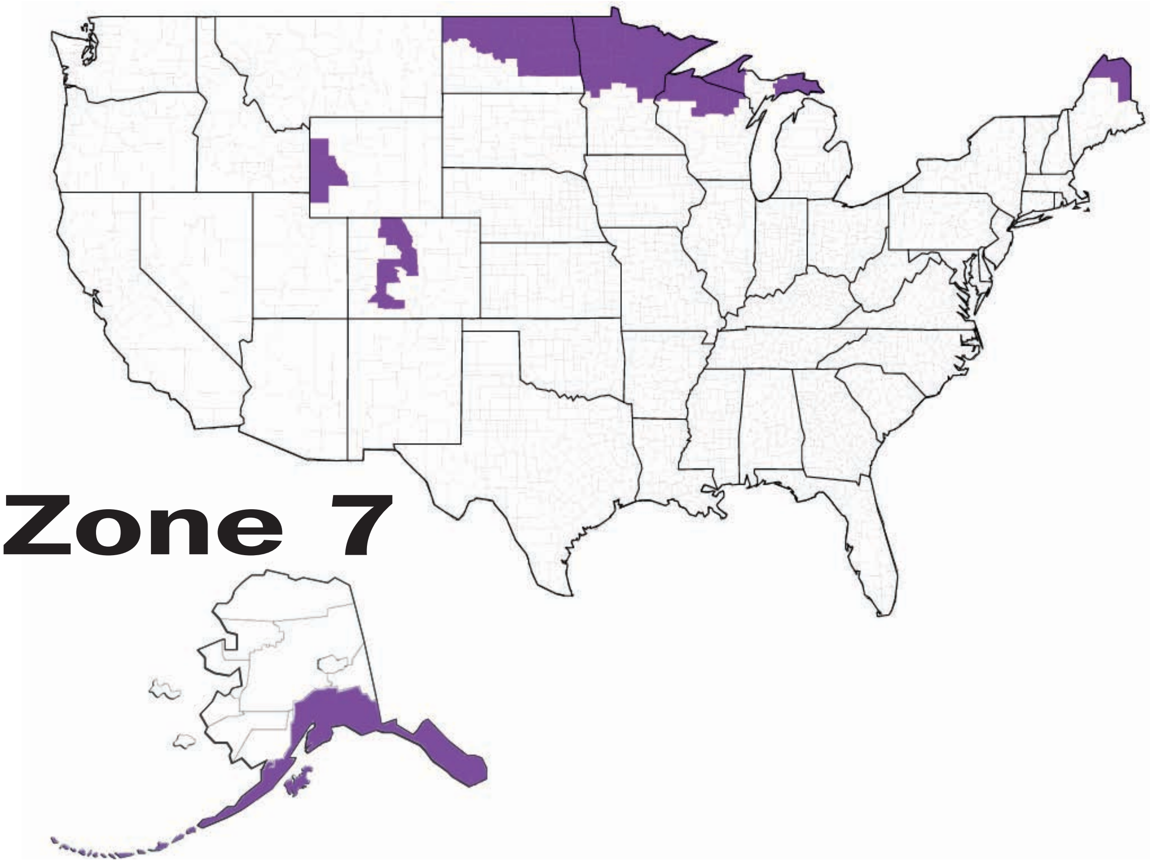
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft^2·°F)	R-13.3 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-7.5 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-5.6 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-7.5 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-13.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-30	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	R-10 for 24 in.	EN11, EN17–18	
		Heated	R-15 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.42	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.40	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8%, Toplighted: 2%–3% North-facing sidelighted: 9%–13%, Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10%	DL1–19, DL36, DL37	
		LPD	1.2 W/ft^2 maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft^2	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥135 and <240 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 6 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	Comply with Standard 90.1*	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	Comply with Standard 90.1*		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP <0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	85% E_c	HV6–7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (*d* < 1.5 in. /*d* ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 7

Alaska

- Aleutians East
- Aleutians West (CA)
- Anchorage
- Angoon (CA)
- Bristol Bay
- Denali
- Haines
- Juneau
- Kenai Peninsula
- Ketchikan (CA)
- Ketchikan Gateway
- Kodiak Island
- Lake and Peninsula
- Matanuska-Susitna
- Prince of Wales-Outer
- Sitka
- Skagway-Hoonah-
- Valdez-Cordova (CA)
- Wrangell-Petersburg (CA)
- Yakutat

Colorado

- Clear Creek
- Grand
- Gunnison
- Hinsdale
- Jackson
- Lake
- Mineral
- Park
- Pitkin
- Rio Grande
- Routt
- San Juan
- Summit

Maine

- Aroostook

Michigan

- Baraga
- Chippewa
- Gogebic
- Houghton
- Iron
- Keweenaw
- Luce
- Mackinac
- Ontonagon
- Schoolcraft

Minnesota

- Aitkin
- Becker
- Beltrami
- Carlton
- Cass
- Clay
- Clearwater
- Cook
- Crow Wing
- Grant
- Hubbard
- Itasca
- Kanabec
- Kittson
- Koochiching
- Lake
- Lake of the Woods
- Mahnomen
- Marsh all
- Mille Lacs
- Norman
- Otter Tail
- Pennington
- Pine
- Polk
- Red Lake
- Roseau
- St. Louis
- Wadena
- Wilkin

North Dakota

- Barnes
- Benson
- Bottineau
- Burke
- Cass
- Cavalier
- Divide
- Eddy
- Foster
- Grand Forks
- Griggs
- Kidder
- McHenry
- McLean
- Mountrail
- Nelson
- Pembina
- Pierce
- Ramsey
- Renville
- Rolette
- Sheridan
- Steele
- Stutsman
- Towner
- Traill
- Walsh
- Ward
- Wells
- Williams

Wisconsin

- Ashland
- Bayfield
- Burnett
- Douglas
- Florence
- Forest
- Iron
- Langlade
- Lincoln
- Oneida
- Price
- Sawyer
- Taylor
- Vilas
- Washburn

Wyoming

- Lincoln
- Sublette
- Teton

Climate Zone 7 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-60	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-15.2 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-7.5 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-5.6 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-7.5 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-12.5 c.i.	EN9, EN15, EN18	
		Steel framed	R-38	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	R-15 for 24 in.	EN11, EN17–18	
		Heated	R-15 for full slab	EN12, EN17–18	
	Doors	Swinging	U-0.50	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% Max	EN20	
		Thermal transmittance—all types and orientations	U-0.33	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.45	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft, 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13%, Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors 7%–10%	DL1–19, DL36–L37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥135 and <240 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 7 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	Comply with Standard 90.1*	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	Comply with Standard 90.1*		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Vriable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP <0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, V10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8,HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (*d* < 1.5 in./*d* ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Zone 8

Alaska

Bethel (CA)

Dillingham (CA)

Fairbanks North Star

Nome (CA)

North Slope

Northwest Arctic

Southeast Fairbanks (CA)

Wade Hampton (CA)

Yukon-Koyukuk (CA)

Climate Zone 8 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-60	EN3, EN15–16, EN18	
		Metal building	R-19 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft^2·°F)	R-15.2 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-21.6 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-10 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-11.2 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-15 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-16.7 c.i.	EN9, EN15, EN18	
		Steel framed	R-38	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	R-20 for 24 in.	EN11, EN17–18	
		Heated	R-15 for full slab	EN12, EN17–18	
	Doors	Swinging	U-0.50	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% Max	EN20	
		Thermal transmittance—all types and orientations	U-0.33	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.45	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8%, Toplighted: 2%–3% North-facing sidelighted: 9%–13%, Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft^2 maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft^2	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge, and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥135 and <240 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 8 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	Comply with Standard 90.1*	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	Comply with Standard 90.1*		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP <0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11, HV12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-8	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in./d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Case Studies 4

The case studies in this chapter illustrate techniques and methods that are discussed in this Guide. They are presented in order of climate zone, from warmest to coldest. Energy numbers are provided to benchmark these buildings against future buildings; however, all these case studies predate the publication of the Guide, and they were not developed using the recommendations in Chapter 3. These schools may or may not have achieved the 30% level if they had been constructed entirely according to the recommendations in this Guide. You are encouraged to view additional case studies and submit your own at www.ashrae.org/aedg. Case studies provide motivation and examples for others to follow.

ZONE 1—WAIPAHU INTERMEDIATE SCHOOL

Waipahu, Hawaii

The Hawaii Department of Education piloted the Waipahu Intermediate School (WIS) cafeteria as a LEED project in educational facilities to support its commitment to conserve resources and provide better facilities. The 19,200 ft^2 cafeteria, opened for the 2006–2007 school year, is designed to serve 750 people at a time.

Daylighting features include shaded north- and south-facing clerestories and jalousies designed to bounce indirect daylight deep into the dining area. This reduces the electric lighting requirements by more than 55%. The roof was designed to create a thermal chimney for stack-effect ventilation, which, in addition to cross-ventilation, eliminates the need for ceiling fans and ductwork.

The State of Hawaii Department of Business, Economic Development, and Tourism Report, *Analyses of Economic, Environmental and Occupant Benefits of Sustainable Design*, and LEED Certification for State of Hawaii and Public School Facilities, included the development of two energy-use scenarios for the cafeteria example: a base case (built to code) and a green case (incorporating high-performance features). The green case resulted in a 16% energy reduction. The kitchen area in the cafeteria example was primarily designed with conventional methods, so its energy use is assumed to be the same for both cases.

Figure 4.1. Cafeteria building exterior views.

Figure 4.2. Cafeteria interior view.

Table 4.1. Waipahu Intermediate School Cafeteria

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Lighting		
Lighting Systems Used	T-8s	EL2
Daylighting		
Window Design	Clerestories with overhangs	DL1–10
HVAC	Natural cooling and ventilation	EN22, HV32
SWH	High-efficiency boiler	WH1–6
System Controls		
Commissioning	Fully commissioned	HV23, CX1–13
Additional Savings		
Kitchen Equipment	High-efficiency gas equipment	AS2
Energy-Use Characteristics		
Baseline Electric Energy Use	14.0 kBtu/ft^2·yr	
Simulated Electric Energy Use	11.7 kBtu/ft^2·yr	

Photos and data are provided by the Hawaii Department of Business, Economic Development, and Tourism.

ZONE 2—DESERT EDGE HIGH SCHOOL

Goodyear, Arizona

Desert Edge High School, west of downtown Phoenix, was constructed in two phases for a total of 218,783 ft^2 and a student capacity of 1600. Phase II was certified LEED Silver in 2006. The total build cost of the school was \$21.3 million at an average of \$97/ft^2. Phase one was opened in time for the 2002–2003 school year, and phase two opened in time for the 2005–2006 school year. This climate zone 2 facility includes classrooms, administrative areas, a media center, a gymnasium, a 522-seat fine arts auditorium, a career technology area, and a student bookstore in the core. An in-school kiosk showcases many of the unique features of the high school through a virtual tour and the display of electricity, water, and carbon dioxide (CO_2) savings. The kiosk also displays real-time animations of the heating and cooling systems, an interactive building directory, bus routes and schedules, real-time weather conditions, and more.

Desert Edge is about 28% more energy efficient than other comparable high schools. The energy efficiency equates to roughly \$58,000 in cost savings per year. The school showcases high-performance building strategies and features for a hot/dry climate zone, including an improved building envelope, daylighting, demand-controlled ventilation, and high-efficiency water-cooled chillers with a water-side economizer. The masonry walls include R-19 cavity insulation, and R-30 insulation is used on the built-up metal deck roof. The windows are high performance, low-e dual-paned glass windows with a U-factor of 0.33. The lighting system takes advantage of daylighting and uses a low-lighting power density to reduce the amount of artificial lighting. Lighting power density is 1.09 W/ft^2 in classrooms and 1.04 W/ft^2 in the gymnasium. Daylighting controls and occupancy sensors further reduce lighting loads. Multiple light switches are used to allow the teachers and students to light only the occupied space when daylighting is not sufficient. A high-efficiency central cooling and heating system uses two centrifugal chillers with a water-side economizer cycle and plate-and-frame heat exchanger. The water-based cooling towers include a chiller bypass to take advantage of indirect evaporative cooling possible in the dry climate. Classrooms have CO_2 sensors that control outdoor air for the fan-coil units.

Figure 4.3. Building exterior with window shading.

Figure 4.4. Building exterior.

(a) (b)

Figure 4.5. (a) Centrifugal chiller and (b) cooling tower.

Table 4.2. Desert Edge High School

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	Concrete block with R-19 insulation and R-30 built-up roof	EN5
Vertical Glazing	Low-e glass with a grey tint; assembled U-factor of 0.33	EN19–20
Lighting		
Lighting Systems Used	T-8 lighting in most of the school with a lighting power density of 1.09 W/ft^2 in classrooms, 1.04 W/ft^2 in the gym, and 1.27 W/ft^2 in the auditorium	EL1–2, EL9–12
Controls	Dual technology occupant sensors used in offices, administrative, and support areas; wall switch occupancy sensors are installed in small offices, storage, or other similar areas	EL6, EL8
Daylighting		
Window Design	Low-e with double glazing and a third pane for integral microblinds	DL1–4, DL9–12
Controls	Daylight sensors used in conjunction with motion sensors	DL13, DL17–18
HVAC		
Equipment	HVAC central cooling and heating use high-efficiency centrifugal chillers with a hydronic economizer cycle with plate and frame heat exchanger and variable-speed pumps	HV10
System Controls		
Measurement and Verification	DDC system with Web-based metering and feedback	
Temperature Control	Individual room controls	
CO_2 Sensors	Installed in each zone of the building to for demand controlled ventilation	
Energy-Use Characteristics	28% better than ASHRAE Standard 90.1-1999	

Photos and data are provided by Emc2 Group Architects Planners, Inc.

ZONE 3—HOMEWOOD MIDDLE SCHOOL

Homewood, Alabama

Homewood Middle School in climate zone 3 is a 190,000 ft^2 facility with a capacity of 1000 students. The school consists of a classroom wing, an administration wing, and an activity wing. The cost to build the school was $23 million, or $121/ft^2. Homewood opened in January 2005, replacing an old school on the same site that was originally built in 1955. When the time came to design the new building, the designers and school district worked together to create an energy-efficient, sustainable building. The result is a school that is 36% more energy efficient than ASHRAE Standard 90.1-1999.

Daylighting is is used throughout the building as one of the primary strategies to achieve energy-efficiency goals. Ninety-five percent of the school utilizes daylighting, and all classrooms in the school have exterior windows. Shading devices, such as overhangs, are used on the south side of the school to reduce solar heat gain and glare in the school. Light shelves are used to project light deeper into the school. Windows on the north side of the school are large to increase the amount of indirect daylight in the school. Electrical lighting is controlled by photo sensors and occupancy sensors to make use of available daylighting and reduce electricity usage. Additional strategies include the following:

- Mass walls are insulated with R-10 continuous insulation
- CO_2 sensors in the gym control the local HVAC system
- A 9.8 EER central chiller VAV HVAC system utilizes air-side economizers

Figure 4.6. Homewood Middle School.

Figure 4.7. Building exterior with light shelves.

(a)

(b)

Figure 4.8. (a) Large north-side windows and (b) school corridor.

Table 4.3. Homewood Middle School

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	Mass walls R-10 c.i.	EN5
Lighting		
Controls	Occupancy sensors and photocell dimmable control	EL6, EL8
Daylighting		
Window Design	Daylighting in all classrooms, gym	DL1–4
HVAC		
Equipment	9.8 EER chiller, VAV	HV5
Cooling Tower	Air cooled	
System Controls		
Measurement and Verification	Yes	HV23
Energy Use Characteristics	36% savings over ASHRAE Standard 90.1-1999	
Measured Energy Cost	1.24 $/ft^2·yr	
Measured Energy Use	64.4 kBtu/ft^2·yr	
Years of Measured Data	2 years	

ZONE 4—KNIGHTDALE HIGH SCHOOL

Knightdale, North Carolina

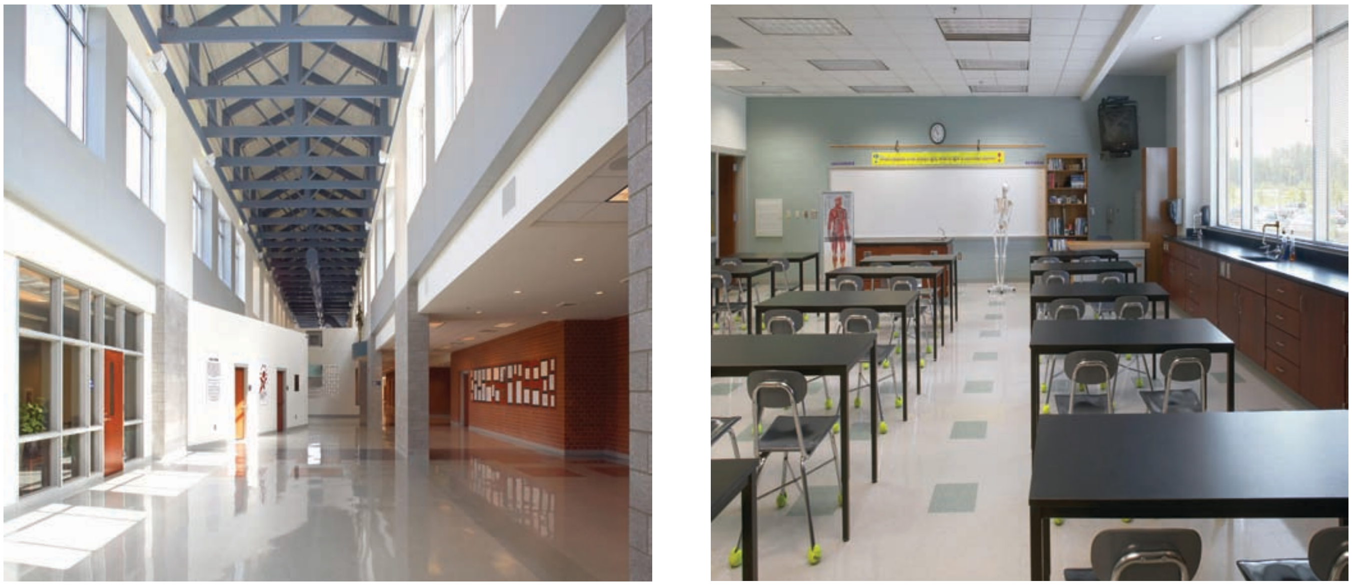
Knightdale High School in climate zone 4 is part of the Wake County School District. The 281,000 ft^2 building was completed for the 2004–2005 school year at a project cost of \$26.5 million, or about \$95/ft^2. The school was built for 1600 students and includes classrooms, offices, public assembly areas, a cafeteria, a gymnasium, athletic fields, and restrooms. The Triangle “J” High Performance Guidelines Version 1.0 guided the design and construction of this building.

The building team committed to high-performance design from the beginning. The project was designed to use 58.7 kBtu/ft^2, and after three years it is operating at 54.4 kBtu/ft^2, annually.

Clerestories provide daylighting in the main entry, the dining commons, and the media center. Additional daylighting is provided by skylights in the dining area and gym corridor. The classrooms in the three-story wing feature large windows to provide daylighting, exterior shading devices on the south-facing windows to control direct sunlight and reduce solar heat gain, dimmable and independently controlled lighting to control daylighting, and multiswitching modes for general classroom lighting.

The building is heated and cooled with a four-pipe chilled- and hot-water system. Hot water is supplied by five high-efficiency condensing boilers, and the chilled water is supplied by standard-efficiency air-cooled chillers. Conditioned air is provided to the classrooms and administration areas with VAV AHUs through a VAV terminal box and hot-water reheat coil in each space. Relative humidity is monitored in the AHU return duct and controlled via AHU fan speed, cooling coils, and heating coils. The HVAC system is controlled through a DDC system.

Figure 4.9. Knightdale High School.



(a) (b)

Figure 4.10. (a) Clerestory at main entrance and (b) classroom lighting system.

Table 4.4. Knightdale High School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	North-south	DL9
Opaque Components	Roof/ceiling R-26; walls R-16	EN3, EN7
Vertical Glazing	Door/window assemblies U = 0.81	EN13
Lighting		
Controls	Dimmable controls in classroom; separate general purpose lighting controls	EL2, EL8
Daylighting		
Window Design	Large windows in three-story section	DL1–DL4
	Exterior light shading on south-facing windows	DL12, DL20, DL22
	Clerestories and skylights in common areas	
HVAC		
Equipment	Standard chiller with variable-frequency drive pumps	HV25
Boilers	Condensing boilers	HV26
Natural Ventilation	VAV system with humidity-controlled cooling and reheat coils; air-handling units (AHUs) use variable-frequency drives and are outfitted with OA economizers for cooling with OA when possible	HV5–6
SWH	Natural gas-fired atmospheric water heater with storage tank, mixing valves and hot water recirculation pumps. SWH system is connected to a digital direct control system or scheduling of operation.	WH1–2
System Controls		
Ventilation	Direct digital control system; OA and CO_2 intake is monitored for each AHU	HV23
Additional Savings		
Exterior/Field/Parking Lot Lighting	The sports field lighting fixtures are provided with internal louvers and hood visors to reduce glare and light trespass off of school property.	EX1–2
Energy Use Characteristics		
Simulated Energy Use	58.7 kBtu/ft^2·yr	
Measured Energy Use	54.4 kBtu/ft^2·yr	
Years of Measured Data	3 years	

Photos and data are provided by the Boney Architects and Wake County Public Schools System.

ZONE 4—THIRD CREEK ELEMENTARY SCHOOL

Statesville, North Carolina

Third Creek Elementary School in Statesville is located in a suburban setting in climate zone 4. The 92,000 ft^2 building was completed in July 2002 at a total project cost of \$8.7 million, or \$95/ft^2 (land purchase excluded). This new construction project consolidated and replaced two aging schools. The finished school was the first K-12 school to earn a LEED v2.0 Gold Certification from the USGBC. Spaces include classrooms, offices, public assembly spaces, cafeteria, gymnasium, athletic field, and restrooms.

The building team made a commitment to high-performance design from the beginning of the project. Examples are the gymnasium, stage, and dining room, which are located so they operate on separate systems for after-hours community use while the academic portion of the school is secured and not using energy. Energy demand was lowered though energy-efficient equipment and design, including extensive daylighting. Third Creek has an east-west axis orientation, with most classrooms facing either north or south. The southern façade has overhangs on the windows to shade from the summer sun. Each of the classrooms makes use of lightshelves to promote the dispersion of daylight. In addition to the lightshelves, reflective ceiling tiles were used to increase the effectiveness of daylighting. Also, in addition to the lighting systems employed within the school, Third Creek makes use of efficient exterior lighting.

Energy modeling shows a reduction in annual energy costs of 25% over ASHRAE Standard 90.1-1999. After the first year of operation, energy reduction increased each year to a 33% reduction in 2005.

Figure 4.11. Floorplan showing north- and south-facing classroom wings.

(a)

(b)

Figure 4.12. (a) Full exterior with view of main entrance and (b) classroom with internal light shelves.

Table 4.5. Third Creek Elementary School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west axis, classrooms facing north and south	DL9
Opaque Components	R-45 roof, R-22 walls	EN3, EN7
Vertical Glazing	Aluminum windows low-e; view glass 46% transmittance center of glass; light shelves glass; 70% transmittance center of glass	EN24
Lighting	Classroom T8	EL2
Controls	Four levels of control per classroom	EL8
	Occupancy sensors	EL6, DL13, L16–18
Daylighting		
Window Design	Overhangs on southern façade	DL20
	Interior light shelves in all classrooms	DL22
HVAC		
Equipment	High-efficiency water-source heat pumps w/ variable-frequency drives—14.5 EER; COP of 4.5	HV2
Boilers	97% thermal efficiency—condensing	HV26
Cooling Tower	5 levels of control to match loads with minimal energy output	
Energy Recovery Ventilators	Control humidity not to exceed 55%	HV8–9
System Controls		
Measurement and Verification	Direct digital control system	HV23
Temperature Control	Classroom by classroom basis	
Additional Savings		
Computers	ENERGY STAR	AS2
Energy Use Characteristics		
Simulated Energy Use	59.6 kBtu/ft^2·yr	
Measured Energy Use	59.8 kBtu/ft^2·yr (purchased)	
Years of Measured Data	3 years	

Photos are provided by Spark Productions and data is provided by Moseley Architects.

ZONE 5—BOLINGBROOK HIGH SCHOOL

Bolingbrook, Illinois

Bolingbrook High School in Bolingbrook, Illinois, is located in a suburban setting in climate zone 5. The 569,000 ft^2 building has a rated capacity of 3600. A master plan for the district included the new high school and renovations to two other high schools, one of which became a middle school. The total project cost for the new school was $96 million, or about $169/$ft^2$. With a commitment to high-performance design, the building team registered the project with the USGBC.

The educational planning concept of school-within-a-school was used in the design, with two academic houses in distinct wings and interior courtyards to maximize exterior views and daylight. In addition, the school incorporated a theatrical performance auditorium, a physical education gym, and a field house that is partially buried to reduce scale. Energy and environmental features include use or inclusion of the following:

- A fully automated digital control system that allows for automatic control of HVAC systems turning on/off via a time schedule set according to the projected use of the different areas
- Fans that do not run unless scheduled and room thermostats that are digitally programmed between 68°F and 74°F so as to optimize energy savings
- Lights equipped with override switches that automatically turn on via a programmed schedule before school starts and automatically turn off after school
- Lights that are equipped with daylight harvesting sensors in the upper levels of the main concourse
- A condensate recovery system projected to save 360,000 gallons of water annually that collects and reuses water from the rooftop chillers
- Bio-swales to filter impurities from surface-water runoff
- A well-irrigation system for athletic fields and indigenous plantings

Figure 4.13. Bolingbrook High School interior courtyard.

(a)

(b)

(c)

Figure 4.14. Daylighting and lighting views of (a) main corridor, (b) media center, and (c) cafeteria.

Table 4.6. Bolingbrook High School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Classrooms facing courtyards	
Opaque Components	2 in. rigid wall insulation in cavity with core insulation in CMU	
Vertical Glazing	1 in. insulated low-e glass	EN19
Roofing System	PVC membrane with white reflectance	EN1
Lighting	T-8 lamps in classrooms, metal halide in hallways	EL2, EL5
Controls	Automatic turnoff based on schedule with override capability in one-hour increments Hallways: light sensors to auto turn off when daylight is sufficient; Classrooms: two switches to allow for 33%, 67% and 100% lighting	EL1–2, EL5, EL8, DL16–17
Daylighting		
Window Design	90% of occupied spaces have daylighting; controls on main corridor with clerestory	DL1–4, DL16–17
HVAC		
Pumps	Constant primary pumping and secondary VSD pumping	HV5–6
System Controls		
Cx	Full Cx included	HV23
Temperature Control	Individual classrooms	
Additional Savings		
Exterior/Field/Parking Lot Lighting	Metal halide cut-off with 0 ft candles at lot line	EX1–2
Energy Use Characteristics		
Simulated Energy Use	86.6 kBtu/ft^2·yr (from LEED submittal)	
Measured Energy Use	91.4 kBtu/ft^2·yr	
Years of Measured Data	3 years (school operates 13 or more hours per day, 7 days per week)	

Photos and data are provided by Wight & Company.

ZONE 5—WHITMAN-HANSON REGIONAL HIGH SCHOOL

Whitman, Massachusetts

Whitman-Hanson Regional High School in climate zone 5 is a 234,500 ft^2 building designed for 1350 students. The total construction cost was $41 million, or $175/ft^2. The school is a pilot project for the Massachusetts Green Schools Initiative, a partnership between the Massachusetts School Building Authority and the Massachusetts Technology Collaborative (MTC).

Whitman-Hanson is 39% more efficient than ASHRAE Standard 90.1-1999. It makes use of daylighting, a well-insulated envelope, energy-efficient mechanical systems, a white roof, and energy-efficient appliances to reduce energy use. Natural light is used in the library, a two-story lecture hall, the classrooms, a performing arts center, and a double gymnasium to reduce the electrical lighting. The cafeteria is lit with natural light through skylights and daylight harvesting. Daylighting sensors are used in each classroom and the gymnasium to control electrical lighting, which comes from high-efficiency fluorescent fixtures, including pendant-mounted, direct/indirect lighting fixtures. The average lighting power density in the school is 1.15 W/ft^2. The exterior walls are insulated with R-10 continuous insulation and 6 in. wall-cavity insulation. Under-slab insulation is used on the floors. The windows are highly insulated and low-e coated to reduce heat loss. They are designed to allow natural light to penetrate further into the building spaces.

The HVAC system helps reduce energy use. Occupancy sensors are used throughout the building to provide adequate heating and cooling. Based on the occupancy, heating and air conditioning of each classroom is controlled by ventilation dampers and VAV boxes. A high-efficiency hybrid chiller is used. The primary base load chiller is a high-efficiency water-cooled chiller, and an air-cooled chiller provides additional capacity for peak periods. High-efficiency condensing boilers, demand-controlled ventilation with an energy recovery system, and variable-flow pumping are additional HVAC energy saving features.

A 51-kW PV system on the roof supplies approximately 5% of the annual energy that is consumed and has become part of the students' curriculum. The school uses the money it saves on energy to purchase high-tech (state of the art) educational aids, including interactive whiteboards and LCD projectors for all classrooms. Other teaching aids include a distance-learning center, cyber cafes, and instructional kiosks.

Figure 4.15. Whitman-Hanson regional high school exterior.

(a)

(b)

Figure 4.16. (a) Daylighted library and (b) classroom.

Table 4.7. Whitman-Hanson Regional High School

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components—Exterior Walls	R-10 c.i. plus 6 in. wall cavity insulation	EN7
Opaque Components—Floors	Under slab insulation	EN10
Vertical Glazing	Low-e	EN19
Lighting		
Lighting System	High-efficiency fluorescent fixtures including pendant-mounted direct-indirect lighting fixtures	EL1–2
LPD	1.15 W/ft^2 average in the school	EL9
Controls	Photosensors in each classroom and the gymnasium	DL17
Daylighting		
Window Design	Highly insulated and low-e coated	
Natural Light	Used in the library, two-story lecture hall, classrooms, performing arts center, and double gymnasium to reduce the use of electrical lighting	DL36
Skylights	Used in the cafeteria with daylight harvesting	DL28
HVAC		
Equipment	Water-cooled chiller for base load; air-based chiller used only for peaking	HV25
Boilers	High-efficiency condensing boiler	HV26
System Controls		
Temperature Control	Occupancy sensors control ventilation dampers and VAV boxes to adjust the heating and A/C in each classroom.	HV5–6
Additional Savings		
Renewable Energy	51 kW PV system on the roof	AS6
Green Technology Cost Information		
Total Capital Cost	2.83% of the total cost	
Incremental Cost	\$4.85/ft^2	
Incentives Received	\$475,000 of the total \$580,000 PV system from MTC	
Expected Payback (w/o Incentives)	Nine years (excluding the solar electric generation)	
Expected Payback (w/Incentives)	Almost immediate (incentives paid most of the initial cost for the green technology)	
Energy Use Characteristics	39% better than ASHRAE Standard 90.1-1999	
Measured Energy Use	60.5 kBtu/ft^2·yr (utility bills)	
MeasuredEnergy Cost	1.80 \$/ft^2·yr	
Years of Measured Data	3 years	

ZONE 6—WESTWOOD ELEMENTARY SCHOOL

Zimmerman, Minnesota

Westwood Elementary School is located in a mixed suburban/rural setting in climate zone 6. The 75,000 ft^2, two-story building has a current capacity of 500 students, and the core facilities have a capacity of 750 students. The school opened in the fall of 2004 and was built at a cost of $12 million, or $160/$ft^2$. Spaces include classrooms, offices, public assembly areas, cafeteria, gymnasium, and athletic field. The school used LEED as the design guidance and was the first K-12 school in Minnesota and the fourth in the nation to earn LEED v2.1 certification.

The building was oriented on the site to maximize solar and wind patterns. The high-performance design included increased insulation, daylighting, energy-efficient lighting with occupancy sensors, low-e glass to control heat gain and loss, displacement ventilation, energy-efficient gas kitchen equipment, and a condensing boiler for heating needs. Operable windows add to the energy-saving features and allow for passive ventilation. The building was designed to meet multiple community and school needs. The gymnasium, stage, and dining room are located strategically so they operate on separate systems after hours.

In order to cut energy use and peak loads, Westwood uses energy recovery ventilators (ERVs). ERVs can recover as much as 80% of the energy from the exhaust airstream and transfer it to the supply airstream for heating and humidification in the winter months. The use of ERVs in the winter can cut humidification costs by up to 60%. The ERVs are used in the opposite manner for cooling in the summer months and transfer sensible and latent energy from the ventilation air to the exhaust airstream.

The original design projected an energy use of 53.7 kBtu/ft^2 annually; however, the actual building operation has been modified from what was modeled due to year-round cooling. During the first three years of operation, the actual annual energy used to operate this building has been 75.9–84.0 kBtu/ft^2, with an average of 78.4 kBtu/ft^2.

Figure 4.17. Westwood Elementary School aerial photo.

Figure 4.18. Pulse condensing boiler.

Table 4.8. Westwood Elementary School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west orientation for classrooms	DL9
Opaque Components	Roof insulation: R-22 Wall insulation: R-18	EN3, EN7
Roofing	5-ply built up roof	
Vertical Glazing	U-factor: 0.29 SHGC: 0.49 Visual transmittance: 0.69	EN19,
Lighting		
Controls	Occupancy and daylighting sensors	EL6, DL17
Fixture Design	15% direct/85% indirect T5 pendent fixtures	EL3
HVAC		
Equipment	Fan-powered VAV w/displacement ventilation	HV5–6
Boilers	94% efficiency HW condensing	HV26
Cooling	Air-cooled chiller (10.7 EER)	HV25
Pumping	Variable-frequency drives (VFDs) on hot-water and chilled-water loops.	HV25–26
Window Design	Operable for natural ventilation	HV32
Energy Recovery	Desiccant well	HV9
SWH	94% efficient condensing (gas)	WH1–2
System Controls		
Measurement and Verification	Systems Cx	HV23
Temperature Control	Web-based building automation system (BAS)	
Demand-Controlled Ventilation	Gymnasium and cafeteria AHUs	
Additional Savings		
Kitchen Equipment	Energy-efficient equipment (gas)	AS2
Energy Use Characteristics		
Simulated Code Base	113.7 kBtu/ft^2·yr	
Simulated Design Model	53.7 kBtu/ft^2·yr (original design—no summer operation)	
Measured Energy Use	78.4 kBtu/ft^2·yr (actual operation)	
Years of Measured Data	3 years	

Photos and data are provided by Elk River Area School District ISD 728 and Johnson Controls.

ZONE 6—ALDER CREEK MIDDLE SCHOOL

Truckee, California

Alder Creek Middle School near Lake Tahoe is located in a rural setting in climate zone 6. The 87,000 ft^2 building opened in 2004. The school was designed to serve 1000 students with an initial capacity of 700 students in sixth through eighth grades. The project was a CHPS demonstration school with a construction cost of $24 million ($30 million with contingency and soft costs), or $275/ft^2.

The school is a showcase of high-performance building strategies, including daylighting, energy efficiency, healthy IAQ, proper acoustics, building Cx, sustainable materials, waste reduction, preventive maintenance, site protection, and water conservation. The spaces in the school include classrooms, offices, public assembly spaces, cafeteria, gymnasium, athletic fields, and restrooms.

Classroom light fixtures are 60% uplight and 40% downlight. The top row of windows is designed to provide daylight to the space. Ground-source heat pumps (GSHPs) operate with an energy savings of more than 51% compared to the typical four-pipe boiler chiller system previously installed. The school uses 288 wells that are drilled 300 ft deep beneath the soccer field.

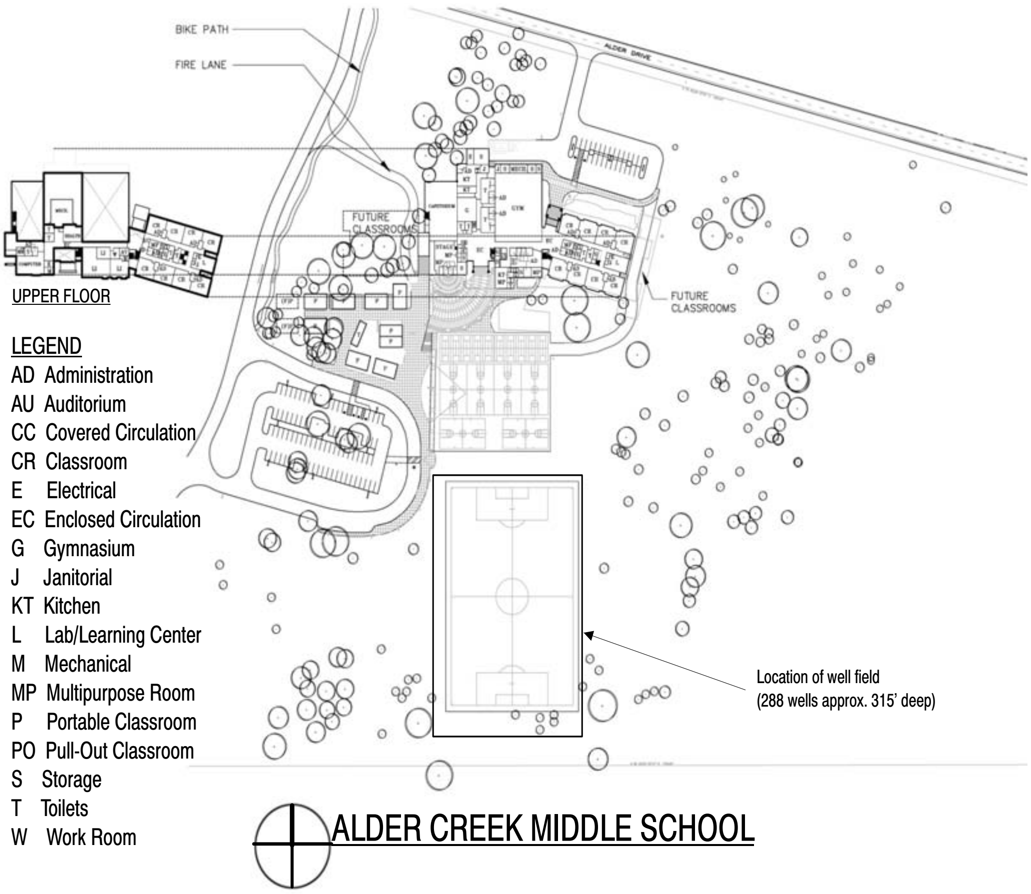
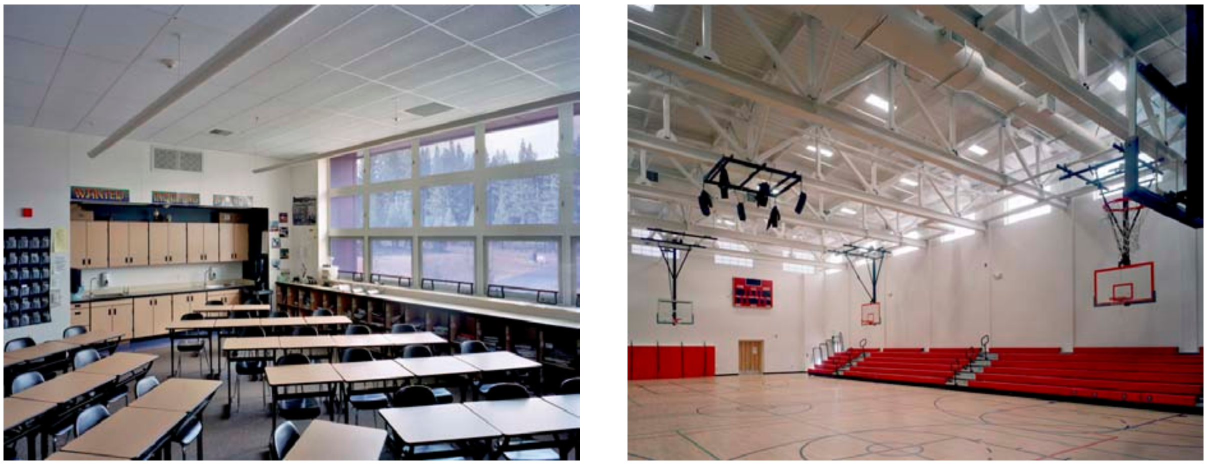


Figure 4.19. Site plan showing geothermal well field location



(a) (b)

Figure 4.20. Alder Creek Middle School (a) classroom lighting system and (b) daylighted gym.

Table 4.9. Alder Creek Middle School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	Roof and walls R-19; cool roof	EN1, EN3, EN7
Vertical Glazing	Low-e	EN19
Lighting		
Lighting Systems Used	T5 direct/indirect in classrooms and offices; T5 HO in gym; T8 in all other areas	EL2–3
Controls	Sensor on row of lights near windows; Room occupancy sensors	EL6
Daylighting		
Window Design	Low-e with dual glazing	DL1–4
Controls	Blinds inside windows act as light shelves	DL12
Skylights	Located in stairwells in classroom wing	
HVAC		
Equipment	GSHPs	HV2
Boilers	Backup and peak use only	HV26
SWH	Dedicated domestic boiler for hot water	WH1–2
System Controls		
Measurement and Verification	EMCS system used district wide	HV23
Temperature Control	Individual room controls with a 5° limit on user control	
CO_2 Sensors	Used in gym and cafeteria	
Additional Savings		
Computers	ENERGY STAR features enabled	AS2
Exterior/Field/Parking Lot Lighting	Metal halide lamps	EX1–3
Energy Use Characteristics		
Simulated Energy Use	25% below Title 24 in California	
Measured Energy Use	54 kBtu/ft^2·yr	
Years of Measured Data	2.75 years	

Photos and data are provided by the Tahoe Truckee Unified School District, CHPS case study, and Lionakis Beaumont Design Group, Inc.

ZONE 7—SILVERTHORNE ELEMENTARY SCHOOL

Silverthorne, Colorado

Silverthorne Elementary in Silverthorne, Colorado, is located in Summit County in climate zone 7. Silverthorne is a 62,500 ft^2 building that houses 430 students ranging from K-5. The school opened in the fall of 2004. The build cost of the school was \$9.3 million, or \$148/ft^2, which is in line with the typical cost of area schools. The building was designed by OZ Architecture of Denver in collaboration with BOORA of Portland Oregon.

At an elevation of 9100 ft, the extreme climate was a factor in the design. By optimizing the building orientation, using daylighting to the fullest, increasing insulation levels, and using natural ventilation and economizers, the design team developed a design that will save the district \$27,000 per year that would otherwise be spent on high utility bills. On warm days, outdoor air enters through the windows and rises to the top floor atria where it is vented by exhaust fans. When windows are closed, efficient mechanical ventilation is used. VAV air handlers deliver fresh air to the rooms and are regulated by CO_2 sensors to ensure adequate ventilation. This design also keeps air-handler noise away from the classrooms, improving acoustics in learning areas.

The design team's goal was for daylighting to provide most of the light needed in classrooms, even on overcast days. In addition to ample windows, daylight is directed to illuminate the back wall of each classroom using light shafts. Daylighting controls in the classrooms and gyms control lights in response to the available daylighting.

Figure 4.21. Interior view of skylights.

(a) (b)

Figure 4.22. (a) Silverthorne Elementary School exterior and (b) classroom lighting system.

Table 4.10. Silverthorne Elementary School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	60 mil EPDM roof with R-30 polyiso insulation and R-19 wall insulation	EN1, EN7
Vertical Glazing	Clear double pane with spectrally selective low-e coating	EN19
Lighting	T-5 linear indirect classrooms and offices; high bay metal halide in gym	EL3, EL5
Controls	Occupancy sensors in all rooms and offices	EL6
Daylighting Controls	Automatic dimming and separate controls for each row of lights in classrooms	EL8
Daylighting		
Window Design	Aluminum frame windows that are thermally broken	DL1–4
Daylighting Design	Light shelves on exterior southern exposure; clerestories for interior hallways; light shafts in back of every classroom; skylight spines along central circulation path, gym and admin offices (see photos)	DL12
HVAC		
Equipment	AHUs have VAV with reheat; cooling is by outdoor air economizer cycle	HV6
Boilers	Condensing boilers with 90+% efficiency	HV26
Cooling Tower	None	
Economizer	Economizer cycle for all cooling	HV13
Service Water Heating	Solar preheat for domestic hot water	WH1, WH3, WH5–6, AS7
System Controls	HVAC controls include limiting outdoor air during unoccupied hours, optimum start/stop and outdoor air reset on heating hot water.	HV21
Cx	Partial commissioning	HV23
OA Control	Individual rooms with CO_2 sensors	
Additional Savings		
Computers	ENERGY STAR	AS2
Renewable Energy	Solar preheat for hot water	AS7
Energy Use Characteristics		
Simulated Energy Use	76.7 kBtu/ft^2·yr	
Measured Energy Use	88.0 kBtu/ft^2·yr	
Years of Measured Data	2 years	

How to Implement Recommendations

5

Recommendations are contained in the individual tables in Chapter 3, "Recommendations by Climate." The following information is intended to provide good-practice guidance for implementing the recommendations, as well as notes of caution to avoid known problems in energy-efficient construction. The sections are divided into *Commissioning*, *Envelope*, *Lighting*, *HVAC*, *Service Water Heating*, and *Additional Savings*. The "Additional Savings" section includes bonus savings—good practice items, which, if implemented, will achieve additional savings above the 30% level.

COMMISSIONING

To reduce project risk, Cx offers a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets the defined objectives and criteria. The CxA is a dedicated person (one with no other project responsibilities) who can execute this process systematically. An independent party, whether a third-party Cx professional or a capable member of the organization, is recommended to help ensure that the strategies and recommendations contained herein and adopted by the owner are implemented in accordance with this Guide and other documented objectives, criteria, and requirements. Cx practice recommendations are offered below. Appendix B summarizes the Cx scope and responsibilities.

Good Design Practice

CX1 Selection of a Commissioning Authority

The selection of a CxA should include the same evaluation process the owner would use to select other project team members. The owner should investigate and consider qualifications in providing Cx services, past performance of projects, costs of services, and availability when making a selection.

Owners may select a member of the organization, the design team, or the construction team as the CxA. Although there are exceptions, most designers are not comfortable operating and testing assemblies and equipment, and few contractors have the technical background or time necessary to thoroughly evaluate performance. Cx requires in-depth technical knowledge of the building envelope; mechanical, electrical, and plumbing systems; and operational and construction experience. The CxA function is best performed by an entity responsible to the owner because political issues often prevent a member of the design or construction organizations from fulfilling this responsibility.

CX2 Design and Construction Schedule

The inclusion of Cx activities in the construction schedule fulfills a critical role in delivering a successful project. The activities and time required for design review and performance verification must be identified to minimize the time and effort needed to accomplish activities and correct deficiencies.

CX3 Design Review

A second pair of eyes provided by the CxA offers a fresh perspective that allows identification of issues and opportunities to improve the quality of the construction documents. Issues identified can be more easily corrected early in the project, providing potential savings in construction costs and reducing risk to the team.

CX4 Defining Commissioning Process at Pre-Bid

The building industry has traditionally delivered buildings without using a verification process. Changes in traditional design and construction procedures and practices require that the construction team be educated about how the Cx process will affect the various trades bidding on the project. The Cx process must be reviewed with the bidding contractors to facilitate understanding of and to help minimize apprehension associated with new practices. Teams who have participated in the Cx process typically appreciate the process because they can resolve problems while their manpower and materials are still on the project. This significantly reduces delays, callbacks, and costs, and enhances their delivery capacity.

CX5 Verifying Building Envelope Construction

The building envelope is a key element of an energy-efficient design. Compromises in assembly performance are common and are caused by a variety of factors that can easily be avoided. Improper placement of insulation, improper sealing or lack of sealing around air barriers, incorrect or poorly performing glazing and fenestration systems, incorrect placement of shading devices, misplacement of daylighting shelves, and misinterpretation of assembly details can compromise the energy performance of the building (see “Cautions” throughout this chapter). The value of the Cx process is that it offers an extension of the quality control processes of the designer and contractor as the team works together to produce quality energy-efficient projects.

CX6 Verifying Electrical and HVAC Systems Construction

Performance of electrical and HVAC systems are key elements of this Guide. How systems are installed will affect how efficiently they can be serviced and how well they will perform. Observations during construction identify problems while they are easy to correct.

CX7 Testing

Systems must be tested to ensure that a project following this Guide will attain the energy savings that can be expected from the recommended strategies and recommendations. If the contractors use the Cx recommendations as intended, systems can be tested quickly, and minor but important issues can be resolved. Owners can use the functional testing process as a training tool to educate their O&M staff about how the systems operate and for system orientation before training.

CX8 Substantial Completion

Substantial completion generally means that the life safety systems are completed and accepted. Contractors typically do not test the systems' performance at substantial completion, nor do we recommend that. The systems may be operational, but they probably do not yet operate as intended. They cannot perform as expected unless all systems operate interactively to provide the desired results. As contractors finish their work, they will identify and resolve many performance problems. The CxA helps to resolve remaining issues.

CX9 Maintenance Manual Submitted and Accepted

The Cx process includes communication of activities that the owner will be responsible for completing to maintain the manufacturers' warranties. Information on the owner's requirements and expectations should be provided to the O&M staff for an understanding of the original objectives and criteria for the project. A systems manual that provides the operators the information needed to optimally operate the building should also be made available.

CX10 Resolve Quality Control Issues Identified Throughout the Construction Phase

Issues identified during the construction process are documented in an issues log and presented to the team for collaborative resolution; they are then tracked and reviewed at progress meetings until they are resolved. Typically the CxA develops and maintains the issues log. The owner's completion and acceptance of the systems and assemblies will be contingent on issues that are still outstanding at the end of the project. Minor issues may be tracked by the owner's O&M staff; others will need to be resolved before the work is accepted. The Cx process finishes with verification that the issues identified have been resolved, and the owner provides direction to the team to resolve issues.

CX11 Final Acceptance

Final acceptance generally occurs after Cx issues in the issues log have been resolved, except for minor issues the owner is comfortable addressing during the warranty period.

CX12 Establish a Building Maintenance Program

Continued performance and control of O&M costs require a maintenance program. O&M manuals provide information that the O&M staff uses to develop this program. Detailed O&M system manual and training requirements are defined in the Cx process and are executed by the project team to ensure O&M staff has the necessary tools and skills. The CxA can help bridge the knowledge gaps of the O&M staff and help the owner develop a program to ensure continued performance. The benefits associated with energy-efficient buildings are realized when systems perform as intended through proper design, construction, and O&M.

CX13 Monitor Post-Occupancy Performance

Establishing measurement and verification procedures with a performance baseline can help a CxA identify when corrective action or repair is required to maintain energy

Table 5.1. Examples of Cool Roofs

Category	Product	Reflectance	Emissivity	SRI
Single-Ply	White PVC (polyvinyl chloride)	0.86	0.86	107
Single-Ply	White CPE (chlorinated polyethylene)			
Single-Ply	White CPSE (chlorosulfonated polyethylene)	0.85	0.87	106
Single-Ply	White TSO (thermoplastic polyolefin)	0.77	0.87	95
Liquid-Applied	White elastomeric, polyurethane, acrylic coating	0.71	0.86	86
Liquid-Applied	White paint (on metal or concrete)	0.71	0.85	86
Metal Panels	Factory-coated white finish	0.90	0.87	113

performance. Utility energy use and factors that affect it should be monitored and recorded to establish building performance during the first year of operation. Tools such as ENERGY STAR's Portfolio Manager[1] can help track energy use and costs.

Variations in utility use can be justified based on changes in conditions, such as weather, occupancy, operational schedule, maintenance procedures, and equipment operations required by these conditions that typically affect energy use. Tracking specific parameters allows the owner to quickly review utility bills and changes in conditions. Poor performance is generally obvious to the reviewer when comparing the various parameters. The CxA can typically help owners understand when operational tolerances are exceeded and can help define the actions that may be required to return the building to peak performance.

ENVELOPE

Good Design Practice

EN1 *Cool Roofs* (Climate Zones: 1 2 3)

To be considered a cool roof, a solar reflectance index (SRI) of 78 or higher is recommended. A high reflectance keeps much of the sun's energy from being absorbed while a high thermal emittance radiates away solar energy that is absorbed, allowing the roof to cool more rapidly. Cool roofs are typically white and have a smooth surface. Commercial roof products that qualify as cool roofs fall into three categories: single-ply, liquid-applied, and metal panels. Examples are presented in Table 5.1.

The solar reflectance and thermal emittance property values represent initial conditions as determined by a laboratory accredited by the Cool Roof Rating Council.

An SRI can be determined by the following equations:

$$\text{SRI} = 123.97 - 141.35(\chi) + 9.655(\chi^2)$$

where

$$\chi = \frac{20.797 \times \alpha - 0.603 \times \varepsilon}{9.5205 \times \varepsilon + 12.0}$$

and

α = solar absorptance = 1 – solar reflectance
ε = thermal emissivity

1. http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

These formulas were derived from ASTM E1980 assuming a medium wind speed. Note that cool roofs are not an alternative to the appropriate amount of insulation.

EN2 *Roofs, Insulation Entirely Above Deck* (Climate Zones: all)

The insulation entirely above deck should be continuous insulation (c.i.) rigid boards. Continuous insulation is important because no framing members are present that would introduce thermal bridges or short circuits to bypass the insulation.

When two layers of c.i. are used in this construction, the board edges should be staggered to reduce the potential for convection losses or thermal bridging. If an inverted or protected membrane roof system is used, at least one layer of insulation is placed above the membrane and a maximum of one layer is placed beneath the membrane.

EN3 *Roofs, Attics, and Other Roofs* (Climate Zones: all)

Attics and other roofs include roofs with insulation that is entirely below (inside) the roof structure (attics and cathedral ceilings) and roofs with insulation both above and below the roof structure. Ventilated attic spaces need to have the insulation installed at the ceiling line. Unventilated attic spaces may have the insulation installed at the roof line. When suspended ceilings with removable ceiling tiles are used, the insulation needs to be installed at the roof line. For buildings with attic spaces, ventilation should be provided equal to 1 ft^2 of open area per 100 ft^2 of attic space. This will provide adequate ventilation as long as the openings are split between the bottom and top of the attic space. Additional ventilation can further improve the performance of the building.

In metal roof building construction, purlins are typically z-shaped, cold-formed steel members, although steel bar joists are sometimes used for longer spans.

The thermal performance of metal building roofs with fiberglass blankets is improved by addressing the thermal bridging associated with compression at the purlins. The two types of metal building roofs are standing seam roofs and through-fastened roofs. Standing seam roofs have very few exposed fasteners and utilize a concealed clip for the structural attachment of the metal roof panel to the purlins. The larger gap between the purlin and the roof sheets, along with the thermal spacer block, provides a thermal break that results in improved performance compared to the standard through-fastened metal roofs. It is recommended that the thermal resistance between the purlin and the metal deck be at least R-8. One means to accomplish this is by using a 3/4 × 3 in. foam block (R-5) over 3/4 in. of compressed fiberglass blanket (R-3). Alternatively, a 2 in. space filled with compressed fiberglass insulation will provide roughly R-8.

Through-fastened metal roofs are screwed directly to the purlins and have fasteners that are exposed to the elements. The fasteners have integrated neoprene washers under the heads to provide a weathertight seal. Thermal spacer blocks are not used with through-fastened roofs because they may diminish the structural load carrying capacity by “softening” the connection and restraint provided to the purlin by the metal roof panels. To meet the performance recommendations of this guide, through-fastened roofs will generally require insulation over the purlins in the conventional manner, with a second lay of insulation added to the system. The second layer of insulation can be placed either parallel to the purlins (on top of the first layer) or suspended below the purlins.

In climate zone 1 the recommended construction is standing-seam roofs with R-19 insulation blankets draped over the purlins.

In climate zones 2 through 8, the recommended construction is standing-seam roofs with two layers of blanket insulation. The first layer is draped perpendicularly over the purlins with enough looseness to allow the second insulation layer to be laid above it, parallel to the purlins.

In any case, continuous rigid insulation or other high performance insulation systems may be used to meet the U-facors listed in Appendix A.

EN4 *Roofs, Single Rafter* (Climate Zones: All)

Single-rafter roofs have the roof above and ceiling below both attached to the same wood rafter, and the cavity insulation is located between the wood rafters. Continuous insulation, when used, is installed on the bottom of the rafters and above the ceiling material. Single rafters can be constructed with solid wood framing members or truss-type framing members. The cavity insulation should be installed between the wood rafters and in intimate contact with the ceiling to avoid the potential thermal short-circuiting associated with open or exposed air spaces.

EN5 *Walls, Mass* (Climate Zones: all)

Mass walls are defined as those with a heat capacity exceeding 7 Btu/ft^2·°F. Insulation may be placed either on the inside or the outside of the masonry wall. When insulation is placed on the exterior, rigid c.i. is recommended. When it is placed on the interior, a furring or framing system may be used, provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

The greatest advantages of mass can be obtained when insulation is placed on its exterior. In this case, the mass absorbs heat from the interior spaces that are later released in the evenings when the buildings are not occupied. The thermal mass of a building (typically contained in the building envelope) absorbs heat during the day and reduces the magnitude of indoor air temperature swings, reduces peak cooling loads, and transfers some of the absorbed heat into the night hours. The cooling load can then be covered by passive (natural) cooling techniques when the outdoor conditions are more favorable. An unoccupied building can also be pre-cooled during the night by natural or mechanical ventilation to reduce the cooling energy use.

Thermal mass also has a positive effect on thermal comfort. High-mass buildings attenuate interior air and wall temperature variations and sustain a stable overall thermal environment. This increases thermal comfort, particularly during mild seasons (spring and fall), during large air temperature changes (high solar gain), and in areas with large day/night temperature swings.

A designer should keep in mind that the occupant will be the final determinant factor on the extent of the usability of any building system, including thermal mass. Changing the use of internal spaces and surfaces can drastically reduce the effectiveness of thermal storage. The final use of the space must be considered when making the cooling load calculations and incorporating possible energy savings from thermal mass effects.

EN6 *Walls, Steel Framed* (Climate Zones: all)

Cold-formed steel framing members are thermal bridges to the cavity insulation. Adding exterior foam sheathing as c.i. is the preferred method to upgrade the wall thermal performance because it will increase the overall wall thermal performance and tends to minimize the impact of the thermal bridging.

Alternative combinations of cavity insulation and sheathing in thicker steel-framed walls can be used, provided that the proposed total wall assembly has a U-factor that is less than or equal to the U-factor for the appropriate climate zone construction listed in Appendix A. Batt insulation installed in cold-formed steel-framed wall assemblies is to be ordered as full width batts and installation is normally by friction fit. Batt insulation should fill the entire cavity and not be cut short.

EN7 *Walls, Wood Frame, and Other* (Climate Zones: all)

Cavity insulation is used within the wood-framed wall; rigid c.i. is placed on the exterior side of the framing. Alternative combinations of cavity insulations and sheathings in thicker walls can be used, provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A. Batt insulation should fill the entire cavity and not be cut short.

In metal building wall construction in climate zones 1–4, a single layer of fiberglass batt insulation is recommended. The insulation is installed continuously, perpendicular to the exterior of the girts, and is compressed as the metal skin is attached to the girts. In climate zones 5–8, one layer of fiberglass batt insulation is recommended along with a layer of rigid continuous insulation (c.i.). The fiberglass layer is installed continuously perpendicular to the exterior of the girts. The rigid c.i. insulation is installed over the fiberglass layer. The fiberglass layer is compressed as the metal skin is attached to the girts.

EN8 *Below-Grade Walls* (Climate Zones: all)

Insulation, when recommended, may be placed either on the inside or the outside of the below-grade wall. If placed on the exterior of the wall, rigid c.i. is recommended. If placed on the interior wall, a furring or framing system is recommended, provided the total wall assembly has a C-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

EN9 *Floors, Mass* (Climate Zones: all)

Insulation should be continuous and either integral to or above the floor. It should be purchased by the conductive R-value. This can be achieved by placing high-density extruded polystyrene as c.i. above the slab with either plywood or a thin layer of concrete on top. An exception: buildings or zones in buildings that have durable floors for heavy machinery or equipment could have insulation placed below the deck.

When heated slabs are placed below grade, below-grade walls should meet the insulation recommendations for perimeter insulation according to the heated slab-on-grade construction.

EN10 *Floors, Steel Joist, or Wood Frame* (Climate Zones: all)

Insulation should be installed parallel to the framing members and in intimate contact with the flooring system supported by the framing member to avoid the potential thermal short-circuiting associated with open or exposed air spaces. Nonrigid insulation should be supported from below, no less frequently than 24 in. on center.

EN11 *Slab-on-Grade Floors, Unheated* (Climate Zones: 6 7 8)

Rigid c.i. should be used around the perimeter of the slab and should reach the depth listed in the recommendation or to the bottom of the footing, whichever is less. In climate zones 5–8 and in cases where the frost line is deeper than the footing, c.i. should be placed beneath the slab as well.

EN12 Slab-on-Grade Floors, Heated (Climate Zones: all)

When slabs are heated, rigid c.i. should be used around the perimeter of the slab and should reach to the depth listed in the recommendation or to the bottom of the footing, whichever is less. Additionally, in climate zones 5–8, c.i. should be placed below the slab. The conductive R-value must be used for the insulation, as radiative heat transfer is small in this application.

Note: In areas where termites are a concern and rigid insulation is not recommended for use under the slab, a different heating system should be used.

EN13 Doors—Opaque, Swinging (Climate Zones: all)

A U-factor of 0.37 corresponds to an insulated double-panel metal door. A U-factor of 0.61 corresponds to a double-panel metal door. If at all possible, single swinging doors should be used. Double swinging doors are difficult to seal at the center of the doors unless there is a center post. Double swinging doors without a center post should be minimized and limited to areas where width is important. Vestibules can be added to further improve energy efficiency.

EN14 Doors—Opaque, Roll-Up, or Sliding (Climate Zones: all)

Roll-up or sliding doors are recommended to have R-4.75 rigid insulation or meet the recommended U-factor. When meeting the recommended U-factor, the thermal bridging at the door and section edges is to be included in the analysis. Roll-up doors that have solar exposure should be painted with a reflective paint (or high emissivity) and should be shaded. Metal doors are a problem in that they typically have poor emissivity and collect heat, which is transmitted through even the best insulated door and causes cooling loads and thermal comfort issues.

Options

EN15 Alternative Constructions (Climate Zones: all)

The climate zone recommendations provide only one solution for upgrading the thermal performance of the envelope. Other constructions can be equally effective, but they are not shown in this document. Any alternative construction that is less than or equal to the U-factor, C-factor, or F-factor for the appropriate climate zone construction is equally acceptable. A table of U-factors, C-factors, and F-factors that correspond to all the recommendations is presented in Appendix A.

Procedures to calculate U-factors and C-factors are presented in the *ASHRAE Handbook—Fundamentals*, and expanded U-factor, C-factor, and F-factor tables are presented in ASHRAE Standard 90.1, Appendix A.

Cautions

The design of building envelopes for durability, indoor environmental quality, and energy conservation should not create conditions of accelerated deterioration, reduced thermal performance, or problems associated with moisture, air infiltration, or termites. The following cautions should be incorporated into the design and construction of the building.

EN16 Truss Heel Heights (Climate Zones: all)

When insulation levels are increased in attic spaces, the truss heel height should be raised to avoid the eave compression. Roof insulation should extend to the exterior of the walls to minimize edge effects.

EN17 Slab-Edge Insulation (Climate Zones: all)

Use of slab-edge insulation improves thermal performance, but problems can occur in regions that have termites.

EN18 Air Infiltration Control (Climate Zones: all)

The building envelope should be designed and constructed with a continuous air barrier system to control air leakage into or out of the conditioned space. An air barrier system should also be provided for interior separations between conditioned space and space designed to maintain temperature or humidity levels that differ from those in the conditioned space by more than 50% of the difference between the conditioned space and design ambient conditions. If possible, a blower door should be used to depressurize the building to find leaks in the infiltration barrier. The air barrier system should have the following characteristics:

- It should be continuous, with all joints made airtight
- Air barrier materials used in frame walls should have an air permeability not to exceed 0.004 cfm/ft^2 under a pressure differential of 0.3 in. water (1.57 lb/ft^2) when tested in accordance with ASTM E 2178
- The system should be able to withstand positive and negative combined design wind, fan, and stack pressures on the envelope without damage or displacement, and should transfer the load to the structure; it should not displace adjacent materials under full load
- It should be durable or maintainable
- The air barrier material of an envelope assembly should be joined in an airtight and flexible manner to the air barrier material of adjacent assemblies, allowing for the relative movement of these assemblies and components due to thermal and moisture variations, creep, and structural deflection
- Connections should be made between
    - (a) foundation and walls
    - (b) walls and windows or doors
    - (c) different wall systems
    - (d) walls and roof
    - (e) walls and roof over unconditioned space
    - (f) walls, floor, and roof across construction, control, and expansion joints
    - (g) walls, floors, and roof to utility, pipe, and duct penetrations
- All penetrations of the air barrier system and paths of air infiltration/exfiltration should be made airtight

Good Design Practice

Vertical Fenestration

EN19 Vertical Fenestration Descriptions (Climate Zones: all)

Fenestration refers to the light-transmitting areas of a wall or roof, mainly windows and skylights, but also including glass doors, glass block walls, and translucent plastic panels. Vertical fenestration includes sloped glazing if it has a slope equal to or more than 60° from the horizontal. If it slopes less than 60° from the horizontal, the fenestration falls in the skylight category. This means that clerestories, roof monitors, and other such fenestration fall in the vertical category.

The recommendations for vertical fenestration are listed in Chapter 3 by climate zone.

To be useful and consistent, the U-factors for windows should be measured over the entire window assembly, not just the center of glass. Look for a label that denotes the window rating is certified by the National Fenestration Rating Council (NFRC). The selection of high-performance window products should be considered separately for each orientation of the building and for daylighting and viewing functions.

To meet the SHGC recommendations for vertical fenestration in Chapter 3, use the SHGC multipliers for permanent projections, as provided in Table 5.5.4.4.1 in ASHRAE Standard 90.1-2004. These multipliers allow for a higher SHGC for vertical fenestration with overhangs. For an overhang with a projection factor greater than 0.5, the recommended SHGC can be increased by 64%. For example, the recommended SHGC in climate zone 1 is 0.25. With an overhang with a projection factor of 0.5, an SHGC of 0.4 is acceptable (see Figure 5.1). Using the SHGC multipliers for vertical fenestration with overhangs makes it easier to meet the high visible transmittance recommendations needed for daylighting (see DL5).

EN20 *Fenestration to Gross Wall Area Ratio* (Climate Zones: all)

The fenestration to gross wall area ratio (FWR) is the percentage resulting from dividing the total vertical fenestration area by the gross exterior wall area. The total vertical fenestration area includes both the view fenestration below 7 ft and the vertical daylighting fenestration (including vertical components of roof monitors and clerestories) above 7 ft. The total vertical fenestration area is the rough opening, i.e., it includes the frame, sash, and other nonglazed window components. The gross exterior wall is measured horizontally from the exterior surface; it is measured vertically from the top of the floor to the bottom of the roof. The gross exterior wall area includes below-grade as well as above-grade walls.

The FWR over all the exterior gross wall area of the school should not exceed 35%. A reduction in the view fenestration will also save energy, especially if glazing is significantly reduced on the east and west facades. The smallest glazed area should be designed in a way that is still consistent with needs for view, daylighting, and passive solar strategies.

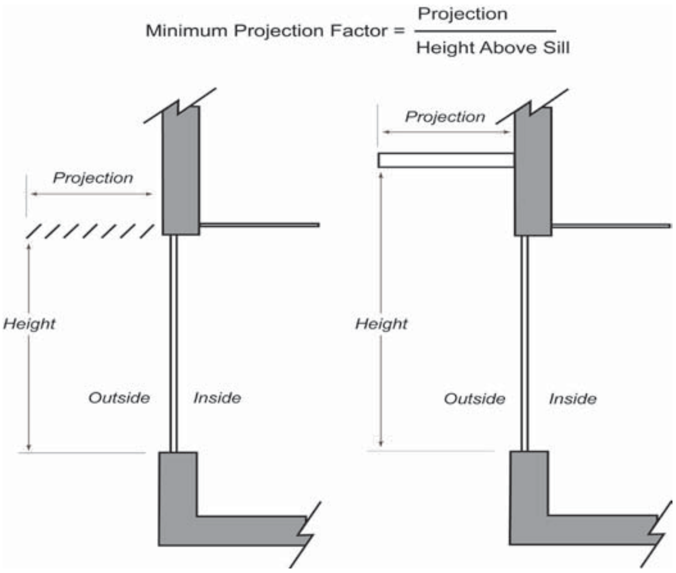


Figure 5.1. Horizontal overhangs.

Window Design Guidelines for Thermal Conditions

Uncontrolled solar heat gain is a major cause of energy use for cooling in warmer climates and thermal discomfort for occupants. Appropriate configuration of windows according to the orientation of the wall on which they are placed can significantly reduce these problems.

EN21 *Unwanted Solar Heat Gain Is Most Effectively Controlled on the Outside of the Building* (Climate Zones: all)

Significantly greater energy savings are realized when sun penetration is blocked before it enters the windows. Horizontal overhangs at the top of the windows are most effective for south-facing facades and must continue beyond the width of the windows to adequately shade them (see Figure 5.1). Vertical fins can be problematic in schools from the perspective of vandalism. Consider louvered or perforated sun control devices, especially in primarily overcast and colder climates, to prevent a totally dark appearance in those environments.

EN22 *Operable Versus Fixed Windows* (Climate Zones: all)

Operable windows offer the advantage of personal comfort control and beneficial connections to the environment. However, individual operation of the windows not in coordination with the HVAC system settings and requirements can have extreme impacts on the energy use of a building's system. Advanced energy buildings with operable windows should strive for a high level of integration between envelope and HVAC system design. First, the envelope should be designed to take advantage of natural ventilation with well-placed operable openings. Second, the mechanical system should use interlocks on operable windows to ensure that the HVAC system responds by shutting down in the affected zone if the window is opened. The window interlock zones need to be designed to correspond as closely as possible to the HVAC zone affected by the open window. See HV32 for more information.

Warm Climates

EN23 *Building Form and Window Orientation* (Climate Zones: 1 2 3 4)

In warm climates, north- and south-facing glass can be more easily shielded and can result in less solar heat gain and glare than can east- and west-facing glass. During site selection, preference should be given to sites that permit elongating the building in the east-west direction and permit orienting more windows to the north and south. A good design strategy avoids areas of glass that do not contribute to the view from the building or to the daylighting of the space. If possible, configure the building to maximize north- and south-facing walls and glass by elongating the floor plan. Since sun control devices are less effective on the east and west facades, the solar penetration through the east- and west-facing glazing should be minimized. This can be done by reducing the area of glazing or, if the glass is needed for view or egress, by reducing the SHGC. For buildings where a predominantly east-west exposure is unavoidable, more aggressive energy conservation measures will be required in other building components to achieve an overall 30% energy savings.

EN24 *Glazing* (Climate Zones: 1 2 3 4)

For north- and south-facing windows, select windows with a low SHGC and an appropriate visible light transmission (VLT) (see EN19). Certain window coatings, called selective low-e, transmit the visible portions of the solar spectrum selectively, rejecting the non-visible infrared sections. These glass and coating selections can provide a balance between VLT and solar heat gain. Window manufacturers market special "solar low-e" windows for warm climates. For buildings in warm climates that do not use a daylight design, north- and south-window glazings should be selected with an SHGC no higher than 0.35. East- and west-facing windows in warm climates should be selected for an SHGC no higher than 0.25. All values are for the entire fenestration assembly in compliance with NFRC procedures and are not simply center-of-glass values. For warm climates, a low SHGC is much more important for low energy use than the window assembly U-factor. Windows with low SHGC values will tend to have a low center-of-glass U-factor because they are designed to reduce the conduction of the solar heat gain absorbed on the outer layer of glass through to the inside of the window. (See also EN19 and DL5.)

EN25 *Obstructions and Planting* (Climate Zones: all)

Adjacent buildings, trees, shrubs, or other plantings effectively shade glass on south, east, and west facades. For south-facing windows, remember that the sun is higher in the sky during the summer, so shading plants should be located high above the windows to effectively shade the glass. Also, be careful to not block south light that is being counted on for daylighting. The glazing of fully shaded windows can be selected with higher SHGC ratings without increasing energy use. The solar reflections from adjacent buildings with reflective surfaces (metal, windows, or, especially, reflective curtain walls) should be considered in the design. Such reflections may modify shading strategies, especially on the north facade.

Cold Climates

EN26 *Window Orientation* (Climate Zones: 5 6 7 8)

Only the south glass receives much sunlight during the cold winter months. If possible, maximize south-facing windows by elongating the floor plan in the east-west direction and relocate windows to the south face. By facing the glazing south and placing it vertically, it is easy to implement overhangs and simple sun control devices that allow for passive heating when desired but prevent unwanted glare and solar overheating in the warmer months. Glass facing east and west should be significantly limited. Areas of glazing facing north should be optimized for daylighting and view. During site selection, preference should be given to sites that permit elongating the building in the east-west direction and permit orienting more windows to the south.

EN27 *Passive Solar* (Climate Zones: 5 6 7 8)

Passive solar energy saving strategies should be limited to non-classrooms or office spaces, such as lobbies and circulation areas, unless those strategies are designed so that the occupants are not affected by direct beam radiation. To use passive solar heating in classrooms, the solar radiation must be diffused as it enters into the classrooms. Consider light-colored blinds, blinds within the fenestration, light shelves, or diffusing films to control solar heat gain. In spaces where glare is not an issue, the usefulness of the solar heat gain collected by these windows can be increased by using hard, massive, and dark-color floor surfaces such as tile or concrete in the locations where the transmitted sunlight will fall. These floor surfaces absorb the transmitted solar heat gain and release it slowly over time to provide a more gradual heating of the structure. Consider higher SHGC, low-e glazing with optimally designed exterior overhangs.

EN28 *Glazing* (Climate Zones: 5 6 7 8)

Higher SHGCs are allowed in colder regions, but continuous horizontal overhangs are still necessary to block the high summer sun angles.

LIGHTING

Energy-efficient lighting systems in schools can be designed with or without daylighting. There are many daylighted options, but this Guide provides guidance on three classroom options, one gymnasium daylighted option, and one non-daylighted option. The daylighted options are as follows:

- Classroom with sidelighting
- Classroom with toplighting
- Classroom with sidelighting and toplighting
- Gym with toplighting

Good Design Practice — Electric Lighting

EL1 *Light-Colored Interior Finishes* (Climate Zones: all)

For electrical lighting to be used efficiently, spaces must have light-colored finishes. Ceiling reflectance should be at least 70% (preferably 80% to 90%), which in general means using smooth white acoustical tile or ceiling paint. The average reflectance of the walls should be at least 50%, which in general means using light tints or off-whites for the wall surface, as the lower reflectance of doors, tack surfaces, and other objects on the walls will reduce the average. Floor surfaces should be at least 20%, for which there are many suitable surfaces. In addition, take the shape and finish of the ceiling into account. A flat painted or acoustical tile ceiling is the most efficient; sloping ceilings and exposed roof structures, even if painted white, may significantly reduce the effective ceiling reflectivity. Lighting systems with indirect components are recommended, but if the ceiling cavity includes exposed structures or exposed ductwork, a higher percentage of downlight may be required. Make sure the ceiling and all components are painted a high-reflectance white.

EL2 *Linear Fluorescent Lamps and Ballasts* (Climate Zones: all)

T8 lamps and electronic ballasts are the standard commercial fluorescent lighting system in the United States. The light-source efficacy and LPD requirements in Chapter 3 can be achieved as long as the more efficient versions of T8 lamps and ballasts are used.

To evaluate the efficacy (lumens per watt) of a lighting system, the mean lamp lumens in typical manufacturers' catalogs are divided by the ballast's rated input power. In these catalogs, the mean lumens are lower than the initial lumens. Mean lumens represent the average light output of the lamp over its rated life, which better characterize actual performance. See Table 5.2.

Also, the mean lumens vary according to color temperature and between standard series (SP) and premium series (SPX) lamps. Low-mercury fluorescent lamps are avail-

Table 5.2. Typical T8 Lamp Catalog Data

T8 Lamp Description	Lumens		Color Temp, K
	Initial	Mean	
F32T8/SP30/ECO	2800	2660	3000
F32T8/SP35/ECO	2800	2660	3500
F32T8/SP41/ECO	2800	2660	4100
F32T8/SP50/ECO	2750	2610	5000
F32T8/SP65/ECO	2700	2565	6500
F32T8/SPX30/ECO	2950	2800	3000
F32T8/SPX35/ECO	2950	2800	3500
F32T8/SPX41/ECO	2950	2800	4100
F32T8/SPX50/ECO	2800	2660	5000

Table 5.3. Low Mercury T8 Lamps Showing CRI and Lumen Variations

Lamp General Description	Minimum CRI	Mean Lumens
Standard Generic F32T8 Low Mercury	75	2520
Efficient Standard F32T8 Low Mercury	78	2610
Premium Standard F32T8 Low Mercury	82	2710
Efficient Premium F32T8 Low Mercury	82	2850
High Efficiency F32T8 Low Mercury	82	2945

able from the major lamp manufacturers and have become the standard for sustainable design projects. Among low-mercury 32-W T8 lamps, there are several choices, as shown in Table 5.4.

The color rendering index (CRI) is a scale measurement identifying a lamp's ability, generally, to adequately reveal color characteristics. The scale maximizes at 100, which indicates the best color-rendering capability. Lamps specified for ambient lighting should have a CRI of 80 or greater to allow the occupants to effectively examine the color characteristics. As shown in Table 5.3, standard T8 lamps are available with lower CRI values than recommended, which may compromise the lighting solution.

Next, select the ballast. This is not trivial, as there are several choices:

- *Standard "generic" instant start electronic ballasts.* The most common and least expensive ballast; the typical input power for a two-lamp normal light level (0.87 ballast factor [BF]) is about 59 W. If you do not specify the ballast, this is what you will receive.
- *Low light level version of standard ballasts.* Similar to the standard ballast, this version operates at 0.78 BF and has input power of about 54 W for a two-lamp ballast. The resulting light level is about 10% less than the standard ballast, but the watts are 10% lower.
- *High light level version of standard ballasts.* Similar to the standard ballast, this version operates at 1.15–1.20 BF and has input power of 74–78 W for a two-lamp ballast. The resulting light level is about 32% higher than the standard ballast, but the watts are 32% higher.
- *Program start ballasts.* Available in low power and normal power models, program start ballasts use an additional watt per lamp to perform programmed starting, which makes lamps last longer when frequently switched.

Table 5.4. Efficacy Values for Different Lamp/Ballast Combinations

Ballasts	Lamps				
	F32T8 Generic Standard	F32T8 Efficient Standard	F32T8 Premium Standard	F32T8 Efficient Premium	F32T8 High Efficiency
Generic Standard Instant Start (59 W, 0.87 BF)	74	77	80	84	87
Low Light Level Instant Start (54 W, 0.78 BF)	73	75	78	82	85
High Light Level Instant Start (74 W, 1.15 BF)	78	81	84	89	92
Program Start (61 W, 0.87 BF)	72	74	77	81	84
Low Light Level Program Start (56 W, 0.78 BF)	70	73	75	79	82
Dimming Rapid Start (64 W max, 0.88 BF max)	69	72	75	78	81
Efficient Instant Start Normal Light Level (54 W, 0.87 BF)	81	84	87	92	95
Efficient Instant Start Low Light Level (48 W, 0.78)	82	85	88	93	96
Efficient Instant Start High Light Level (70 W, 1.15 BF)	83	86	89	94	97
Efficient Dimming (58 W, 0.87 BF max)	76	78	81	86	88

Does not meet efficacy criteria

Meets 75 MLPW efficacy criteria

Meets 75 and 85 MLPW efficacy

- *Dimming ballasts.* Dimming ballasts are also rapid start, which is less efficient than either instant or programmed starting. At 0.87 BF, most dimming ballasts require 62–64 W for two lamps. The added power is used to add extra heat to the lamp cathodes to permit proper dimming operation.
- *High-efficiency versions of all of the above.* Efficient electronic ballasts are now available for almost every type listed above. Better electronics require 1–3 fewer watts per lamp to deliver similar performance, but they cost more and are less common.

To determine the system efficacy, multiply the lamp mean lumens by the number of lamps and the BF, then divide by the ballast input watts. For example, using two standard generic lamps and a generic two-lamp ballast, the system efficacy is as follows:

$$\frac{2 \text{ lamps} \times 2520 \text{ mean lumens} \times 0.87 \text{ ballast factor}}{59 \text{ Watts}} = 74.3 \text{ MLPW}$$

Table 5.4 shows combinations of various lamps and ballasts (with two lamp ballasts; values for one-, three-, and four-lamp ballasts will be slightly different). Use this table to select T8 lamps and ballasts to meet the LPD and efficacy recommendations of Chapter 3. Low-wattage (“energy-saving”) T8 lamps may also be considered, but may result in lower ambient light levels or an increased number of fixtures or lamps to achieve recommended light levels. Because they cannot be dimmed and have other limitations, these lower wattage lamps are not recommended for new construction.

EL3 *Fluorescent T5 Sources* (Climate Zones: all)

As an alternative to T8 lamps, T5HO and T5 lamps may also be used. Standard T5 lamps offer at least 85 MLPW with any ballast (their actual rating is greater than 90). T5HO lamps offer at least 75 MLPW on any ballast, including dimming ballasts, but because of their high output, they offer superior overall performance in several key applications.

Other than size, the key difference between T5 and T8 lamps involves performance at rated temperature. T5 lamps reach peak light output and efficacy when surrounding air is 35°C (about 95°F) compared to 25°C (77°F) for T8 lamps. In other words, T8 lamps are better suited for suspended classroom lighting systems; T5 and T5HO lamps are better suited for enclosed luminaires and for luminaires in tall spaces, such as gyms.

An advantage of T5s is reduced use of natural resources (glass, metal, phosphors) in the lamp, plus the ability to use smaller luminaires than comparable T8 systems. However, because of their smaller size, the brightness of T5 and T5HO lamps is significantly higher than that of T8 lamps and may be a concern in open luminaires.

EL4 *Compact Fluorescent* (Climate Zones: all)

To achieve the LPD recommendations in Chapter 3, compact fluorescent lamps (CFLs) can be used for a variety of applications, such as utility lighting, downlighting, and wall-washing. Suitable lamps include twin tube, multiple twin tube, twist tube, and long twin tube lamps. Only pin-based CFLs are included in this group, since a screw-based lamp can be replaced with an incandescent lamp and is therefore not compliant with most energy codes. Suitable luminaires have integral hard-wired electronic ballasts.

Because the efficacy of CFLs is only 30–60 MLPW, they should not be used for general lighting in most space types. To meet the efficacy requirements of this Guide, some CFL-and-ballast combinations must be avoided (see Table 5.5).

EL5 *Metal Halide* (Climate Zones: all)

To achieve the LPD recommendations in Chapter 3, metal halide lamps may be used for general lighting in large spaces, outdoor lighting, and for accent lighting and wall-washing in low wattages. In the metal halide family, there are two primary types: ceramic metal halide (CMH) lamps and quartz metal halide (QMH) lamps. Both types

Table 5.5. System Efficacy of CFL-Ballast Systems

Lamp Type	Magnetic Ballast and Pre-Heat Lamp (2 Pin Lamps with Integral Starters)	Electronic Ballast (4 Pin Lamp) (Program Start Except † Instant Start)
5–13 W Twin Tube	All < 50	52–57 (13 W only)
10–26 W Double Twin Tube	All < 50	13 W 57† 18 W 52 26 W 53
13–42 Watt Triple and Quad Twin Tube and Most Twist Tube Lamps	N/A	13 W 53† 18 W 53 26 W 55 32 W 51 42 W 57
2D	28 W < 50	28 W 63
Long Twin Tube	18 W < 50 24/27 W < 50 36/39 W < 50	18 W 46
	40 W 53	24/27 W 61 36/39 W 64 40 W 60

Does not meet efficacy criteria

Meets 50 MLPW efficacy criteria for utility and special are high-intensity discharge lamps in which intense light energy is generated inside an arc tube made either of ceramic or quartz glass. The two types are comparably efficient. CMH lamps have very good color in the warm (3000 K) and neutral (4000 K) ranges; QMH lamps' color rendering quality is mediocre except in high color temperature lamps (5000 K and above).

Metal halide lamps may be further distributed into low-wattage (150 W and lower) and high-wattage (higher than 150 watts). All low-wattage lamps are "pulse start" and can be operated on either magnetic ballasts or more efficient electronic ballasts. High-wattage lamps are available in both probe start (less efficient) and pulse start (more efficient). Just recently, electronic ballasts have become practical for indoor use of pulse start metal halide; most ballasts for high-wattage lamps are magnetic.

With metal halide lamps, their apparent high efficacy is often undone by their high rate of lumen depreciation. Probe start metal halide lamps operated on magnetic ballasts will lose more than 45% of their rated lumen output over life; with pulse start lamps, the losses are at least 35% on magnetic ballasts but can be reduced to only about 20% by using electronic ballasts. Because MLPW take lumen depreciation into account, the type of ballast plays a significant role in system efficacy. As a result, a number of lamps and ballasts do not meet the efficacy criteria, as shown in Table 5.6 (not a comprehensive list).

Note:

- Metal halide lamps require a warm-up time and restrike time of up to 15 minutes if turned off during operations. Therefore, a supplemental emergency source is required that will provide light during the restrike time.
- Color consistency in appearance (color temperature) may be a problem, as QMH lamps age, especially if used in an indirect luminaire.

EL6 *Occupancy Sensors* (Climate Zones: all)

Use occupancy sensors in all classrooms, offices, mechanical rooms, restrooms, and special-use spaces like music practice rooms. The greatest energy savings are achieved with manual ON/automatic OFF occupancy sensors if daylight is present. This avoids unnecessary operation when

Table 5.6. System Efficacy for Metal Halide Lamp-Ballast Systems

Lamp	Type	Magnetic Ballast	Electronic Ballast (Minimum Efficacy, Some Ballasts Will Be Higher)
35/39-Watt CMH	Pulse start only	43	53
50-Watt QMH	Pulse start only	33	40
70-Watt CMH	Pulse start only	45	51
100-Watt CMH	Pulse start only	51	60
150-Watt CMH	Pulse start only	59	67
175-Watt QMH	Probe start	41	NA
	Pulse start	62	66
400-Watt QMH	Probe start	51	NA
	Pulse Start	71	75
400-Watt CMH	Pulse Start	72	76

Does not meet efficacy criteria — Meets 50 MLPW efficacy criteria for uility — Meets 75 and 85 MLPW efficacy electric lights are not needed and greatly reduces the frequency of switching. In non-daylighted areas, ceiling-mounted occupancy sensors are preferred. In every application, the occupant should not be able to override the automatic OFF setting, even if it is set for manual ON. Unless otherwise recommended, factory-set occupancy sensors should be set for medium to high sensitivity and a 15-minute time delay (the optimum time to achieve energy savings without excessive loss of lamp life). Review the manufacturer's data for proper placement and coverage.

The two primary types of occupancy sensors are passive infrared (PIR) and ultrasonic. PIR sensors can see only in a line-of-sight and should not be used in rooms where the user cannot see the sensor (e.g., storage areas with multiple aisles, restrooms with stalls). Ultrasonic sensors can be disrupted by high airflow and should not be used near air duct outlets. Dual-mode sensors that combine PIR with another technology, such as ultrasound or audible noise, should be considered for problem areas. The best solutions use both technologies.

Note:

- Motion sensors should not be used with high-intensity discharge (HID) lamps because of warm-up and restrike times.
- Fluorescent lamps and CFLs should use program start ballasts if short ON/OFF cycles are expected.
- In classrooms, consider a timer bypass for the motion sensor to prevent lights flashing when only the teacher is present and working quietly.

EL7 *Exit Signs* (Climate Zones: all)

Use LED exit signs or other sources that use no more than 5 W per face. The selected exit sign and source should provide the proper luminance to meet all building and fire code requirements.

EL8 *Circuiting and Switching* (Climate Zones: all)

In addition to the customary general lighting of classrooms, lighting and controls must now take into account the requirements of video images. For cost and other practical reasons, most classrooms will use a low-cost video projector connected to a personal computer, laptop, DVD, cable, or VCR. Teachers will use a combination of video and computer-generated images, ranging from slide presentations to recorded programs and streaming Internet, to teach classes at all levels. New schools should be designed with the anticipation of substantial daily classroom time with the lights dimmed and video replacing the whiteboard as the principal teaching medium.

This creates two substantially different "scenes":

- A "bright" scene in which classic qualities of classroom lighting and daylighting are appropriate. Light levels of 30–70 footcandles at every point, reasonably even surface brightness, and a cheerful feeling are the result of this type of design.
- An audiovisual (AV) scene in which the electric lighting and daylighting are controlled to limit the ambient light on the screen to less than 7–15 footcandles. This permits the average inexpensive projector to achieve at least 10:1 image contrast on an ordinary pull-down screen when it is properly sized for the room. Darkened ceilings and upper walls are essential, and daylighting must be controlled or eliminated. Use of darkening shades is generally recommended.

There are many ways to do this, but the challenge is to make the resulting situation as foolproof as possible. In particular, this involves the potential conflict between daylighting and the darkened AV scheme. There is the distinct chance that once shades are put in place for AV, they will be left there all day, effectively preventing daylighting. The preferred solution is to educate teachers about the importance of daylighting. An alternative and more foolproof solution is to use electrically operated shades that automatically retract when lights are turned on for the bright scene; unfortunately, this is considered too expensive for most projects. Another approach, designing the room for AV concurrent with daylighting, is very difficult to do and forces some very specific architectural decisions that some projects cannot include.

The California Public Interest Energy Research (PIER) research project addressed this situation and contains a number of reports and research data. For more information, see “Project 4.5: Integrated Classroom Lighting Systems—Goals and Objectives in the Advanced Lighting Luminaires and Systems Project Descriptions” at http://www.archenergy.com/lrp/index.htm.

For most other spaces in an education facility, the controls for switching and dimming of the lighting system should *not* be readily accessible. The controls should be located in a supervised location or one that is accessible by the building staff only. General use spaces, such as corridors, should be controlled by a time of day scheduling system and may be integrated with daylight harvesting. For gymnasiums and multipurpose rooms, consider a modern preset dimming or control system, especially if touch-screen control and other modern AV interfaces are planned.

For assembly spaces, the room needs to be equipped with an emergency lighting system that can produce at least one 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 that can provide egress lighting for at least 90 minutes. The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires the 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.

EL9 Electrical Lighting Design for Schools (Climate Zones: all)

The 1.1 W/ft^2 LPD (shown in the recommendation tables in Chapter 3) for the non-daylighted options in climate zones 1, 2, and 5–8 represents an average LPD for the entire building. Individual spaces may have higher power densities if they are offset by lower power densities in other areas.

In climate zones 3 and 4, the recommended LPD is 0.9 W/ft^2. In these zones, the lighting load is a higher percentage of total energy use caused by smaller heating and cooling loads and must be reduced further to meet the whole building savings of 30%. The lighting savings for the non-daylighted option result from the higher performance electrical lighting system.

The daylighted options use a slightly higher LPD of 1.2 W/ft^2, as shown in Chapter 3. The increased LPD is recommended for the daylighted options because the lighting savings result from the lights dimming or turning off from the daylight rather than an aggressive lighting power reduction.

EL10 Classroom Lighting (Climate Zones: all)

Classrooms are typically designed for a single lighting scene in which conventional classroom lighting levels are maintained, and the lights are turned off for AV uses. However, classroom lighting design is changing rapidly because of computers and the Internet. The approach addressed in this Guide is to design classrooms with two lighting scenes: one for general lighting and one where stray lighting is controlled to permit maximum AV screen contrast. This approach specifically addresses classrooms where advanced teaching technologies (computers, video, computer projection, etc.) are to be used, but is appropriate for all classroom types.

For best results, provide a flat, white acoustical tile or gypsum board ceiling at least 9 ft 6 in. above the finished floor with a direct/indirect suspended lighting system. By using a classroom lighting system designed for this application, including energy-efficient ballasts and controls (see EL2), the lighting system can operate at an LPD lower than 1.0 W/ft^2, including supplemental whiteboard lighting. Choosing among the many options includes consideration of the grade level, teaching technology, budget, and whiteboard relevance.

Classroom lighting can be accomplished by using luminaries with indirect distribution, direct distribution, or a combination of both. These options include the following:

- *Direct*, in which all of the light is radiated downward. Direct lighting systems tend to have high efficiency but produce light of fair-to-poor visual comfort. Uniformity and shadowing problems can also result from direct lighting.
- *Indirect*, in which all the light is radiated upward, and, in turn, reflected downward by the ceiling. Indirect lighting systems are generally less efficient than direct lighting systems but usually produce light of superior quality, visual comfort, and uniformity.
- *Direct-indirect*, in which approximately equal (40%–60% to 60%–40%) amounts of light are radiated downward and upward. In general, direct/indirect lighting is used to provide comfortable but efficient illumination in spaces of medium room cavity ratios such as libraries and offices.
- *Semi-indirect,* in which a modest amount of light is directed downward (10%–40%) and a larger amount of light is directed upward (60%–90%). In general, semi-indirect lighting is used in large spaces, such as open office areas and classrooms, to provide comfortable lighting with relatively high efficiency.
- *Semi-direct,* in which a modest amount of light is directed upward (10%–40%) and a larger amount of light is directed downward (60%–90%). In general, semi-direct lighting is used in spaces with very high ceilings, low-reflectance ceiling surfaces, and open structures that result in poor ceiling cavity reflectance.

Lack of visual comfort has been identified as a major complaint of almost all direct lighting systems. The principal cause of discomfort is the contrast between a very bright luminaire and a comparatively dark adjacent ceiling. There is no way that a direct luminaire, including the so-called “recessed indirect” basket luminaires, can produce indirect light onto the ceiling to reduce this contrast. Totally indirect luminaries do provide a soft, glare-free lighting quality, but do not provide three-dimensional modeling and sparkle for visual interest. Therefore, suspended luminaries that provide a combination of indirect and direct distribution should generally be used. Low ceiling applications would be the exception.

Current products offer 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.

These lighting systems are typically suspended 15–18 in. from the ceiling, depending on the specific luminaire. If the ceiling is not at least 9 ft 6 in., special consideration should be made.

Pendant indirect or direct/indirect lighting systems are particularly well suited for integration with daylight systems, since both approaches require higher ceilings and secondary reflective surfaces. In daylighted rooms, pendant systems should be run parallel to the primary windows or daylight source so 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 two rows. Daylight controls can then switch or dim each row separately. This would be the preferred choice if the budget allows.

For classrooms in which advanced teaching technologies, such as video and computer projection are to be used, the lighting system should 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. Pendant luminaires equipped with optical controls or dimming ballasts allow relatively precise low-light level settings. The general lighting system should not exceed 1.1 W/ft^2, and the highly controlled lighting system should use less, with switching to prevent simultaneous use.

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. Switched daylighting scenes can be created by switching luminaire rows or rows of lamps.
- *Any time, low-level scene.* General lighting lamps off, controlled downlight lamps on or on with manual dimming controls. In a single lamp direct/indirect system, dimming to low level with extinguishing of luminaire closest to the screen is encouraged.

Acceptable performance can also be achieved with a direct/indirect luminaire with dimming, provided that the closest row of luminaires to the screen is switched off in the AV mode.

The key to achieving a suitable design is to reduce the ambient light level on the projection screen to 7–15 vertical footcandles or less. Some daylighting systems will create too much vertical illumination, so the ability to darken the room with shades is critical. However, even at night, a generic indirect lighting system tends to produce relatively high levels of vertical illumination. Simply switching off the lights in the front half of the room fails to reduce light levels on the screen enough—typically there will still be 6 to10 footcandles of vertical illumination on the screen in this condition—so with the exception of very low budget projects in which screens are a minor consideration, this guideline should be followed.

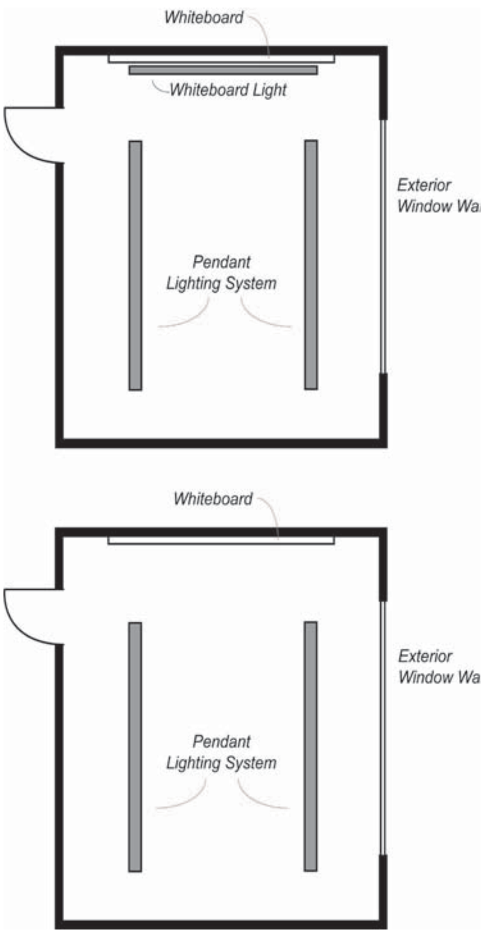


Figure 5.2. Recommended lighting system with (top) and without (bottom) whiteboard light.

As the use of the teaching board evolves, it remains an important part of education at all levels. 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." Energy use is about the same, but the slightly more expensive system with board light (see Figure 5.2) is recommended for improved student attention with board activities.

To coordinate with a ceiling-mounted computer video projector, two rows of luminaires are recommended for classrooms up to about 30 ft wide, as shown in Figure 5.2. (For larger classrooms, consider these principles and make the necessary adjustments.)

Note:

- *Low Ceiling Solutions.* If the ceiling is lower than 9 ft and suspended fixtures may be accessible to students, recessed lighting "troffers" should be considered. The most efficient recessed lighting systems use T5 lamps with special lenses and reflectors to minimize glare (see Figure 5.3). Troffers are more efficient than pendant lighting systems, but produce light that is less comfortable and makes AV integration more difficult. The use of stepped or full dimming ballasts is recommended, and for better AV integration, switch the back of the room separately from the front.

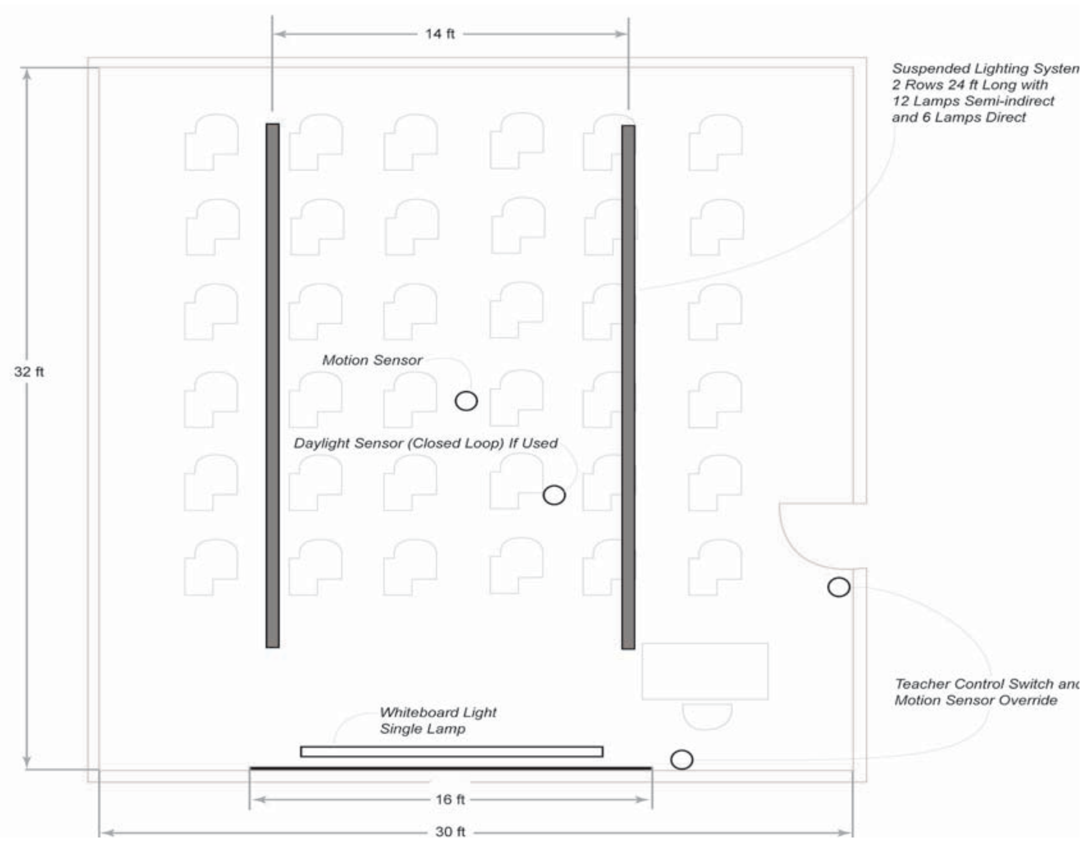


Figure 5.3. Classroom lighting design.

EL11 *Gym Lighting* (Climate Zones: all)

Most school gyms are simple, high- bay structures with open trusses or bar joists. Whenever possible, a combination of daylighting and electric lighting is desirable, but for many reasons electric lighting will be the principal design solution.

Daylighting design is especially well suited to the high ceilings and large open space of gymnasiums. Skylights over the center of the playing area, just like downlights, are preferred. Wall wash toplighting or high sidelighting with light shelves or louvers can be effective techniques for gyms, but care must be used to prevent very bright surfaces. Direct sun penetration into gyms should be prevented at all times. See DL36 and DL37 for further gym/multipurpose daylighting guidance.

For electric lighting, high bay luminaires are easily attached to the structure, with the luminaires suspended within the "truss space," such that the bottom of the luminaire is flush with the lowest beam or truss member. In the rare instance where the gym has a finished ceiling, recessed lighting might be considered, but basic high bay lighting systems are by far the most common approach. The height of the gym space's ceiling plays a major role in choosing gym lighting systems. Most gyms will have a room cavity ratio (RCR) of about 2.5. By comparing the coefficient of utilization (CU) of luminaires being considered, an efficient lighting system can be selected. For most gyms, luminaires with spacing to mounting height of less than 1.4 is appropriate.

Fluorescent systems that use multiple T5HO or T8 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 used. Systems that use multiple CFLs 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 and everyday use. The long warm-up and restrike periods of metal halide lighting are drawbacks, since switching lights off regularly is not recommended for these systems. Be certain to use pulse-start lamps. These systems are compatible with daylighted gyms if they have switched lighting levels.

A separate downlight system that uses 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 5–10-minute cool-off and restrike delay.
- A dimmable tungsten downlighting system can make the gym more appealing for social events, and can serve as a "house" lighting system for many of the gym's performance and entertainment uses.

Note:

- 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 to a volleyball or basketball player.
- Choose luminaires with shields to protect lamps from inadvertent damage by sports equipment.

- As a place of assembly, the room needs to be equipped with an emergency lighting system that can produce at least one 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 that can provide egress lighting for at least 90 minutes.
- The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires 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.
- 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 AV interfaces are planned. Typical gym lighting systems and patterns are shown in Table 5.7 and Figure 5.4.

EL12 *Lighting for a Multipurpose Room* (Climate Zones: all)

Because multipurpose rooms often serve as cafeterias, study halls, social gathering spots, special event spaces, community meeting halls, and AV facilities, the lighting and controls must provide proper operation for every intended use of the room.

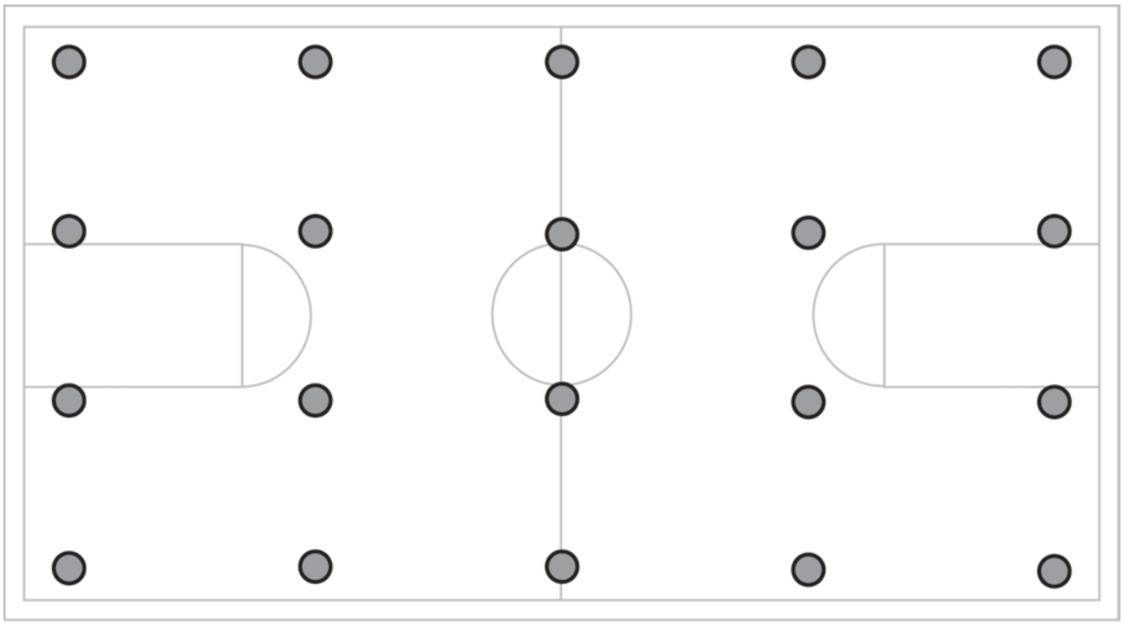
Multipurpose rooms can be successfully daylighted, either from high clerestories or toplighting approaches. However, near-blackout capability for the daylight system is probably most important in this type of space, so operable louvers or blinds are highly recommended. If the daylight system can be reduced to a minimum of 1–3 footcandles, most reduced light functions, including stage performances, can operate effectively. A small amount of sunlight can be a cheerful presence in a multipurpose room used as a cafeteria, as long as it can be blocked when needed. See DL36 and DL37 for further multipurpose room daylighting guidance.

At a minimum, a multipurpose room should have at least two independent lighting systems:

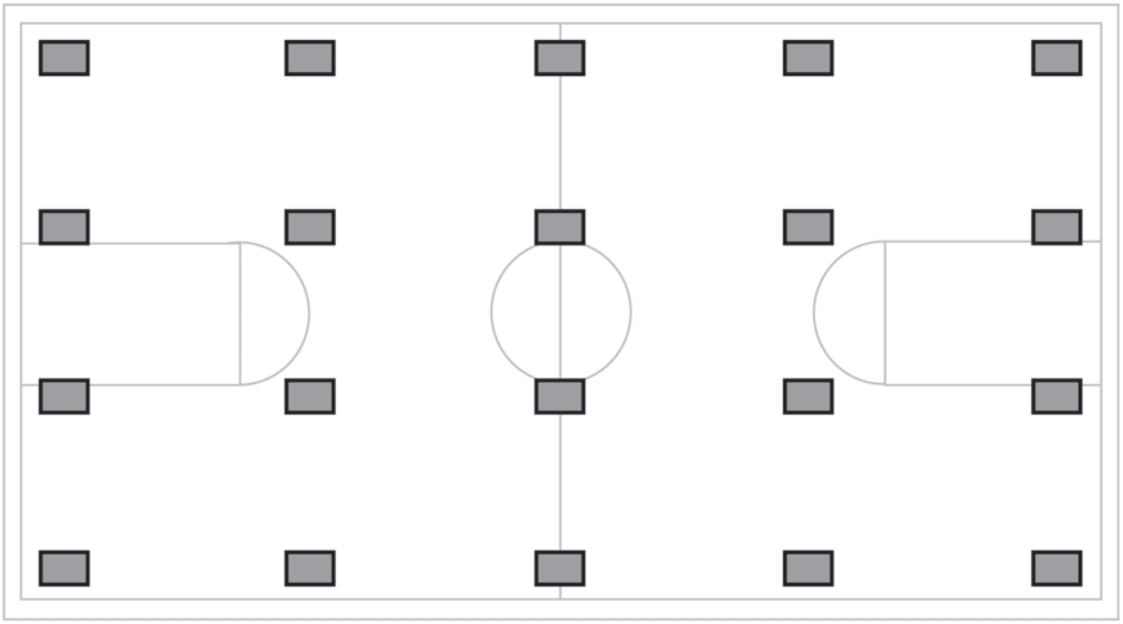
- A general lighting system that provides 20–30 footcandles of uniform illumination with standard T8 lamps
- A dimmable “house lighting” system that supports AV and social uses of the room, producing no more than five footcandles

Table 5.7. Gym Lighting Systems

Applications	Lighting Systems	Lamp Watts (Fixture Input Watts)	Spacing Area (Approx Grid)	Notes
PATTERN 1 HID Lighting	CMH or QMH metal halide lamp with proper electronic ballast ***Note:*** high frequency electronic for QMH and low frequency electronic for CMH	250 (275) 320 (345) 350 (370) 400 (425)	306 (17 ft × 18 ft) 383 (19 ft × 20 ft) 411 (20 ft 6 in. × 20 ft) 472 (21 ft 6 in. × 22 ft)	Mounting height at least 20 ft AFF. Set lamp height for proper spacing criterion (<1.1 W/ft^2)
PATTERN 2 High Bay Fluorescent T5HO	T5HO with high bay reflector system and ballast designed for at least 60°C ambient temperature and 80°C case temperature in a properly designed luminaire with spacing criterion of <1.3	(4) T5HO with BF = 1.0 IS ballast (226 W) (6) T5HO with BF = 1.05 IS ballast (344 W)	251 (16 × 15 ft, 9 in.) 382 (19 × 20 ft)	Mounting height at least 20 ft AFF Choose reflector for proper spacing criterion (<1.1 W/ft^2)



Lighting Option
Pattern 1



Lighting Option
Pattern 2

Figure 5.4. Gym lighting patterns.

In addition, theatrical lighting may be added to illuminate specific stage or performance locations. The lighting used for performance only is exempt from the LPD recommendations.

For the general lighting system, consider one of the types previously suggested for classroom lighting. If suspended luminaires are chosen, be careful to locate luminaries so as not to interfere with AV and other uses of the room. If the room use includes any sports or games, all lighting systems should be protected from damage.

For the house lighting system, consider recessed or surface downlights. Halogen lighting is recommended for its superior color, inexpensive dimming, and good light control. Luminaires should use standard infrared (IR) halogen parabolic aluminized reflector (PAR) lamps or T6 lamps. The lighting beam patterns should overlap at head height to provide excellent uniformity for a variety of functions. Black baffles or cone trims are recommended for AV applications. The house lighting system should be laid out to prevent light from striking walls or screens. 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 AV use and some social functions.

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.

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 have 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. Consider placing the lighting in zones that have individual manual override switches to permit an unoccupied zone to be deactivated.

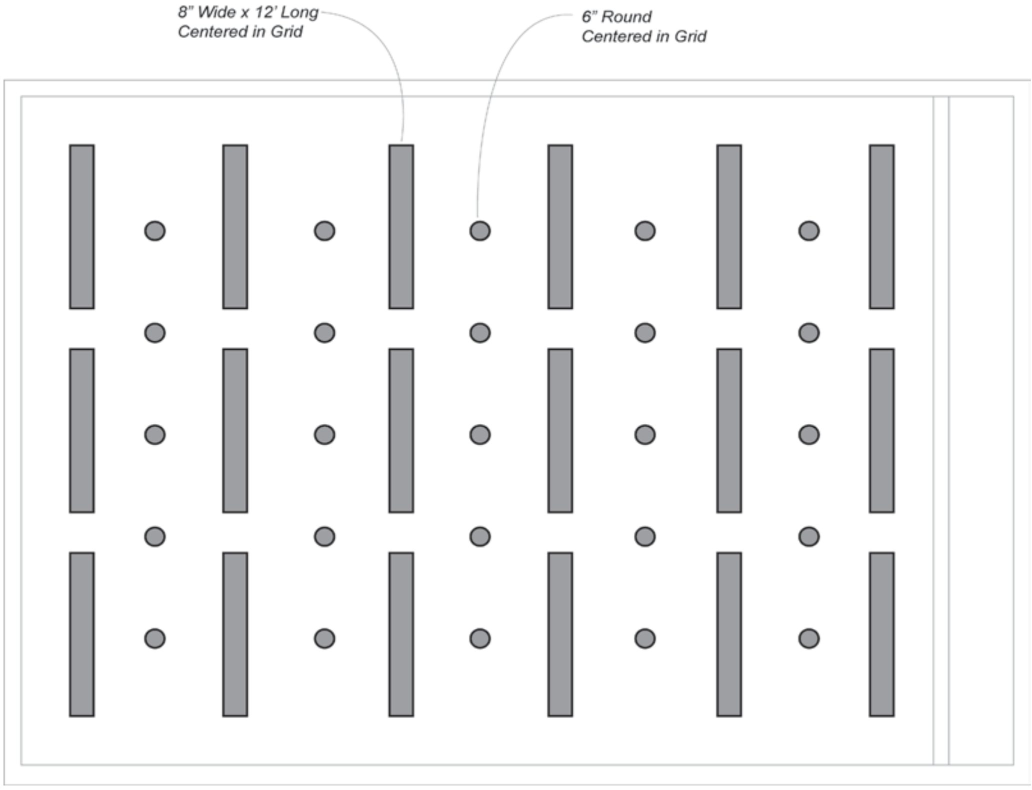
Figure 5.5 shows a typical multipurpose room with two lighting schemes. Figure 5.5a shows pendant-mounted luminaries, and Figure 5.5b shows recessed troffers. Both schemes have a separate system of downlights to serve as "house" lights for social and AV use.

Note:

- As a place of assembly, the room needs to be equipped with an emergency lighting system that can produce at least one footcandle, on average, along the path of egress.
- 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.
- 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.

EL13 Lighting for a Library or Media Center (Climate Zones: all)

The library or media center is a multipurpose space with a variety of tasks; therefore, it is an excellent space to consider a task ambient lighting system. Daylight is an excellent choice for providing basic ambient light in a library. Reading areas and storytelling niches especially benefit from gentle daylight and view windows. With thoughtful



(a)

(b)

Figure 5.5. (a) Multipurpose room indirect/direct lighting option and (b) multipurpose room direct lighting option.

daylight design, only the task lighting at checkout desks or stack areas needs to be on during the day. In addition, these can be connected to occupancy sensors to reduce their hours of operation.

Provide lighting for a library as follows:

- A lighting system with standard T8 lamps that provide 20–50 footcandles of general illumination in casual reading, circulation, and seating areas
- Overhead task lighting at locations such as conventional card files and circulation desks; in libraries where these tasks have been computerized, the general lighting system will provide proper illumination without overhead task lighting
- Task lighting (CFLs or T8 lamps) at carrels and other obvious task locations
- Stack lights with T8 or T5 lamps in areas where stack locations are fixed, and general overhead lighting in areas with high-density stack systems
- Special lighting for media rooms, as required

The general lighting system may be one of the types previously suggested for classroom lighting (EL10). With adequate ceiling height, suspended lighting systems are preferable. Overhead lighting systems for task locations should also be selected from among choices suitable for classrooms or offices. The general lighting system can be designed to become more “dense” in task areas such as circulation desks, thus minimizing the number of luminaire types. Or this may be an area where supplemental specialty luminaires are added for the additional benefit of navigating through the space.

Task lighting at carrels and other locations should be selected according to architecture and finish details. Two common options include the following:

- Under-shelf task lights with high color rendering T8 or T5 lamps
- Table or floor lamps equipped with CFLs up to 40 W

Stack lighting should use luminaires that are specifically designed for lighting stacks. There are several choices, but generally, a single continuous T8 or T5 lamp system will provide adequate illumination. Where the stack locations need flexibility (stacks relocated or placed off axis), an indirect lighting system or a linear stack light mounted from the stacks will provide the most flexibility.

Media rooms for video monitoring and editing, sound monitoring and editing, distance learning, and video teleconferencing have special requirements. Lighting must be designed to meet those specific needs and lighting controls must be provided to enable the room to be used for the varying needs.

Figure 5.6a shows a typical library lighting design. The design illustrates general lighting that uses troffers, table lights for study desks, task lights at kiosks, and stack lights. Using high ballast factor two-lamp troffers, this design works at an overall power density of 1.27 W/ft^2. Increasing stack lights to a high ballast factor increases overall connected power to 1.38 W/ft^2. The stacks to the right on the plan are half height. Figure 5.6b shows an indirect/direct lighting option for a library.

Library spaces tend to be among the most expensive to light. These recommendations provide a good balance between cost, energy efficiency, and good lighting practice.

A control system that activates the general lighting system according to a calendar program and uses motion sensing for off hours should be used. In areas with plentiful daylight, use automatic daylight switching or dimming to reduce electric lighting by day. In addition, in areas such as reference stacks that are less frequently used, 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

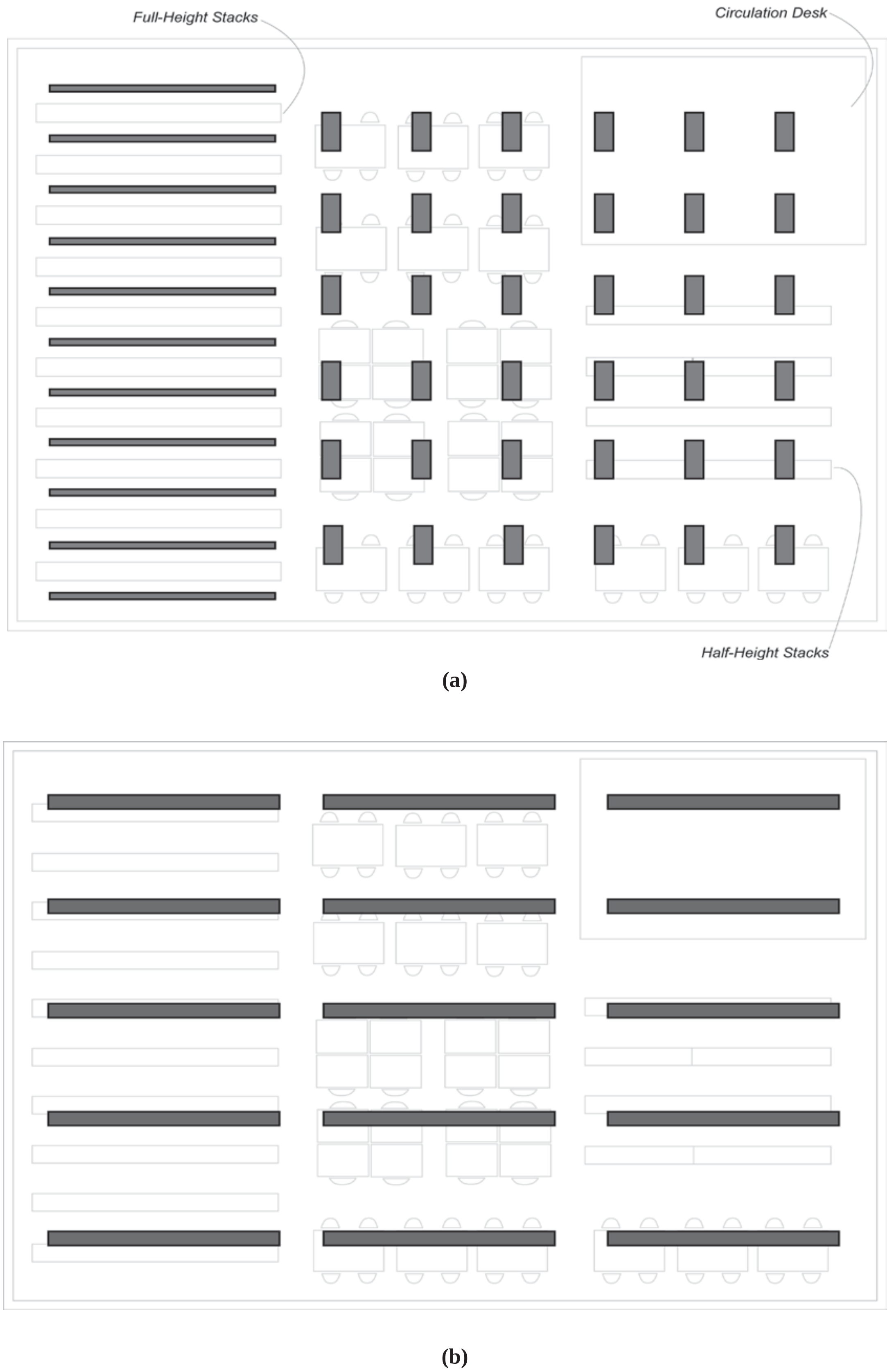


Figure 5.6. (a) Typical library lighting design and (b) library indirect/direct lighting option.

the aisle is occupied. Individual reading and study rooms should use motion sensors, with personal motion sensors and plug strips should be used at study carrels, especially those with fixed computers.

Technology Case Study: Salem Middle School, Apex, NC

Salem Middle School in Apex, North Carolina, is a 158,000 ft^2 building completed in 2003. High-performance design features included in the design are the daylighting in common areas and photosensors that control interior lights in the daylit areas. T8 lamps and electronic ballasts are used to light the school. Figure S1-1 shows how clerestories/light monitors were used to provide daylighting for the media center.

Figure S1.1. Media center daylighting.

Note:

- As a place of assembly, the room needs to be equipped with an emergency lighting system that can produce at least one 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 that can provide egress lighting for at least 90 minutes.
- The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires 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.
- Switching and dimming of the lighting system should *not* be readily accessible. Locate controls in a supervised location.
- 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.
- Under-cabinet task lights should be specified carefully. Avoid traditional “inch light” systems with magnetic ballasts that use twin-tube CFLs and old-style linear lamps like the F6T5 (9 in.), F8T5 (12 in.), and F13T5 (21 in.). Use task lights employing modern F14T5 (22 in.), F21T5 (34 in.), F28T5 (46 in.), F17T8, F25T8, or F32T8 lamps. Always use electronic ballasts, and consider dimming for all task lights.
- Desk lamps and table lamps with linear fluorescent lamps or hardwired CFLs should be used. Medium based screw-in CFLs are not a good choice for new projects, since they can be replaced with incandescent lamps and therefore do not comply with most energy codes.

EL14 Corridor Lighting (Climate Zones: all)

Corridor lighting in schools must provide lighting for wall-mounted lockers and information boards in addition to the normal corridor function. Vertical illuminance is important for these tasks and the corridor lighting system should provide light at high angles. Luminaires should be aligned parallel to the corridor walls to provide good quality light and to make light useful for lockers.

Given the choices of luminaires, an attractive solution that is suitable for any type of corridor ceiling construction, including indoor and outdoor corridors, acoustical tile or gypsum board ceilings, etc., should be possible.

Corridors are generally excellent spaces for daylighting. Furthermore, daylight in corridors provides an important safety feature of guaranteed lighting during any day-

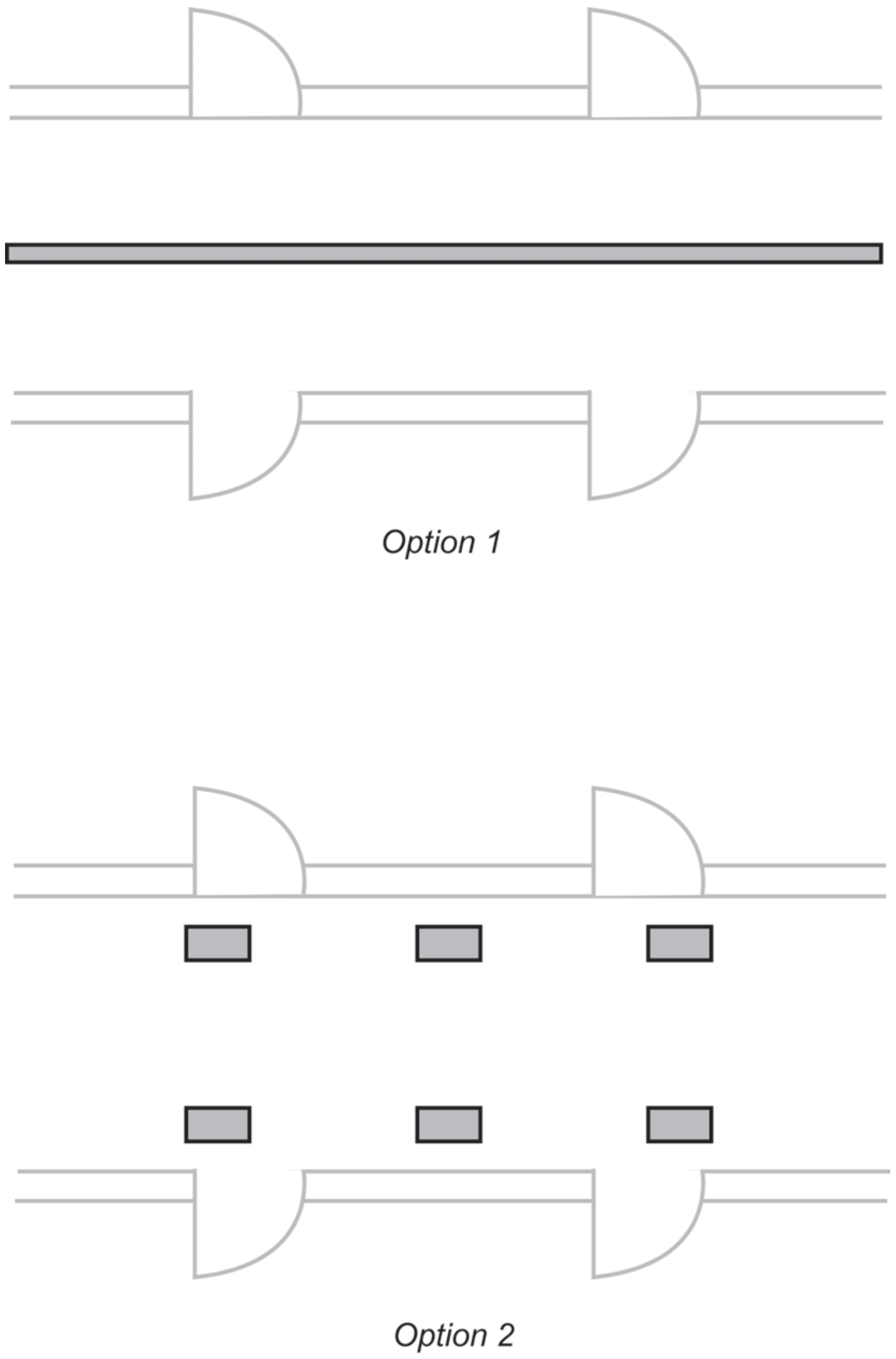


Figure 5.7. Corridor lighting options.

time emergency. 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 and has less glare. As with electric lighting, illuminating the corridor walls should be the primary objective. Several lighting systems are available:

- With high ceilings, a suspended lighting system similar to the classroom or library lighting may be used with an indirect or indirect/direct distribution.
- Interior corridors may use "recessed indirect" luminaires that should be oriented with the lamp 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 wraparound luminaires, preferably vandal-resistant or high abuse types.
- Exterior corridors should use surface-mounted wraparounds or ceiling-mounted, high-abuse luminaires. In some cases, wall-mounted, high abuse luminaires may be acceptable.

Luminaires should use T5 or T8 lamps and electronic ballasts. Outdoor corridors and corridors with plentiful daylight should use automatic daylight switching or dimming to reduce electric lighting by day. Figure 5.7 shows typical lighting options for corridors.

Technology Case Study: Salem Middle School, Apex, NC

Salem Middle School in Apex, North Carolina, is a 158,000 ft^2 building completed in 2003. High-performance features included in the design are the daylighting in common areas and photosensors that control interior lights in the daylit areas. T8 lamps and electronic ballasts are used to light the school. Figure S2.1 shows how clerestories/light monitors were used to provide daylighting in the corridors.

Figure S2.1. Corridor daylighting.

Note:

- Ensure that the luminaires are not overly "institutional" in appearance. If required by the application, choose one of many modern "rough-service" luminaires that are attractive and durable.
- In general, recessed downlights have insufficient vertical illumination to provide good service in corridors. However, recessed downlights that use CFLs may be preferred for lobbies and similar applications where a dressier appearance is desired.

- The corridors need to be equipped with an emergency lighting system that can produce at least one footcandle, on average, along the path of egress. The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires 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.
- Switching of the lighting system should *not* be readily accessible. In general, switching should use an automatic time-of-day control system with motion sensor override during normal off hours, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

- In addition, provide automatic daylighting controls, including dimming or switching off lights in corridors having windows, skylights, or other forms of natural lighting.

EL15 *Lighting for Offices and Teacher Support Rooms* (Climate Zones: all)

The main office is another multifunction space. The administration staff provides services, including reception for visitors, reporting/record keeping (classroom lists, attendance records), support for the principal, support for the teaching staff, and care for students, when a nurse is not on site. As with most office workers today, computer work comprises a significant part of the day, and the lighting system must provide high-quality light.

In many schools the offices are located in the interior of the building and do not have windows to the exterior. The lighting system should provide some light on the vertical walls to help the space feel more open.

- With high ceilings, a suspended lighting system similar to the classroom or library lighting may be used with an indirect or indirect/direct distribution.
- For lower-ceiling office spaces, “recessed indirect” systems should be considered, as they provide visual comfort for the workers and light on the upper wall surfaces.
- For support areas, recessed fluorescent lens troffers with at least 78% fixture efficiency and using T8 premium lamps and electronic ballasts should be used.

Where offices are located on an exterior wall and daylight strategies are being implemented, the approach to daylighting control is similar to the classroom

For teacher support areas (making copies, work preparation) where computers are not in use, troffer lighting systems generally offer excellent efficiency but with some loss of visual comfort. They make excellent use of the low-cost, widely used T8 lamp system. Systems operating at about 1 W/ft^2 will generate 50–60 footcandles maintained average with very good uniformity. Separate task and ambient systems may create a more comfortable atmosphere.

For non-dimming applications, luminaire light and power can be varied by choice of ballast factor. Use the information in EL2, and specify ballasts accordingly.

Note:

- Lens troffer lighting systems are low 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.
- Recessed parabolics with a 45° cutoff provide glare control but will not provide light on the upper walls. This makes the office space seem dark.

EL16 *Lighting for Locker Areas and Restrooms* (Climate Zones: all)

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 area or restroom. The high light levels from daylight promote good maintenance. For privacy and security reasons, daylight is often best provided in these spaces via diffusing skylights or other toplighting strategies. Often these spaces can be designed to need no additional electric light during the day.

This Guide generally recommends fluorescent luminaires that use standard T8 lamps or CFLs. 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. Tamper-resistant hardware is also recommended. Wall mounted rough-service lights include the following:

- Linear lights that use T8 lamps and electronic ballasts
- Rectangular, oval, and round lights that can be equipped with CFLs (low-wattage HID lamps can also be used in these luminaires, but are not recommended)
- Recessed ceiling lights are generally troffers that use the polycarbonate lens and tamper-resistant hardware, as well as more robust components; these luminaires are available in 1 × 4 ft, 2 × 2 ft, and 2 × 4 ft versions with standard T8 lamps and electronic ballasts

For showers, use either surface or recessed luminaires designed for CFLs. 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.

In general, choose luminaires that are attractively styled to prevent an overly institutional appearance. For spaces that do not have daylighting, controls should perform in one of the following ways:

- Continuously on during normal school hours, with a night/emergency light on all the time.
- 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.

REFERENCES

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Good Design Practice — Daylighting

DL1 *General Principles* (Climate Zones: all)

Daylighting is essential for the most energy-efficient and sustainable school design. Effective daylighting uses sunlight to offset electrical lighting loads. When properly designed, daylighting saves energy in lighting loads and reduces cooling loads. In addition to energy benefits, a number of studies have shown that daylight can also help improve learning.[2] From a student and teacher productivity standpoint, classrooms (particularly special needs classrooms) are the most beneficial spaces to daylight.

Daylighting must provide controlled, quality lighting. For daylighting to save energy, it must be "superior" to the electrical lighting. Otherwise, the habit of walking into a space

2. http://www.h-m-g.com/projects/daylighting/projects-PIER.htm

and turning on the lights will never be broken. Develop a daylighting strategy that will provide superior lighting for at least 50% of the hours of school operation. From an energy perspective, a daylighting strategy that is not quite good enough may not result in energy savings because the electric lights will not be turned off. If designed correctly, a daylighting strategy can reduce the following:

- Electricity for lighting and peak electrical demand
- Cooling energy and peak cooling loads
- Maintenance costs associated with lamp replacement

Cooling loads can be reduced by providing just the right amount of daylighting in a school. Because the lights are out, internal gains are reduced. The lumens per watt (efficacy) of a well-designed daylighting system is higher than that of electric lighting sources. In other words, to meet the same lighting need, daylighting produces less heat. However, to achieve this reduced cooling, the following criteria must be met:

- No more solar radiation is allowed to enter the building than is required to meet the lighting design criteria.
- Overhangs and other shading devices are properly sized to control solar radiation during peak cooling times.
- The electric lights, through the use of photosensors, are automatically dimmed or turned off.

DL2 *Consider Daylighting Early in the Design Process* (Climate Zones: all)

The most economic and effective daylighting strategies are very well integrated into the design from structural, mechanical, electrical, and architectural standpoints. To do it well, the many interrelated aspects of the school's architecture, landscape, and engineering must be considered. Properly integrated, mechanical cooling equipment can be reduced because overall cooling loads are reduced. To do so, the daylighting system needs to be optimized by developing a design to reduce peak cooling loads. This will allow for proper trade-offs between the daylighting and the sizing of the cooling system.

If properly integrated, common architectural components may serve dual functions, reducing first cost. An example is that white single-ply roofing can serve as a waterproofing membrane and increase radiation into a roof-mounted daylighting aperture (see DL30). Only a comprehensive, well thought-out-approach will provide a low-cost system that achieves the desired benefits.

The opposite is true without integrated design. If the daylighting system is designed and bid as an alternate, the daylighting strategy will probably not be nearly as cost-effective or resource smart. The problem arises if the designers think that the daylighting components will have a good chance of being eliminated. A designer with this mindset will be unlikely to risk designing a smaller mechanical cooling system, thinking that he or she may have to pay to redo the design.

The best way to guarantee a low-cost daylighting strategy is to fight against this instinct and integrate daylighting early in the schematic design phase. With good schematic design cost estimates that reflect the added daylighting components and the reduced cooling equipment and multi-use of building components, the designer will soon see that the net daylighting costs are very reasonable.

DL3 *Space Types* (Climate Zones: all)

Daylighting the classroom is most critical, since that is where the teachers and the students spend most of their time. In addition, the potential for savings is the greatest in the classrooms.

Table 5.8. Application for Daylighting Strategies

	Sidelighted Classrooms	Toplighted Classrooms	Sidelighted and Toplighted Classrooms	Toplighted Gym
Uniform Light Distribution	●	●●	●●	●●
Low Glare	●	●●	●●	●●
Top Floor/Single Story	●	●●	●●	●●
Middle/Ground Floors	●●	○○	○○	○○
Reduced Energy Costs	●	●●	●●	●●
Low First Cost	●	●	●	●
Cost-effectiveness	●	●	●	●
Low Maintenance	●	●	●	●

●● Etremely good application ● Good application ○○ Etremely poor application

Guidelines are also provided for the gymnasium/multipurpose room because this space is typically used for more hours. Specific guidelines are not provided, but daylighting should also be considered for the cafeteria, media center, administrative areas, and corridors.

DL4 *How to Select Daylighting Strategies* (Climate Zones: all)

For this Guide, four daylighting strategies are presented; three for classrooms and one for gymnasiums. For each strategy, there are several options and variations depending on climate and orientation. These strategies are designed to provide the recommended illuminance for the classrooms and gym over most of the occupied daytime hours.

These strategies are based on all classroom spaces being oriented so the windows face either north or south. Although daylighting can be achieved for other orientations, the recommendations in this document do not apply to those orientations. The four patterns are summarized below, and more specific information is provided in DL20–37. Table 5.8 summarizes the application criteria for each daylighting strategy.

- *Classrooms with sidelighting only.* Two variations of this are provided, one for north-facing and one for south-facing classrooms. South-facing classrooms are assumed to have overhangs and light shelves to bounce the daylighting deeper into the space.
- *Classrooms with toplighting only.* Only one option is provided for toplighting, which is a south-facing roof monitor positioned in the center of the space and coupled with light baffles to bounce and filter light.
- *Classrooms with a combination of sidelighting and toplighting.* This daylighting pattern combines the south- or north-facing classrooms described in the first bullet with top lighting at the back walls of the classrooms. The toplighting may be provided by either skylights or roof monitors, depending on climate and other design constraints.
- *Gyms with Toplighting.* Two variations of this daylighting pattern are provided, one with roof monitors and one with skylights.

DL5 *Recommended Daylighting Fenestration to Floor Area Ratios* (Climate Zones: all)

For view and a positive connection to the outdoors, provide view windows below the 7 ft height. East and west glass should be minimized, and shading should be provided on the south side. Overhangs and lightshelves are not needed on north view glass. See EN21 for more infor-

Table 5.9. Daylighting Fenestration to Floor Ratios

Daylighting Strategy	Classroom	Gymnasium/Multipurpose Room
South-Facing Roof Monitor	8%–11%	5%–8%
North-Facing Roof Monitor	12%–15%	7%–10%
South Light Shelf	8%–11%	
South Light Shelf with Blinds Between Glazing	15%–20%	
High, North Glazing	15%–20%	
Skylights		3%–5%
Tubular Daylighting Devices		2%–3%

mation. Glazing above 7 ft is designed to provide daylighting, and should be sized according to the daylighting fenestration to floor area ratios (FFR) in Table 5.9. These basic rules will help you determine the right amount of daylighting fenestration for particular systems. These numbers can be fine-tuned by using a daylighting analysis particular to the climate and the actual space configuration and use. These rules assume a VLT of the vertical daylighting fenestration of 65%–75%. For the horizontal daylighting fenestration (skylights), a 60% VLT is assumed. Further details about each daylighting strategy are provided in DL20–37.

DL6 *Separate View Windows from Daylighting Strategy* (Climate Zones: all)

In designing daylighting systems, the view glass must be separated from the daylighting glass. To maximize the energy efficiency, the daylighting glazing is sized and placed to provide good quality lighting to the space, independent of the view glass. Additional glazing can be added, but only for view glass. The larger the view glass, the lower the energy performance of the building.

Windows both for view and for daylighting should only be located on the north and south facades. Windows on the east and west should be minimized, as it causes excessive cooling loads and is not effective for heating because of the sun angles.

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.

In schools, wall space is precious. As a result, view windows often serve as display areas. Additionally, these windows are almost always accompanied by blinds that can readily be closed by the teachers and students. Although view windows are recommended to provide a connection with the outdoors, they should not be considered as a contributor to daylighting. Even if they are not covered by artwork or blinds, they have limited benefit, lighting only the spaces very close to the window. Daylighting fenestration should only include that which is located above door height, about 7 ft. It is best to build the daylighting design around roof monitors; high, south-side light shelf apertures; or high, north glass transom windows.

DL7 *Lighting Design Criteria* (Climate Zones: all)

Design the daylighting system to provide enough—but not too much—lighting. Classroom daylighting systems should be designed to meet the following criteria[3]:

- 45–50 footcandles of average illumination for general instruction
- 30 vertical footcandles on the teaching wall (non-AV mode) with an uniformity illuminance ratio (maximum to minimum) not to exceed 8:1

3. See the “Overview” section of the “Lighting and Daylighting” chapter of the *CHPS Best Practices Manual*, 2006 Edition, pages 196–203, for more detail. See also the *IESNA Handbook*, Section 10, Figure 10.9, 9th edition.

- 7–15 footcandles on the teaching wall of average illumination for AV mode
- Uniformity illuminance ratio not to exceed 8:1
- Glare illuminance ratio not to exceed 20:1

The same criteria for lighting quality and quantity apply to electric lighting and daylighting. When the criteria cannot be met with daylighting, electric lighting will meet the illuminance design criteria. The objectives are to maximize the daylighting and to minimize the electric lighting. To maximize the daylighting, without oversizing the fenestration, in-depth analysis may be required.

For sunny climates, designs can be evaluated on a sunny day at the summer solar peak. For cloudy climates, a typical cloudy day should be used to evaluate the system. Typically, the glazing to floor ratio percentage will increase for cloudy climates. Daylighting can still work for a school in a cloudy climate. Cloudy climates can produce diffuse skies, which create good daylighting conditions and minimize glare and heat gain.

DL8 *Use Daylighting Analysis Tools to Optimize Design* (Climate Zones: all)

This Guide is designed to help achieve energy savings of 30% without energy modeling, but energy and daylighting modeling programs make evaluating energy-saving trade-offs faster and daylighting designs far more precise. To better optimize the daylighting and building design, a point-by-point model should be used to analyze typical classroom daylighting patterns to ensure the design criteria are met. (See CHPS, *Best Practices Manual, Volume II–Design*, pages 205–208 for a detailed description of available tools.) At a minimum, daylighting should be evaluated for multiple design conditions, including sunny and cloudy conditions, the summer and winter solstices, the peak cooling day, the equinox, and three times during the day: 9:00 a.m., noon, and 3:00 p.m. The analysis tool should be able to predict illumination and surface brightness for a grid of points within the space and to calculate performance during all hours of operation.

Annual savings will have to be calculated with an annual whole-building energy simulation tool after the daylighting design tools have been used to determine the footcandles in the classrooms and the window sizes have been appropriately sized. Current daylighting analysis tools do not help with heating and cooling loads or other energy uses. They predict only illumination levels and perhaps electric lighting use.

DL9 *Building Orientation* (Climate Zones: all)

Cost-effective daylighting starts with good orientation. For classrooms and most other spaces, the vertical facades that provide daylighting should be oriented within 15° of either north or south. Sidelighted daylighting solutions can be developed for other orientations, but they are beyond the recommendations provided in this document and are typically less effective. Orientation is less important if toplighting is used as the primary daylighting pattern, since roof monitors can be rotated on the roof. However, even with roof monitors, the main axis of the building should still be within 15° of north/south or east/west. East and west glass is problematic from a solar heat gain perspective, and provides nonuniform daylighting.

In integrating the building into the overall site, make sure that the daylighting apertures are not shaded by adjacent buildings, trees, or elements of the school building (self shading).

DL10 *Ceiling Height* (Climate Zones: all)

For all daylighted classrooms, a minimum 10 ft ceiling height is recommended. When daylighting must be provided entirely from sidelighting, a higher ceiling is recommended at the perimeter wall, and the ceiling should be sloped when possible. See DL26 for additional information.

DL11 *Outdoor Surface Reflectance* (Climate Zones: all)

Consider the reflectance of the roofs, sidewalks, and other surfaces in front of the glazing areas. The use of lighter roofing colors can increase daylighting concentration and in some cases reduce the glass area needed for roof monitors or clerestories. However, a light-colored walkway in front of view windows should be considered carefully. Although a light-colored surface may improve daylighting, depending on the design of the facade, it may also cause unwanted reflections and glare.

DL12 *Eliminate Direct Beam Radiation* (Climate Zones: all)

An essential component of any good daylighted school design is the elimination of uncontrolled, direct beam radiation onto the work plane. This is critical for all classrooms, libraries, media centers, and administrative spaces, but less critical for some gymnasiums, multipurpose spaces, and corridors. Use strategies that bounce, redirect, and filter sunlight so that direct radiation does not directly enter space. A good test is to evaluate sun angles at 9:00 a.m., noon, and 3:00 p.m. on the equinox and at the summer solar peak, and make sure that there is no direct solar radiation on the work plane[4] inside a band of 4 ft from the edges of the walls. If this criterion is met, interior shades will be unnecessary, except possibly to darken the space for AV purposes. With advances in AV technology, including flat screens and LCD projectors, room darkening is less important than it was in the past.

The purpose of shading is to prevent direct solar penetration into the space, which can be a source of glare and excess heat gain. There are various types of shading strategies that should be implemented in the following order:

- *External Shading.* Methods that optimize the amount of direct sun that reaches the glazing. These include major building and architectural elements such as overhangs, soffits, trellises, awnings, and external light shelves. This method is the most effective, as it prevents excess solar heat gain and glare.
- *Shading Integral with the Glazing.* Methods in which the glazing rejects unwanted solar gain. These include coloration (absorption), reflectivity, and selective transmission; opaque elements integral to the glazing, such as ceramic frit patterns or integrated PV; or baffles or blinds between glazing panels.
- *Internal Shading.* Methods for filtering and controlling solar gain that has already entered the space. These include baffles, louvers, rolling shades, blinds, and internal light shelves. Internal shading can be vertically mounted for a window or mounted in other planes such as skylight wells.

The success of daylighted schools depends on how occupants interact with the daylighting system. This is particularly true for blinds or shades that are available for adjustment by occupants. Occupants are motivated to close the blinds but not to reopen them. Occupants adjust blinds for the long term. If blinds are left closed, the daylighting potential will not be realized. If temporary darkening of a specific space is not functionally required, do not install shades or blinds on the daylighting glass. Unnecessary blinds will result in reduced performance, increased first costs, and higher long-term maintenance expenses.

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4. Typically, a surface 30 in. above the floor (maybe less for lower elementary grades).

DL13 *Daylighting Control for Audiovisual Activities* (Climate Zones: all)

If a classroom requires darkening for AV or other functions, consider motorized roller shades or motorized vertical blinds for apertures that are out of reach. This may seem to result in higher maintenance costs, but such controls can have the opposite effect. The mechanical stress placed on manual operators by the students and teachers (because of uneven cranking) limits the effective life of these devices to less than ten years. The inconvenience associated with the process also results in a number of these shades being left closed. Motorized shades, which cost more up front, will provide operators with greater ease of operation and result in a better performing daylighting design. Some motorized devices can also be programmed to reset in the open position at the beginning of each day.

Some teachers still use overhead projectors, but most use TV monitors or LCD projectors. All these teaching tools require that the light level at the specific location of the screen fall in the range of 5–7 footcandles for optimum contrast. Slightly higher levels (7–15 footcandles) should still provide acceptable light levels for the visual aids, but the reduced contrast will make them harder for the students to read.

As an option to shading the daylighting apertures, consider locating the screen or monitor in a part of the room that has less daylight and does not produce glare on the screen. This is typically easy to accomplish by locating the TV monitor high, in a corner of the space, and not adjacent to or facing a window.

Whiteboards need sufficient light (about 30 footcandles) with an illuminance ratio not exceeding 8:1. Whiteboards have a specular surface and should be carefully located so that there is no reflected glare from daylighting apertures or lighting fixture. Since the whiteboard is typically in the same location as the overhead projection screen, separate control of the teaching surface light is essential. To address both needs, intentionally darken the area of the teaching wall that has the screen and then use electric lighting to enhance the wall when the whiteboard is used.

DL14 *Interior Finishes for Daylighting* (Climate Zones: all)

Select light colors for interior walls and ceilings to increase light reflectance and reduce lighting and daylighting requirements. Minimum surface reflectances are shown in Table 5.10. The color of the ceiling, walls, floor, and furniture have a major impact on the effectiveness of the daylighting strategy. When considering finish surfaces, install light colors (white is best) to ensure the daylight is reflected throughout the space.

Consider a ceiling tile or surface that has a high reflectivity. Make sure that the ceiling tile reflectance includes the fissures within the acoustical tiles, as these irregularities affect the amount of light absorbed. Do not assume that the color of a tile alone dictates its reflectance. When selecting a tile, specify a minimum reflectivity. Most manufactures

Table 5.10. Minimum Reflectance

Location	Minimum Reflectance
Walls Above 7 ft	70%
Ceiling	70% (preferably 80%–90%)
Light Wells	70%
Floors	20%
Furniture	50%
Walls Below 7 ft	50%

will list the reflectance as if it were the paint color reflectance. The Cx provider should verify the reflectance.

DL15 *Calibration and Commissioning* (Climate Zones: all)

Even a few days of occupancy with poorly calibrated controls can lead to permanent overriding of the system and loss of savings. All lighting controls must be calibrated and commissioned after the finishes are completed and the furnishings are in place. Most photosensors require daytime and nighttime calibration sessions. The photosensor manufacturer and the quality assurance (QA) provider should be involved in the calibration. Document the calibration and Cx settings and plan for future recalibration as part of the school maintenance program.

DL16 *Dimming Controls* (Climate Zones: all)

For the classroom and gym daylighted options, daylighting controls are recommended in all classroom spaces and gyms/multipurpose spaces. For the non-daylighted option, view windows may still be included in the design. In this case, daylighting controls are still recommended for all zones within 15 ft of a sidelighted edge or within 10 ft of a toplighted edge.

In all regularly occupied daylighted spaces such as classrooms, gyms, and offices, continuously dim rather than switch electric lights in response to daylight to minimize occupant distraction. Specify dimming ballasts that dim to at least 20% of full output, with the ability to turn off when daylighting provides sufficient illuminance. Provide a means and a convenient location to override daylighting controls in spaces that are intentionally darkened to use overhead projectors or slides. The daylighting control system and photosensor should include a 15-minute time delay or other means to avoid cycling caused by rapidly changing sky conditions, and a one-minute fade rate to change the light levels by dimming. Automatic multilevel daylight switching may be used in non-regularly occupied environments, such as hallways, storage, restrooms, lounges, and lobbies.

DL17 *Photosensor Placement and Lighting Layout* (Climate Zones: all)

Correct photosensor placement is essential: consult daylighting references or work with the photosensor manufacturer for proper location. Mount the photosensors in a location that closely simulates the light level (or can be set by being proportional to the light level) at the work plane. Depending on the daylighting strategy, photosensor controls should be used to dim particular logical groupings of lights. Implement a lighting fixture layout and control wiring plan that complements the daylighting strategy. In sidelighted classrooms, locate luminaires in rows parallel to the window wall, and wire each row separately. Because of the strong difference in light that will occur close to the window and away from the window, having this individual control by bank will help balance out the space. In a space that has a roof monitor, install one photosensor that controls all the perimeter lights and a second that controls all the lights within the monitor well. In gymnasiums, ganged fluorescent fixtures coupled with dimmable ballasts are a great way of eliminating the problems typically associated with using metal halide fixtures (long-restrike time).

DL18 *Photosensor Specifications* (Climate Zones: all)

Photosensors used for classrooms should be specified for the appropriate illuminance range (indoor or outdoor) and must achieve a slow, smooth linear dimming response from the dimming ballasts.

In a *closed-loop system*, the interior photocell responds to the combination of daylight and electric light in the daylighted area. The best location for the photocell is above an unobstructed location, such as the middle of the classroom. If using a lighting system that provides an indirect component, mount the photosensor at the same height as the luminaire or in a location that is not affected by the uplight from the luminaire.

In an *open-loop system*, the photocell responds only to daylight levels but is still calibrated to the desired light level received on the work surface. The best location for the photosensor is inside the skylight/roof monitor well.

DL19 *Select Compatible Light Fixtures* (Climate Zones: all)

First consider the use of indirect lighting fixtures that more closely represent the same effect as daylighting. Indirect lighting spreads light over the ceiling surface, which then reflects the light to the task locations; with the ceiling as the light source, indirect lighting is more uniform and has less glare.

In addition, insist on compatibility between ballast, lamps, and controls. Ensure that the lamps can be dimmed and that the dimming ballasts, sensors, and controls will operate as a system.

Classroom Sidelighting

The sidelighting patterns shown in Figure 5.8 are appropriate for south- and north-facing classrooms, within 15° of true. Sidelighting strategies can be used in classrooms on any floor; Figure 5.8 shows sidelighting for a two-floor school. DL20–27 provide further information on sidelighting strategies.

DL20 *South-Facing Classrooms—Configuration of Apertures* (Climate Zones: all)

The choice of fenestration and the placement of the apertures are critical. If uncontrolled, direct beam radiation enters the classroom window. It can create glare and the teacher will simply close the blinds and negate the daylighting strategy.

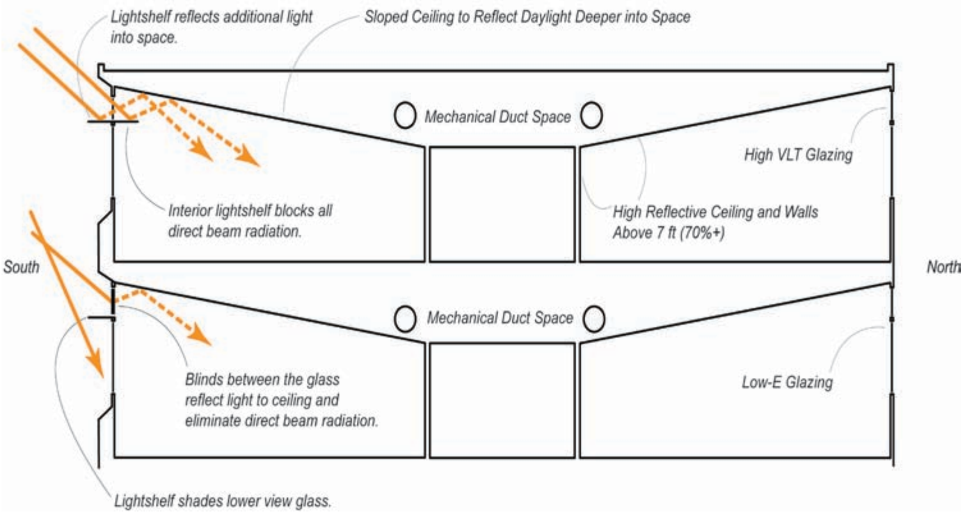

Figure 5.8. Classroom sidelighting.

A light shelf is recommended for south-facing walls. The daylighting windows above the light shelf should be as continuous as possible; the daylighting window is typically 3–5 ft high. The window should be positioned as close to the ceiling as possible, within structural constraints (see Figure 5.11).

An overhang should be positioned over the daylighting aperture and sized with the light shelf to prevent direct sun from entering the space. Set the cutoff angle of the light shelf or louvers to eliminate direct sun penetration at the back of the space during normal school hours. If there are operable shades on the upper glazing that are seasonally adjusted, the cutoff angle may be increased by 20° (see Figure 5.9).

An option to the light shelf would be to add mini-blinds between the panes of glass, and in cold climates, add a third pane. In this case, the interior portion of the light shelf may be eliminated, but the outer portion is still needed to shade the vision glass (see Figure 5.10).

For north-facing classrooms, a light shelf is not needed because its benefits are related to the reflection of direct solar radiation, and north facades experience little direct solar gain.

DL21 *South-Facing Classrooms—Glazing Area and Fenestration Type* (Climate Zones: all)

The area of the daylighting aperture should be in the range of 80–110 ft² for a typical 1000 ft² classroom. This recommendation is based on glazing with a light transmission of 65%–75%. Glazing with a lower light transmission may be used, but the aperture should be increased to maintain the same visible aperture. Where windows are used specifically for daylighting, consider the use of uncoated clear glass or low-e coated clear glass with a high VLT. A larger daylighting aperture with a lower VLT has the advantage of providing the same amount of daylight but with less glare and contrast. The disadvantage is that typically the costs associated with all the components of the daylighting system are higher.

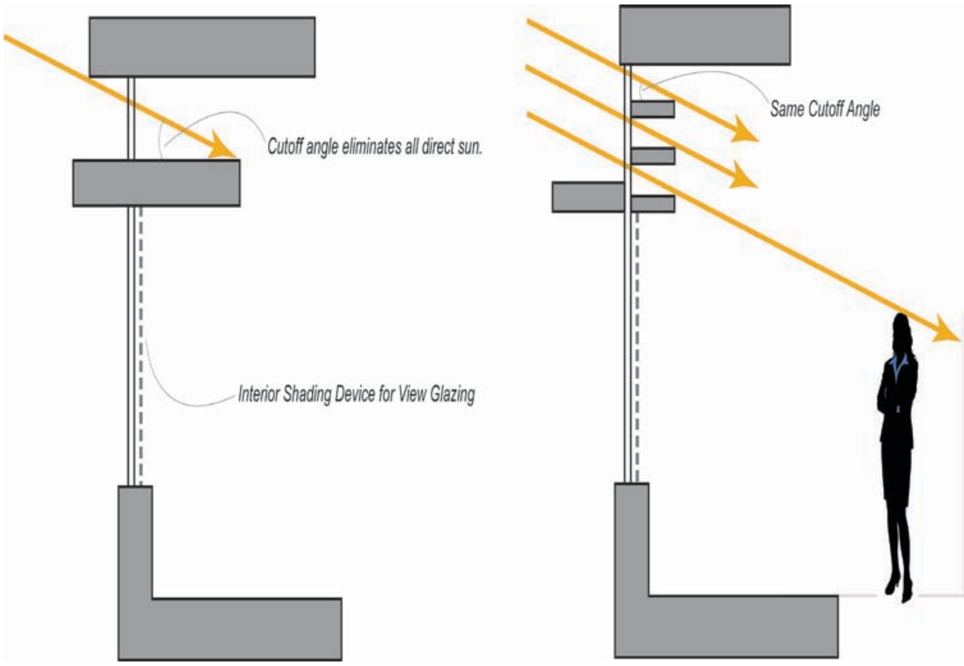

Figure 5.9. Overhang cut-off angle.

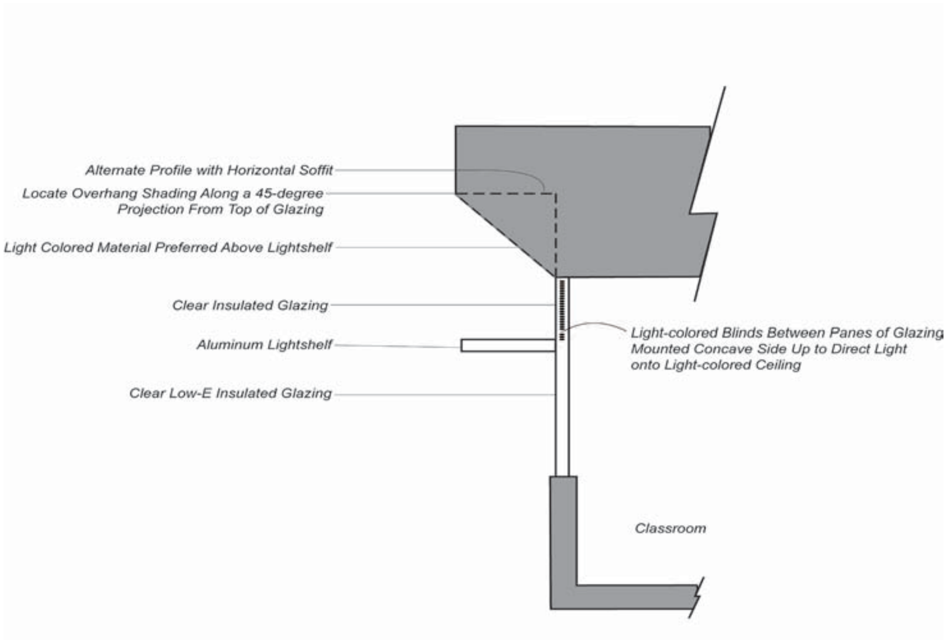

Figure 5.10. Light shelf details.

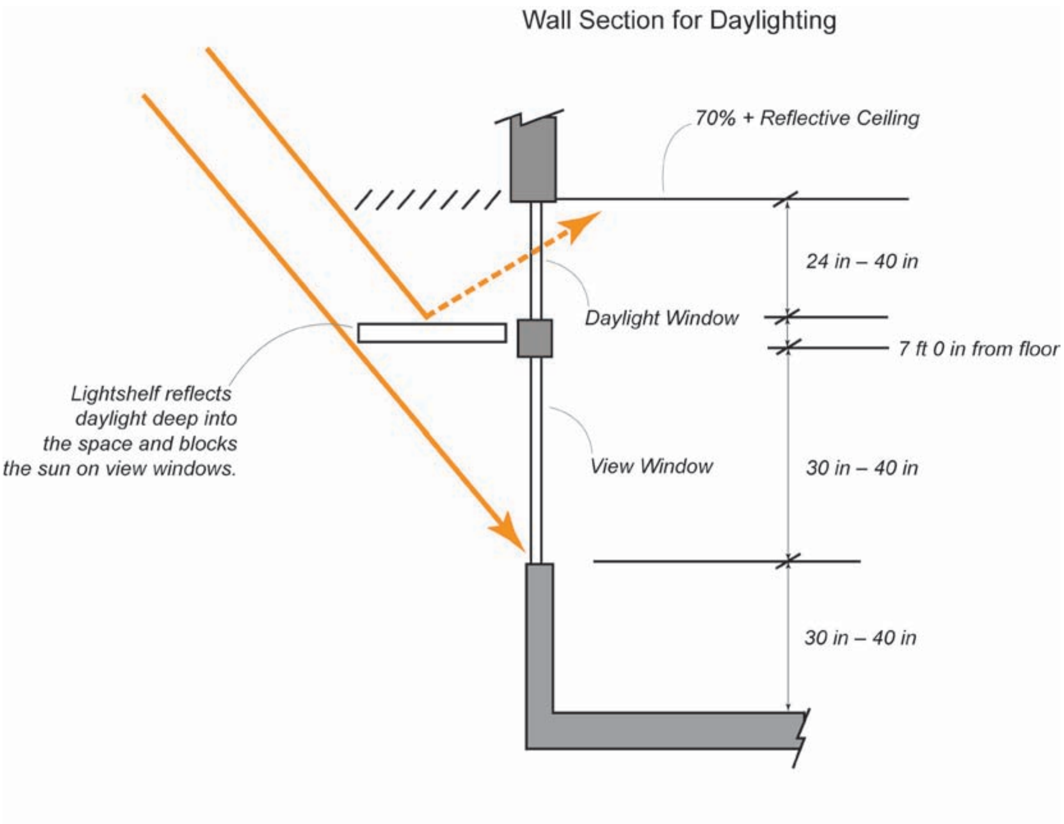

Figure 5.11. Light shelf details.

The view windows below 7 ft do not require high light transmission glazing, so values between 0.35 and 0.50 are acceptable. Higher VLTs are preferred in predominantly overcast climates. VLTs below 0.35 may appear noticeably tinted and dim, and may degrade luminous quality and views. However, lower VLTs should be used for higher FWRs. Lower VLTs may also be appropriate for other conditions of low sun angles or light-colored ground cover.

Thermal comfort can also be compromised by poor fenestration choice, especially for the view glazing, which is closer to occupants. Poorly insulated windows add to a winter chill or summer sweat, but windows with low U-factors keep glass surface temperatures closer to the interior air temperature, improving thermal comfort. In addition, east-west windows and unshaded south windows (if they cannot be avoided) can increase cooling loads.

In all cases, windows should be made of high-quality construction, incorporate thermal breaks, and include the appropriate glazing for the particular application.

Carefully consider the visible light, solar transmission, and insulation qualities of the particular daylighting glazing system, with particular emphasis on how much additional glazing will be needed to achieve the same VLT. If the design is to effectively address energy and create a good daylighting strategy, the size of the daylighting apertures needs to be minimized and the transmission maximized.

The desirable color qualities of daylighting are best transmitted by neutrally colored tints that alter the color spectrum to the smallest extent. In particular, avoid dark green and bronze glazing. To the greatest extent possible, avoid the use of reflective glass or low-e coatings with a highly reflective component, even for view glass. These reduce the quality of the view, and the mirrored effect is unpleasant to occupants after dark.

DL22 *South-Facing Classrooms—Make Light Shelf Durable and Reflective* (Climate Zones: all)

Select durable materials for interior and exterior light shelves and, if reachable, design them to be able to carry the weight of a person. Aluminum exterior light shelves are a good compromise between good reflectance with little or no maintenance and cost. Incorporate white finishes on the top of interior light shelves. Aluminized acrylic sheets applied to the top of the interior shelf allows light to bounce further back into spaces and can improve performance in deeper rooms without toplighting.

DL23 *South-Facing Classrooms—Horizontal Blinds between Glazing* (Climate Zones: all)

As an alternative to interior light shelves, consider horizontal blinds between glazings. The horizontal blinds should be highly reflective and have either flat or curved blades. If curved, they should be curved upward (turned opposite to how they are normally installed). Because of potential dirt buildup and maintenance, they should be placed between panes of glazing. If this option is used, consider the transmission of the blinds and increase the glazing area accordingly.

Most shades that are available today are operable and can be closed. However, if the space does not need to be temporarily darkened, the angle of the internal blinds should be fixed, angled up to the ceiling by the recommended cutoff angle for light shelves. By fixing the angle and not allowing the occupants to operate the blinds, there will less opportunity to override the daylighting benefits. If the internal blinds do need to be operated for darkening purposes, provide two fixed positions: the one described above and a second “closed” position.

DL24 *North-Facing Classroom—Configuration of Apertures* (Climate Zones: all)

The window should extend as close as possible to the ceiling. Window area below door height of about 7 ft should be considered as view glazing and not considered as a contributor to daylight. The daylighting glazing should be as continuous as possible along the façade. If continuous fenestration cannot be provided for structural or other reasons, the windows should be placed in the corners of the space with the opaque wall for shear or structure located in the center of the wall. This will light the walls perpendicular to the daylighting wall and provide better illuminance ratio and surface brightness.

From a daylighting perspective, high north glazing can be a good option into spaces up to a distance equal to 1.5–2.0 times the height of the top of the window. Like north-facing roof monitors, it takes more glazing than a south light shelf would to achieve the same annual contribution, so the energy performance is not quite as good. The most significant advantage is that controlling direct beam radiation is not usually a problem.

Often, when implementing a daylighting strategy in classrooms that face both north and south, the designer is faced with the challenge of establishing a common ceiling height. On the south side-light shelves that generally require less glazing than high, north transom apertures can be used, unless blinds between the glass or a south-facing fenestration with a lower VLT is used. In this case, the height of the south aperture will quite closely match the height of north transom glazing. To maintain a common ceiling height, consider some of the lower view glass on the north as an integral part of your daylighting strategy. Because blinds would typically not be needed on the north to block direct beam radiation, it is logical to include some lower view glass. The big drawback is that the window area could still be used as a display board, which blocks the light.

DL25 *North-Facing Classroom—Glazing Area and Fenestration Type* (Climate Zones: all)

For glazing with a VLT of 65%–75%, a daylighted area of 150–200 ft^2 is recommended for a typical 1000 ft^2 classroom. If glazing with a lower VLT is used, the area should be increased accordingly. Because of the lack of direct beam radiation on the north, light shelves provide no benefit and should not be used. Assuming that lower north side view glass is considered in your daylighting strategy, it would be advisable to use low-e glass in this case because of comfort, sacrificing the 10%–20% reduction in visible light benefit.

DL26 *South- and North-Facing Classrooms—Sloped Ceilings* (Climate Zones: all)

When daylight can be provided only from the side, the ceiling should be sloped down to the back wall. A sloped ceiling can achieve a higher window head, which will result in greater daylighting penetration into the space. The slope will also provide a brighter ceiling.

By sloping the ceiling from the outside wall to the back of the space, it is often possible to encroach into the ceiling cavity space just at the window area, not increase floor-to-floor dimensions, and still have enough space for ductwork.

DL27 *South- and North-Facing Classrooms—Recognize the Limits of Side Daylighting* (Climate Zones: all)

Sidelighting is an effective strategy for daylighting spaces in rooms with tall ceilings. For rooms with low ceilings, effective daylight can be provided only for spaces within 15–20 ft from the window. To daylight the whole classroom, consider wall washing skylights or roof monitors to supplement the sidelight.

Classroom Toplighting

One daylighting pattern is provided in this Guide for toplighting. Other options may be explored for specific school applications; however, they are beyond the scope of this Guide.

Roof monitors that incorporate vertical south glazing and properly sized overhangs and interior baffles have the following advantages:

- Create a very uniform lighting throughout the space
- Can be used to daylight spaces far from the perimeter of the building
- Create passive heating benefits, allowing more radiation to enter the space in the colder months
- Create a more diffuse, filtered lighting strategy
- Reduce glare and contrast

The limitation of roof monitors is that they can be used in single story designs only or on the top floors of multi-story designs (see Figure 5.12).

Technology Case Study:
Zach Elementary School
Fort Collins, CO

Zach Elementary School is located in Fort Collins, Colorado, and is part of the Poudre School District in climate zone 5. Zach, a 67,412 ft^2 facility with a capacity of 525 students, uses daylighting in all the classrooms with high north- or south-facing clerestories.Tinted view windows are separated from the clerestory windows. The south-facing clerestory windows make use of overhangs to provide shade and light shelves to reflect daylight deeper into the classrooms. North- facing windows have no shading or light shelves. The T-grid ceilings have also been sloped down from the clerestories to improve the daylighting effect, as shown in Figure S3.1.

Figure S3.1. North-facing classroom with daylighting and sloped ceilings.

DL28 Sizing the Roof Monitors (Climate Zones: all)

For a 1000 ft^2 classroom, the well opening of the roof monitors should be approximately 20 × 20 ft. The key to sizing the south-facing glazing in the monitor is to provide the desired level of daylighting illumination at the summer solar peak on a clear day. Size the glazing and the overhangs so that daylighting provides the required illumination (see DL7) during the summer peak cooling condition. With south-facing glazing, this strategy will result in more daylight entering the space during other times of the year, when the sun has a lower altitude—just what is needed. The glazing area, if south-facing, is typically 25% less than if north-facing to provide the same daylighting.

A fully daylighted 1000 ft^2 classroom should have an 8%–11% monitor FFR, with 65%–75% VLT for the daylighting fenestration. Glazing with a lower light transmission may be used, but the aperture should be increased to maintain the same effective visible aperture area (fenestration area × VLT). Where windows are used specifically for daylighting, consider the use of uncoated clear glass or low-e coated clear glass with a high VLT. A larger daylighting aperture with a lower VLT has the advantage of providing the same amount of daylight but with less glare and contrast. The disadvantage is that the costs associated with all the components of the daylighting system are typically higher.

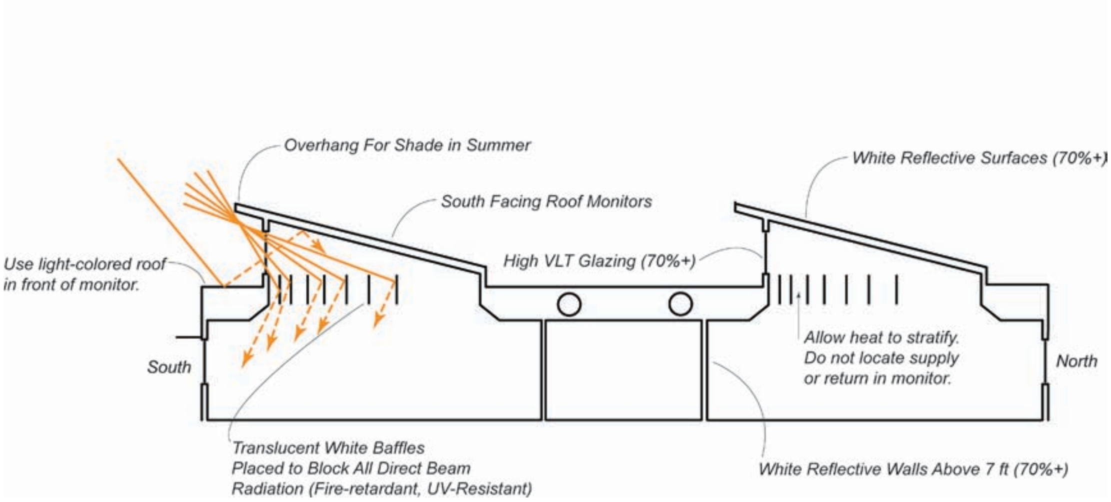

Figure 5.12. Classroom toplighting.

To provide optimal levels, the following process can be used:

- Determine the target lighting level (recommended illuminance).
- Multiply that level by two, which equals the target maximum (solar noon) daylight illuminance level.
- Evaluate winter maximum (solar noon); this number should no greater than twice (and preferably 1.5 times) the solar peak.

DL29 *Overhang for Roof Monitor* (Climate Zones: all)

Assuming the school is in a location that has a winter heating requirement, consider placing the overhang the same as if designing a passive solar building. Start by placing the outer point of the overhang at an angle about 45° from horizontal, above the head of the window. This will allow most of the solar gain to enter during the winter, even at noon when the altitude is low.

By moving the overhang in and out, and simulating these conditions during peak cooling times (as well as with annual simulations), you will be able to determine the correct, optimum location. The overhang should not allow any more radiation entering the space during peak cooling times than is necessary to deliver the footcandles necessary (see DL7). If during peak cooling time the space has higher footcandle levels than is necessary, this will increase your cooling loads.

Design the south-facing monitor to capture passive heating in the winter months. This will help to offset the heat not being provided when electric lights are off. Do not overextend the overhang. It will hurt the daylighting contribution as well as the passive heating benefit.

DL30 *Use Light-Colored Roofing in Front of Monitors* (Climate Zones: all)

Specify a light-colored roofing material to reflect additional light into the glazing. A white single-ply roofing material (aged reflectance of 69%) typically provides the best long-term reflectance.[5] This compares to black EPDM of 6%, a gray EPDM of 23%, or a light-colored rock ballast of 25%.

5. LBNL. 2005. Aging and weathering of cool roofing membranes. Report 58055, Lawrence Berkley National Laboratory, Berkeley, California, http://repositories.cdlib.org/cgi/viewcontent.cgi?article=3574&context=lbnl

When white single-ply roofing is placed directly in front of the south-facing roof monitors, the glazing area in the monitors is able to be reduced by up to 20% because of the additional reflected radiation entering the monitor.

The white color also provides an overall benefit by reflecting solar radiation that would otherwise be absorbed and re-radiated downward into the conditioned space. Energy savings also result as a benefit of a lowered cooling load.

DL31 *Use Baffles to Block Direct Beam Radiation and Diffuse Light* (Climate Zones: all)

In the roof monitor light well assemblies, white baffles should hang parallel to the glass and be spaced to ensure that no direct beam enters the space. The spacing and depth of the baffles should be determined so that when standing inside the room looking out, the occupants cannot see the sky. This will ensure that no direct beam light can strike the work plane. Baffles should have the following characteristics:

- The baffles should be fire-retardant and UV resistant.
- The baffles should be light-colored and translucent to reflect the sunlight into the space and help eliminate contrast from one side of the baffle to the other.

DL32 *Minimize Contrast at Well-Ceiling Intersection* (Climate Zones: all)

At the bottom of the light well, contrast is significantly reduced if there is a transition between the vertical and the horizontal planes. A 45°-angled plane is good, but a curved transition is even better. To achieve this curved effect, many designers now use fiber-reinforced plaster curved sections that nicely receive gypsum board.

DL33 *Address the Monitor Design* (Climate Zones: all)

To help reduce conductive gains and losses, the walls and ceiling of the roof monitor should be insulated and should incorporate appropriate insulation and moisture barriers as recommended in EN2 through EN18.

Make sure that the colors used within the monitor well are very light. White is best. Darker colors will result in a considerable loss in efficiency.

Also consider acoustic issues. If acoustical ceiling material is used, make sure that the reflectance and the acoustical properties are high. Often manufacturers, in presenting the reflectance of an acoustical tile, will specify the paint color. Remember to account for the reduced reflectance caused by the fissures in the tile.

DL34 *Let the Heat Stratify* (Climate Zones: all)

A key to achieving the desired cooling reductions is to rely on the stratification of heat within the monitor. Do not attempt to remove this heat by placing supply and return grilles in this area, but instead allow the heat to stratify. This benefit is often overlooked in designing daylighted spaces and comparing one strategy to another.

DL35 *Minimize the Depth of the Ceiling Cavity* (Climate Zones: all)

The depth of the well is very important. The deeper the well, the harder it is for the radiation to reflect down into the space. For example, in a 20 × 20 ft^2 sky well that is 7 ft deep and has 70% reflectance, the loss in effectiveness will be 50%.

Classroom Sidelighting Plus Toplighting

This daylighting pattern is appropriate for one-story buildings or for the top floor of a multistory school. It combines the sidelighting recommendations of the previous pattern with small interior skylights or roof monitors to balance daylighting across the space. Figure 5.13 shows a cross section for this pattern. See DL20–27 for recommendations for implementing this type of daylighting strategy. For an example of this type of daylighting, see the Silverthorne Elementary School climate zone 7 case study.

Gym Toplighting

For spaces with high ceilings, such as gyms, or for larger spaces, such as multipurpose rooms, cafeterias, and commons, a basic daylighting design that uses toplighting is recommended. Toplighting has the distinct advantage of providing useful daylight under most conditions, and allows for almost any orientation of the space.

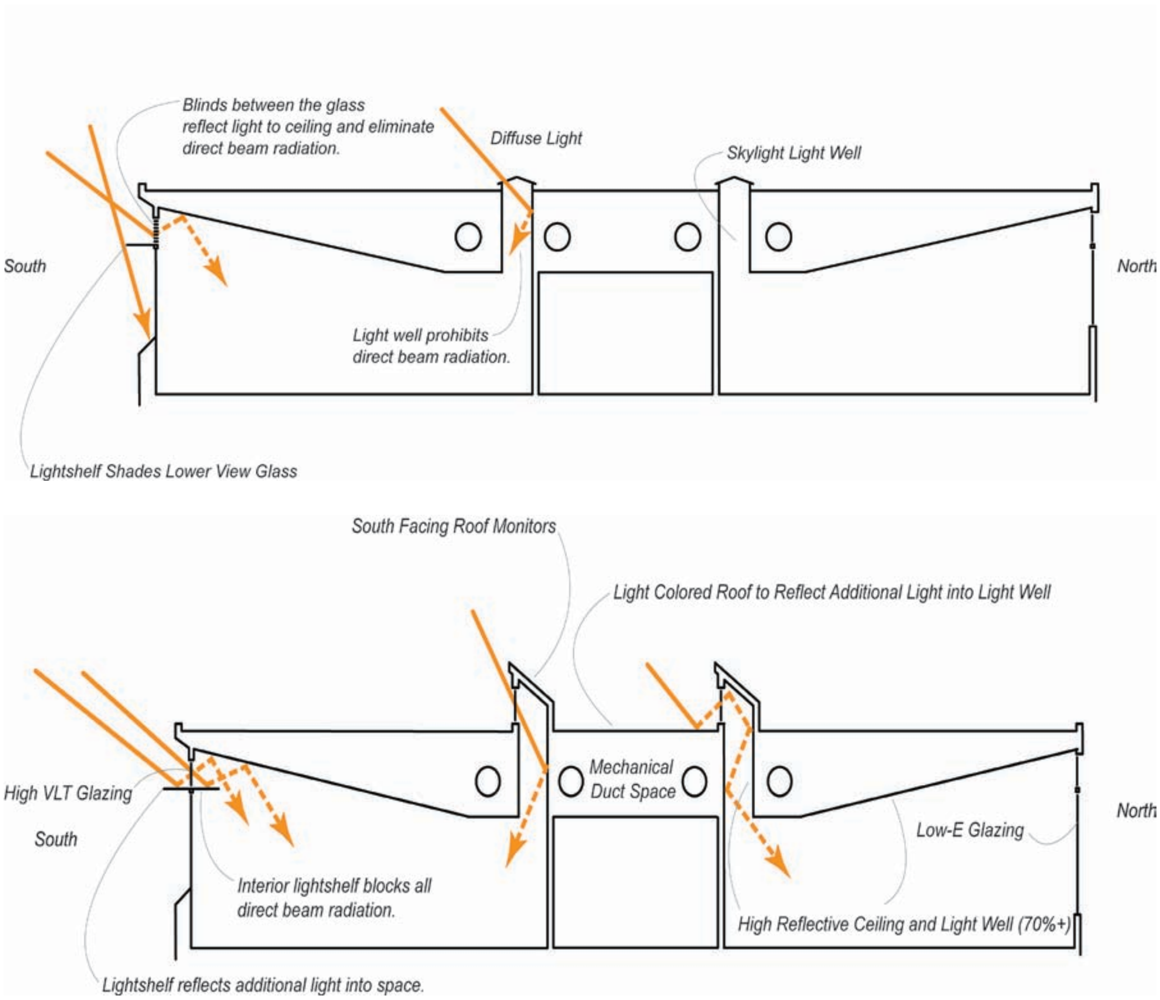

Figure 5.13. Sidelighted classroom enhanced with toplighted skylights or roof monitors.

DL36 Gym Toplighting Sizing

For those performing daylighting calculations using a daylighting program, the optimum daylighting performance will generally be achieved when the maximum average light level reached under winter conditions is no more than about 200 fc, and there is never any direct sun penetration. In the warmer peak cooling months, footcandle levels should average no more than 1.5 times the design footcandle level. This will produce useful daylight ranging from about 30–200 footcandles (30–70 footcandles for roof monitors) on average, from 9:00 a.m. until 3:00 p.m. in most climate zones.

To provide optimal levels the following process can be used:

- Determine the target lighting level (recommended illuminance).
- Multiply the target level by two; this will equal the target maximum (solar noon) daylight illuminance level.
- Evaluate winter maximum (solar noon); this number should no greater than twice (and preferably 1.5 times) the solar peak.

DL37 Gym Toplighting—Glazing Area (Climate Zones: all)

There are two recommended approaches for gym toplighting. The first is to use a grid of skylights. This approach works well in overcast and cool climates. A horizontal daylighting FFR of about 4%–5% is suggested using diffusing or prismatic skylights with VLT of at least 60%. If possible, skylights should be splayed to reduce glare. Many smaller skylights are better than a few larger ones. As a rule, the maximum dimension of a skylight should be about one-fourth the skylight's height above the floor. Use a point-by-point daylighting analysis tool (DL8) to determine the optimum size of the skylights.

The second option is to use a south- or north-facing roof monitor with clerestory. A north-facing clerestory is relatively simple in all climates, but requires a fairly large glazed area (7%–10% of the floor area) to produce enough daylight. A south-facing clerestory can be smaller (5%–8% of the floor area), but it must be carefully designed with an overhang to shade direct summer sunlight and interior baffles to diffuse direct sunlight and prevent glare. High north or south wall daylighting patterns are not recommended, as glare can easily be produced that affects sports performance. Figures 5.14–5.16 show typical toplighted gymnasium floor plans.

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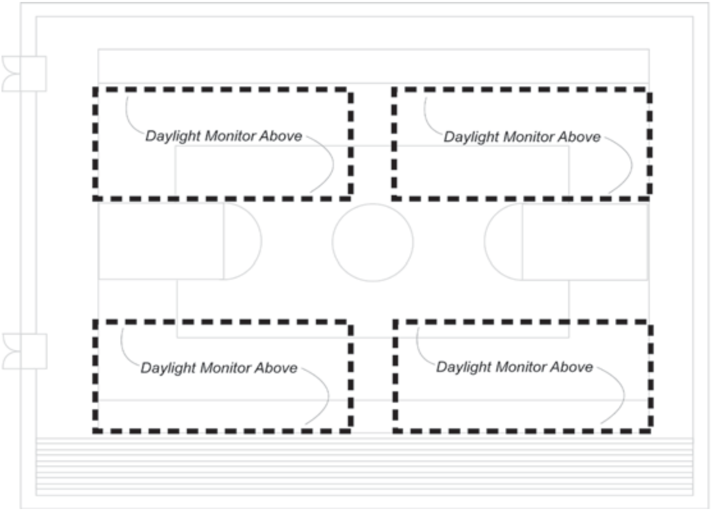

Figure 5.14. Typical 7600 ft² gymnasium floor plan with four roof monitors.

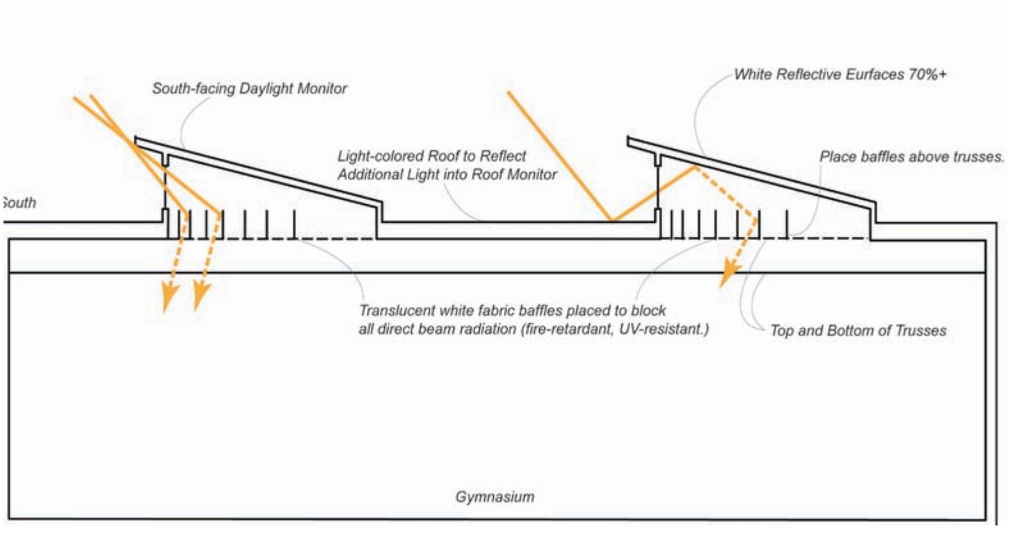

Figure 5.15. Typical 7600 ft² gymnasium floor plan with four roof monitors.

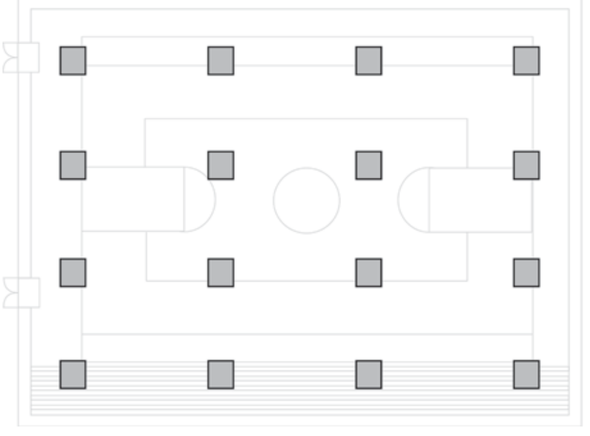

Figure 5.16. Typical 7600 ft² gymnasium floor plan with skylights.

Technology Case Study:
R.D. and Euzelle P. Smith Middle School
Chapel Hill, NC

The primary energy efficiency strategy used in the design of R.D. & Euzelle P. Smith Middle School in Chapel Hill, North Carolina, was daylighting. The school uses south-facing monitors to provide most of the daylighting in the classrooms, media center, and main corridor (see Figure S4.2). These monitors enable the electric lighting to be off most of the day, reducing peak cooling. Within the monitors are unevenly spaced fire-retardant, UV-resistant fabric baffles that help distribute the light uniformly and eliminate any potential glare problems (see Figure S4.3). The monitor allows hot air to stratify, keeping this air from entering the conditioned space of the room.

Recessed windows on the exterior classroom walls are equipped with clear, low emissivity double glazing. South facing windows contain a light shelf above the view windows (see Figure S4.1), allowing more light to come into the classroom without glare. North-facing windows do not have light shelves. The white roofing (cool roof) material reflects additional light to the light monitors. This daylighting strategy reduced the cooling load by 19%, or 78 tons.

As part of the daylighting system, the electric lighting system uses T8 lamps, dimming ballasts, and occupancy sensors, which add to the energy savings of the daylighting system. DOE-2 simulation models estimated a 64% reduction in electric lighting. Measured data show a reduction of 85% on sunny days and 60% on cloudy and partly cloudy days.

Daylighting in the gymnasium is also provided by south-facing roof monitors with translucent fabric baffles in the light wells. These features eliminate direct glare and effectively diffuse light throughout the space. Clear, double-pane glazing is used to maximize visible light transmittance and minimize glass to floor ratio. Adequate overhangs over the monitor windows protect the spaces from direct light during peak cooling periods.

Figure S4.1 Exterior light shelves.

Figure S4.2 South-facing monitors.

Figure S4.3. Classroom daylight monitors.

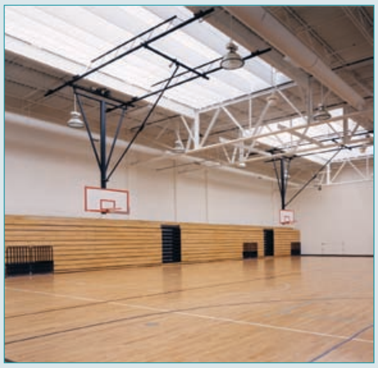

Figure S4.4. Gym toplighting.

Exterior Lighting

The following recommendations are not included in the recommendation tables in Chapter 3 because parking lots and grounds are often beyond the control of the individual school. If designing for parking lots and grounds, follow recommendations EX1–4.

Good Design Practice

EX1 *Exterior Lighting Power* (Climate Zones: all)

Limit exterior lighting power to 0.15 W/ft^2 for parking lot and grounds lighting. Calculate only for paved areas, excluding grounds that do not require lighting.

Limit exterior decorative facade lighting to 0.2 W/ft^2 of illuminated surface. This does not include lighting of walkways or entry areas of the building that may also light the building. Facade lighting can improve safety and security. Limit the lighting equipment mounting locations to the building and do not install floodlights onto nearby parking lot lighting poles. Use downward-facing lighting to comply with light trespass and light pollution concerns.

EX2 *Sources* (Climate Zones: all)

All general lighting luminaires should use pulse-start metal halide, fluorescent, induction, or compact fluorescent amalgam lamps with electronic ballasts.

- Standard high-pressure sodium lamps are not recommended because of their reduced visibility and poor color-rendering characteristics.
- Incandescent lamps are not recommended.
- For colder climates in climate zones 6–8, fluorescent lamps and CFLs must be specified with cold-temperature ballasts. Use CFL amalgams.

EX3 *Parking Lighting* (Climate Zones: all)

Parking-lot lighting locations should be coordinated with landscape plantings so that tree growth does not block effective lighting from pole-mounted luminaires.

Parking lot lighting should not be significantly brighter than lighting of the adjacent street. Follow IESNA RP-33-1999 recommendations for uniformity and illuminance recommendations.

Notes:

- For parking lot and grounds lighting, do not increase luminaire wattage to use fewer lights and poles. Increased contrast makes it harder to see at night beyond the immediate fixture location. Do not use floodlights and non-cutoff wallpacks, as they cause hazardous glare and encroach on neighboring properties. Limit lighting in parking and drive areas to not more than 360 W pulse-start metal halide lamps at a maximum 25 ft mounting height in urban and suburban areas. Use cutoff luminaries that provide all light below the horizontal plane and help eliminate light trespass.
- Consider PV-powered, grid-independent parking lot lighting when trenching over 200 ft is required to provide power to remote locations.

EX4 *Controls* (Climate Zones: all)

Use an astronomical time switch for all exterior lighting. Astronomical time switches can retain programming and the time setting during loss of power for at least ten hours. If a building energy management system is being used to control and monitor mechanical and electrical energy use, it can also be used to schedule and manage outdoor lighting energy use. Turn off exterior lighting not designated for security purposes when the building is unoccupied.

REFERENCES

IESNA. 1994. IESNA DG-5-94, *Lighting for Walkways and Class I Bikeways*. New York: Illuminating Engineering Society of North America.

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LRC. 1996. *Outdoor Lighting Pattern Book*. Troy, NY: Lighting Research Center.

HVAC

Although many types of HVAC systems could be used in K-12 schools, this Guide assumes that one of the following six system types is to be used.

- HV-1: Single-zone, packaged DX units (or split DX systems) with indirect gas-fired heaters, electric resistance heat, or heat pump
- HV-2: WSHPs or GSHPs with a dedicated OA ventilation system
- HV-3: Unit ventilators with a water chiller and a water boiler or electric resistance heat
- HV-4: Fan coils with a water chiller and a water boiler or electric resistance heat and a dedicated OA ventilation system
- HV-5: Multiple-zone, VAV packaged DX rooftop units with a hot-water coil, indirect gas furnace, or electric resistance in the rooftop unit and a hot-water coil or electric resistance in the VAV terminals.
- HV-6: Multiple-zone, VAV air handlers with a water chiller and a hot-water coil, indirect gas furnace, or electric resistance in the air handler and a hot-water coil or electric resistance in the VAV terminals.

Unique recommendations are included for each HVAC system type in the climate-specific tables in Chapter 3. Some system types, however, are not recommended for certain climate zones because of the impact of humidity on energy use.

This Guide does not cover purchased chilled water for cooling, or solar, steam, or purchased steam for heating. These and other systems are alternative means that may be used to achieve the energy savings target of this Guide.

Good Design Practice

HV1 *Single-Zone, Packaged DX Units (or Split DX Systems)* (Climate Zones: all)

In this system, a separate packaged DX unit (or split DX system) is used for each thermal zone. This type of equipment is available in pre-established increments of capacity.

The components are factory designed and assembled and include outdoor-air and return-air dampers, fans, filters, heating source, cooling coil, compressor, controls, and air-cooled condenser. The heating source is provided by either an indirect-fired gas burner, electric resistance heat, or by reversing the refrigeration circuit to operate the unit as a heat pump. Gas heaters are part of the factory assembled unit. Electric resistance heaters can be part of the factory-assembled unit or can be installed in the duct system. Heat pump units may also use an auxiliary heat source (typically electric resistance heat) during the defrost cycle.

The components can be assembled as a single package (such as a rooftop unit) or a split system that separates the evaporator and condenser/compressor sections. Single packaged units are typically mounted on the roof or at grade level outdoors. Split systems generally have the indoor unit (including fan, filters, and coils) located indoors or in an unconditioned space, and the condensing unit located outdoors on the roof or at grade level. On smaller systems, the fan is commonly incorporated in an indoor furnace section. The indoor unit may also be located outdoors; if so, it should be mounted on the roof to avoid installing ductwork outside the building envelope. The equipment should be located to meet the acoustical goals of the space, while minimizing fan power, ducting, and wiring.

Performance characteristics vary among manufacturers, and the selected equipment should match the calculated heating and cooling loads (sensible and latent), also taking into account the importance of providing adequate dehumidification under part-load conditions (see HV8). The equipment should be listed as being in conformance with electrical and safety standards with its performance ratings certified by a nationally recognized certification program.

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV2 *Water-Source (or Ground-Source) Heat Pumps* (Climate Zones: all)

In this system, a separate WSHP is used for each thermal zone. This type of equipment is available in pre-established increments of capacity. The components are factory-designed and assembled and include a filter, fan, refrigerant-to-air heat exchanger, compressor, refrigerant-to-water heat exchanger, and controls. The refrigeration cycle is reversible, allowing the same components to provide cooling or heating.

Individual WSHPs are typically mounted in the ceiling plenum over the corridor (or some other noncritical space) or in a closet next to the occupied space. The equipment should be located to meet the acoustical goals of the space and minimize fan power, ducting, and wiring. This may require that the WSHPs be located outside of the space.

In a traditional WSHP system, all the heat pumps are connected to a common water loop. A cooling tower and a hot water boiler are also installed in this loop to maintain the temperature of the water within a desired range.

A variation of this system takes advantage of the Earth's relatively constant temperature, and uses the ground instead of the cooling tower and boiler. GSHP systems (see AS3) do not actually get rid of heat, they store it in the ground for use at a different time. During the summer, the heat pumps extract heat from the building and transfer it to the ground. When the building requires heating, this stored heat can be recaptured from the ground. In a perfectly balanced system, the amount of heat stored over a given period of time would equal the amount of heat retrieved. This offers the potential to reduce (or eliminate) the energy used by a cooling tower and/or boiler, but installation costs may be higher because of the geothermal heat exchanger.

OA is conditioned and delivered by a separate dedicated ventilation system. This may involve ducting the outdoor air directly to each heat pump, delivering it in close proximity to the heat pump intakes, or ducting it directly to the occupied spaces. Depending on the climate, the dedicated OA unit may include components to filter, cool, heat, dehumidify, or humidify the OA (see HV12).

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV3 *Unit Ventilators* (Climate Zones: 2B 3B 3C 4 5 6 7 8)

In this system, a separate unit ventilator is used for each thermal zone. The components are factory-designed and assembled and include OA- and return-air dampers, filters, a fan, heating and cooling coils, and controls.

Unit ventilators are typically installed in each conditioned space or in the ceiling plenum above the corridor (or in some other noncritical space). However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized. This may require that the unit ventilators be located outside the space.

All the unit ventilators are connected to a common water distribution system. Cooling is provided by a centralized water chiller. Heating is provided by a centralized boiler or by electric resistance heat located inside each unit ventilator.

OA is brought in through each unit ventilator, providing the opportunity for air-side economizer cooling. The selected equipment should match the calculated heating and cooling loads (sensible and latent), taking into account the importance of providing adequate dehumidification under part-load conditions (see HV8).

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV4 *Fan-Coils* (Climate Zones: all)

In this system, a separate fan-coil unit is used for each thermal zone. The components are factory-designed and assembled and include filters, a fan, heating and cooling coils, controls, and possibly OA- and return-air dampers.

Fan-coils are typically installed in each conditioned space, in the ceiling plenum above the corridor (or some other noncritical space), or in a closet adjacent to the space. However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized. This may require that the fan coils be located outside of the space.

All the fan-coils are connected to a common water distribution system. Cooling is provided by a centralized water chiller. Heating is provided by either a centralized boiler or by electric resistance heat located inside each fan-coil.

OA is conditioned and delivered by a separate dedicated ventilation system. This may involve ducting the outdoor air directly to each fan-coil or ducting it directly to the occupied spaces. Depending on the climate, the dedicated outdoor-air unit may include components to filter, cool, heat, dehumidify, or humidify the outdoor air (see HV12).

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV5 *Multiple-Zone, VAV Packaged DX Rooftop Units* (Climate Zones: all)

In this system, a packaged DX rooftop unit serves several individually controlled zones. Each thermal zone has a VAV terminal unit that is controlled to maintain temperature in that zone. The components of the rooftop unit are factory-designed and assembled and include OA- and return-air dampers, filters, fans, cooling coil, heating source, compressors, condenser, and controls. The components of the VAV terminal units are factory-designed and assembled and include an airflow-modulation device, controls, and possibly a heating coil, fan, or filter.

VAV terminal units are typically installed in the ceiling plenum above the occupied space or adjacent corridor. However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized.

All the VAV terminal units served by each rooftop unit are connected to a common air distribution system (see HV20). Cooling is provided by the centralized rooftop unit. Heating is typically provided by an indirect-fired gas burner, a hot water coil, or an electric resistance heater inside the rooftop unit, individual heating coils (hot-water or electric resistance) located inside the VAV terminal units, or perimeter radiant heat located in the occupied space.

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

For VAV systems, the minimum supply airflow to a zone must comply with local code, and the current versions of *ANSI/ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality* (for minimum OA flow) and ASHRAE Standard 90.1 (for minimum turndown before reheat is activated).

HV6 Multiple-Zone, VAV Air Handlers (Climate Zones: all)

In this system, a central air handler serves several individually controlled zones. Each thermal zone has a VAV terminal unit that is controlled to maintain temperature in that zone. The components of the VAV air handler include OA- and return-air dampers, filters, fans, cooling coil, heating source, and controls. The components of the VAV terminal units are factory designed and assembled and include an airflow modulation device, controls, and possibly a heating coil, fan, or filter.

VAV terminal units are typically installed in the ceiling plenum above the occupied space or adjacent corridor. However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized.

All the VAV terminal units served by each air handler are connected to a common air distribution system (see HV20). All the air handlers are connected to a common water distribution system. Cooling is provided by the centralized water chiller. Heating is typically provided by an indirect-fired gas burner, a hot-water coil, or an electric resistance heater located inside the VAV air handler; individual heating coils (hot water or electric resistance) located inside the VAV terminal units; or perimeter radiant heat located in the occupied space.

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

For VAV systems, the minimum supply airflow to a zone must comply with local code, and the current versions of ASHRAE Standards 62.1 (for minimum outdoor airflow) and 90.1 (for minimum turndown before reheat is activated).

HV7 Cooling and Heating Load Calculations (Climate Zones: all)

Accurate sizing of equipment leads to lower equipment costs, lower utility costs, better dehumidification performance, and more comfortable conditions.

Design cooling and heating loads must be calculated in accordance with generally accepted engineering standards and handbooks, such as the methods described in Chapter 30 in the *2005 ASHRAE Handbook—Fundamentals*. Safety factors should be applied cautiously to prevent oversizing of equipment. Oversized cooling equipment has limited ability to reduce capacity at part-load conditions, which causes short-cycling of compressors. This, in turn, limits the system's ability to dehumidify (see HV8). It can also result in large changes in supply-air temperature, which may affect occupant comfort.

Cooling and heating loads of OA must be included in the load calculations, as well as accurate lighting and plug loads. Separate load calculations must be performed on each thermal zone type, and on each occupancy/activity zone type.

HV8 *Part-Load Dehumidification* (Climate Zones: all)

Most basic, constant-volume systems (small packaged rooftop units, DX split systems, fan-coils, WSHPs, etc.) supply a zone with a constant amount of air regardless of the cooling load. The system must deliver warmer air under part-load conditions to avoid overcooling the space.

In a typical chilled-water application, a modulating valve reduces system capacity by throttling the water flow rate through the cooling coil. The warmer coil surface that results provides less sensible cooling (raising the supply-air dry-bulb temperature), but it also removes less moisture from the passing airstream (raising the supply-air dew point).

In a typical DX application, the compressor cycles off regularly to avoid overcooling. As the compressor operates for a smaller percentage of the hour, dehumidification capacity decreases significantly. The compressor does not run long enough for the accumulated condensate to fall into the drain pan, and it stays off for longer periods of time, allowing the remaining moisture on the coil surface to re-evaporate while the fan continues to run.

Briefly stated, a basic constant-volume system matches sensible capacity to the sensible load; dehumidification capacity is coincidental. As the load diminishes, the system delivers ever warmer supply air. Some dehumidification may occur, but only if the sensible load is high enough. As a result, the space relative humidity will tend to increase under part-load conditions. Therefore, select systems that minimize the number of hours that the space relative humidity remains above 60%. Following are some (but not all) of the possible methods for improving part-load dehumidification.

For Single-Zone, Packaged Units or Split DX Systems (see HV1). Packaged rooftop units (or split DX systems) could be equipped with reheat (using heat recovered from the refrigeration circuit) for direct control of space humidity. Alternatively, a dedicated OA system (see HV12) could be added and designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the local DX units.

For WSHPs or GSHPs (see HV2). The dedicated OA system (see HV12) should be designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the WSHP units. Alternatively, some WSHPs could be equipped with hot gas reheat for direct control of space humidity.

For Unit Ventilators (see HV3). Unit ventilators could be equipped with multiple-speed fans or face-and-bypass dampers for improved part-load dehumidification or with a reheat coil for direct control of space humidity. Consider using recovered heat when using reheat. Alternatively, a dedicated OA system (see HV12) could be added and designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the unit ventilators.

For Fan-Coil Units (see HV4). The dedicated OA system (see HV12) should be designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the fan-coil units. Alternatively, fan-coils could be equipped with multiple-speed fans for improved part-load dehumidification or a reheat coil for direct control of space humidity. Consider using recovered heat when using reheat.

For Multiple-Zone, Packaged VAV Rooftop Units (see HV5). VAV systems typically dehumidify effectively over a wide range of indoor loads, as long as the VAV rooftop unit continues to provide cool, dry air at part-load conditions. One caveat: use caution when resetting the supply air temperature (SAT) during the cooling season. Warmer supply air means less dehumidification at the coil and higher humidity in the space. If SAT reset is used, include one or more zone humidity sensors to disable the reset if the relative humidity within the space exceeds 60%.

For Multiple-Zone, VAV Air Handlers (see HV6). VAV systems typically dehumidify effectively over a wide range of indoor loads, as long as the VAV rooftop unit continues to provide cool, dry air at part-load conditions. One caveat: use caution when resetting the SAT or chilled water (CHW) temperature during the cooling season. Warmer supply air (or water) means less dehumidification at the coil and higher humidity in the space. If SAT or CHW reset is used in a humid climate, include one or more zone humidity sensors to disable reset if the relative humidity within the space exceeds 60%.

HV9 *Exhaust Air Energy Recovery* (Climate Zones: all)

Exhaust air energy recovery can provide an energy-efficient means of reducing the latent and sensible outdoor air cooling loads during peak summer conditions. It can also reduce the outdoor air heating load in mixed and cold climates. HVAC systems that use exhaust air energy recovery should be resized to account for the reduced outdoor air heating and cooling loads (see *ASHRAE Handbook—HVAC Systems and Equipment*).

For some HVAC system types, the climate-specific tables in Chapter 3 recommend either exhaust air energy recovery or DCV. If the energy recovery option is selected, this device should have a total effectiveness of at least 50% for A climate zones (humid) or a sensible effectiveness of at least v50% for B climate zones (dry). There is no recommendation for energy recovery for C climate zones (marine).

Sensible energy recovery devices transfer only sensible heat. Common examples include coil loops, fixed-plate heat exchangers, heat pipes, and sensible energy rotary heat exchangers (sensible energy wheels). Total energy recovery devices not only transfer sensible heat, but also moisture (or latent heat); that is, energy stored in water vapor in the airstream. Common examples include total energy rotary heat exchangers (also known as total energy wheels or enthalpy wheels) and fixed-membrane heat exchangers (see Figure 5.17).

An exhaust-air energy recovery device can be packaged in a separate energy recovery ventilator (ERV) that conditions the outdoor air before it enters the air-conditioning unit, or the device can be integral to the air-conditioning unit.

For maximum benefit, the system should provide as close to balanced outdoor and exhaust airflows as is practical, taking into account the need for building pressurization and any exhaust that cannot be ducted back to the energy recovery device.

Exhaust for energy recovery may be taken from spaces requiring exhaust (using a central exhaust duct system for each unit) or directly from the return airstream (as with a unitary accessory or integrated unit). (See also HV15, "Exhaust Air Systems.")

Where an air-side economizer is used along with an ERV, add bypass dampers (or a separate OA path) to reduce the air-side pressure drop during economizer mode. In addition, the ERV should be turned off during economizer mode, to avoid adding heat to the outdoor airstream. Where energy recovery is used without an air-side economizer, the ERV should be controlled to prevent the transfer of unwanted heat to the outdoor airstream dur-

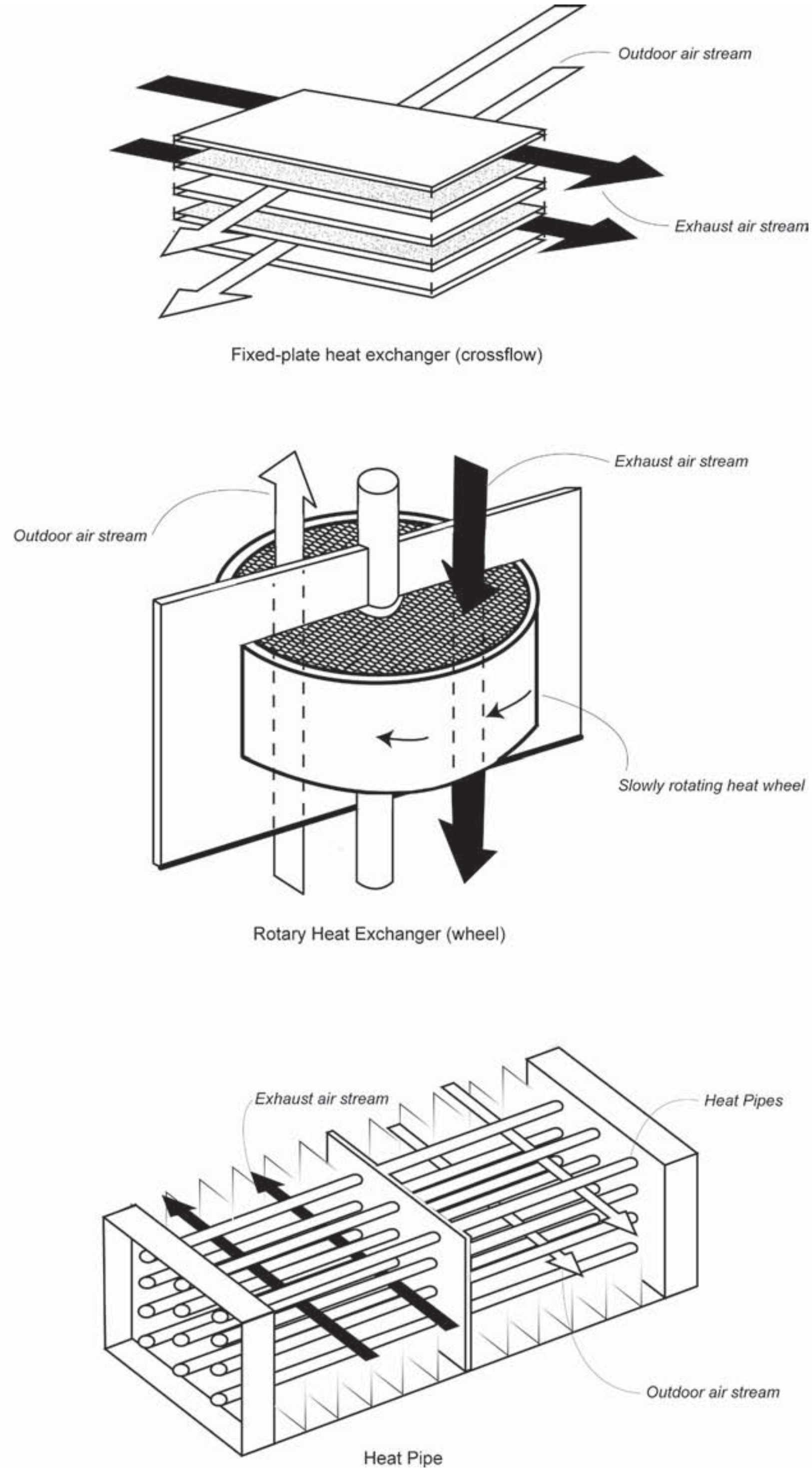

Figure 5.17. Examples of exhaust air energy recovery devices.

ing mild outdoor conditions. In cold climates, follow the manufacturer's recommendations for frost prevention.

HV10 HV Cooling and Heating Equipment Efficiencies (Climate Zones: all)

The cooling and heating equipment should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level where shown. In some cases, recommended equipment efficiencies are based on system size (capacity).

There are many factors in making a decision whether to use gas or electricity, such as availability of service, utility costs, operator familiarity, and impact of source energy use. Efficiency recommendations for both types of equipment are provided to allow the user to choose.

HV11 Ventilation Air (Climate Zones: all)

The zone-level outdoor airflows, and the system-level intake airflow, should be determined based on the current version of ASHRAE Standard 62.1, but should not be less than the values required by local code unless approved by the authority with jurisdiction. The number of people used in computing the breathing zone ventilation rates should be based on known occupancy, local code, or the default values listed in ASHRAE Standard 62.1.

For Single-Zone, Packaged Units, or Split DX Systems (see HV1). Each packaged DX unit (or indoor unit of a split DX system) should have an OA connection through which OA is introduced and mixes with the recirculated air. The OA can be mixed with the recirculated air either in the ductwork prior to the air-conditioning or heat pump unit, or at the unit's mixing plenum. In either case, the damper and duct/plenum should be arranged to promote mixing and to minimize temperature stratification. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone or to each individual packaged unit (or indoor unit in a split DX system).

For WSHPs or GSHPs (see HV2). The dedicated OA system (see HV12) should deliver the conditioned OA directly to each zone, to the intake of each individual heat pump (where it mixes with recirculated air, either in the ductwork prior to the heat pump or in a mixing plenum attached to the heat pump), or to the supply side of each WSHP (where it mixes with supply air from the heat pump before being delivered to the zone).

For Unit Ventilators (see HV3). Each unit ventilator should have an OA connection through which OA is introduced and mixes with the recirculated air. The dampers should be arranged to promote mixing and to minimize temperature stratification. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone or to each individual unit ventilator.

For Fan-Coil Units (see HV4). The dedicated OA system (see HV12) should deliver the conditioned OA directly to each zone, to the intake of each individual fan-coil (where it mixes with recirculated air, either in the ductwork prior to the fan-coil or in a mixing plenum attached to the fan-coil), or to the supply side of each fan-coil (where it mixes with supply air from the fan-coil before being delivered to the zone).

For Multiple-Zone, Packaged VAV Rooftop Units (see HV5). Each rooftop unit should have an OA intake through which OA is introduced and mixes with the recirculated air, prior to being delivered to the zones. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone, to individual dual-duct VAV terminals that serve each zone, or to the OA intake of one or more packaged VAV rooftop units.

For Multiple-Zone, VAV Air Handlers (see HV6). Each VAV air handler should have an OA intake through which OA is introduced and mixes with the recirculated air, prior to being delivered to the zones. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone, to individual dual-duct VAV terminals that serve each zone, or to the OA intake of one or more VAV air handlers.

Notes:

- The occupant load, or exit population, used for egress design to comply with the fire code is typically much higher than the zone population used for ventilation system design. Using occupant load, rather than zone population, to calculate ventilation requirements can result in significant overventilation, oversized HVAC equipment, and excess energy use.
- Buildings with multiple-zone, recirculating ventilation systems (MZS) can be designed to account for recirculated OA, as well as system population diversity (D), using the equations found in ASHRAE Standard 62.1. In effect, the MZS design approach allows ventilation air to be calculated on the basis of how many people are in the building (system population at design) rather than the sum of how many people are in each space (sum-of-peak zone population at design). This can reduce the energy required to condition ventilation air in K-12 schools. Refer to the *Standard 62.1 User's Manual* (ASHRAE 2007) for specific guidance.
- For all zones, time-of-day schedules in the BAS should be used to introduce ventilation air only when a zone is expected to be occupied.

HV12 Dedicated Outdoor Air Systems (Climate Zones: all)

Dedicated outdoor air systems (DOAS) can reduce energy use by decoupling the heating, cooling, and dehumidification of OA for ventilation from sensible cooling and heating in the zone. The OA is conditioned by a separate dedicated OA unit that is designed to heat, cool, and dehumidify the OA, and to deliver it dry enough to offset space latent loads (Mumma and Shank 2001). Terminal HVAC equipment, which is located in or near each space, heats or cools recirculated indoor air to maintain space temperature. Terminal equipment may include fan-coil units, WSHPs, zone-level air handlers, radiant cooling panels, fan-powered VAV terminals, or a dual-fan, dual-duct arrangement. Dedicated OA systems can also be used in conjunction with multiple-zone recirculating systems, in which the ventilation system is sized based on ASHRAE Standard 62.1.

Consider delivering the conditioned OA cold (not reheated to neutral) whenever possible, and use recovered energy to reheat only when needed. Providing cold (rather than neutral) air from the dedicated OA unit offsets a portion of the space sensible cooling loads, allowing the terminal HVAC equipment to be downsized and use less energy. In addition, implementing system-level control strategies and exhaust air energy recovery (see HV9) can help minimize energy use.

There are many possible DOAS configurations (see Figure 5.18 for a few typical ones). The salient energy-saving feature of dedicated OA systems is the separation of ventilation air conditioning from zone air conditioning.

HV13 Economizer (Climate Zones: 3 4 5 6 7 8)

Economizers, when recommended, help save energy by providing free cooling when ambient conditions are suitable to meet all or part of the cooling load. In humid climates, consider using enthalpy-based controls (versus dry-bulb temperature controls) to help ensure that unwanted moisture is not introduced into the space. Economizers are not recommended in climate zone 1, but there may be some applicability in dry areas in climate zone 2.

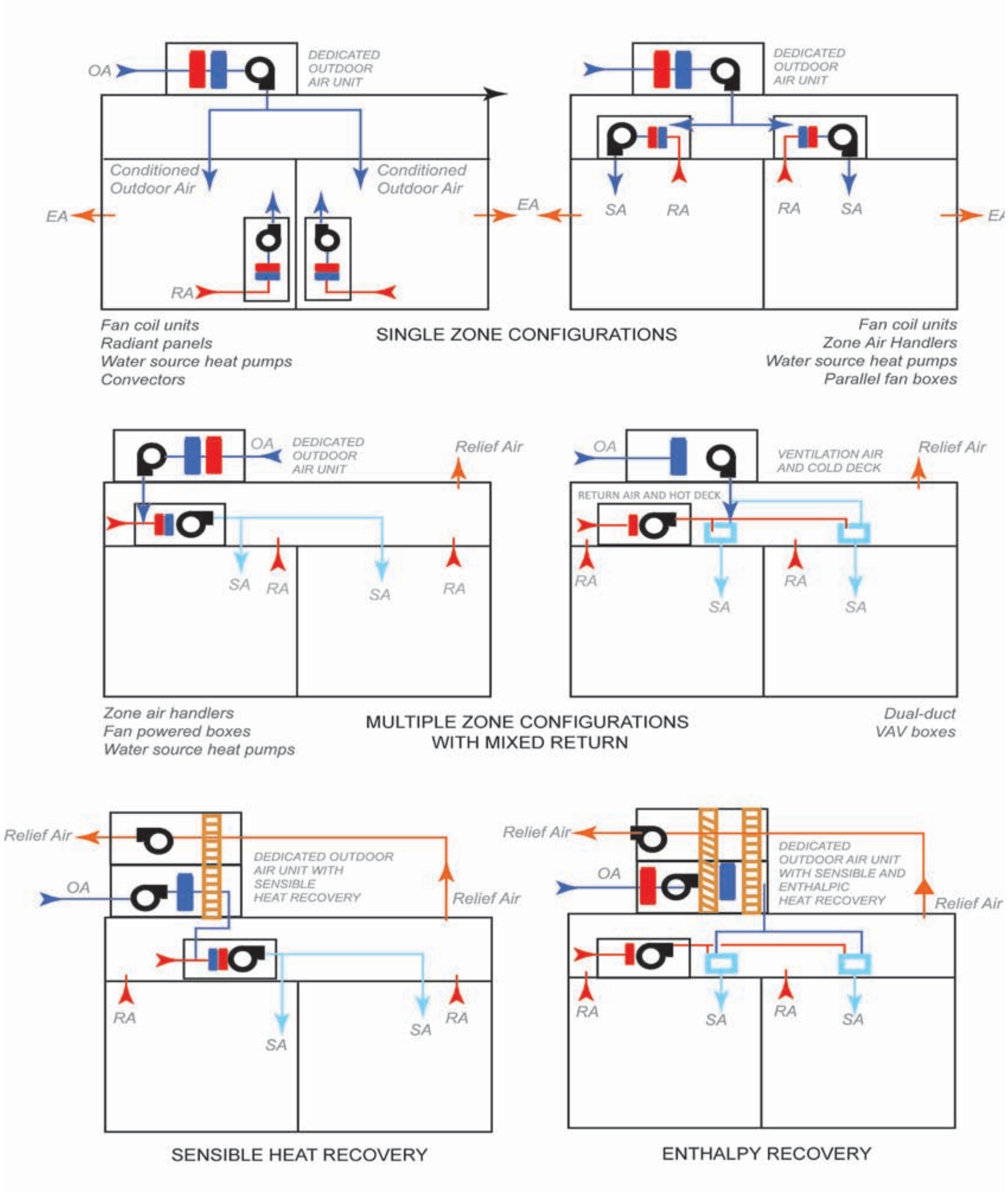

Figure 5.18. Examples of DOAS configurations.

Non-dedicated OA systems should be capable of modulating the OA, return air, and relief air dampers to provide up to 100% of the design supply air quantity as OA for cooling. (See HV12 for discussion of DOAS.) A motorized outdoor air damper should be used instead of a gravity damper to prevent unwanted OA from entering during the unoccupied periods when the unit may recirculate air to maintain setback or setup temperatures. The motorized OA damper for all climate zones should be closed during the entire unoccupied period, except when it may open in conjunction with an unoccupied economizer or pre-occupancy purge cycle.

Periodic maintenance is important with economizers, as dysfunctional economizers can cause substantial excess energy use because of malfunctioning dampers or sensors (see HV30).

HV14 *Demand-Controlled Ventilation* (Climate Zones: all)

DCV can reduce the energy required to condition OA for ventilation. To maintain acceptable IAQ, the setpoints (limits) and control sequence must comply with ASHRAE Standard 62.1. Refer to the *Standard 62.1 User's Manual* (ASHRAE 2007) for specific guidance.

For some HVAC system types, the climate-specific tables in Chapter 3 recommend either exhaust air energy recovery or DCV. If the DCV option is selected, the controls should vary the amount of OA in response to the need in a zone. The amount of OA could be controlled by (1) a time-of-day schedule in the BAS; (2) an occupancy sensor (such as a motion detector) that indicates when a zone is occupied or unoccupied; or (3) a CO_2 sensor, as a proxy for ventilation airflow per person, that measures the change in CO_2 level in a zone relative to the level in the OA. A controller will then operate the OA, return air, and relief air dampers to maintain proper ventilation.

CO_2 sensors should be used in zones that are densely occupied, with highly variable occupancy patterns during the occupied period, such as gymnasiums, auditoriums, multipurpose spaces, cafeterias, and some classrooms. For the other zones, occupancy sensors should be used to reduce ventilation when a zone is temporarily unoccupied. For all zones, time-of-day schedules in the BAS should be used to introduce ventilation air only when a zone is expected to be occupied.

Multiple-zone, recirculating systems (such as VAV systems) require special attention to ensure adequate OA is supplied to all zones under varying loads. Employing DCV in a DOAS requires an automatic damper and sensor for each DCV zone.

Selection of the CO_2 sensors is critical in both accuracy and response ranges. CO_2 sensors should be certified by the manufacturer to have an error of 75 ppm or less and be factory calibrated. Inaccurate CO_2 sensors can cause excessive energy use or poor IAQ, so they need to be calibrated as recommended by the manufacturer (see HV30).

Finally, when DCV is used, the system controls should prevent negative building pressure. If the amount of air exhausted remains constant while the intake airflow decreases, the building may be under a negative pressure relative to outdoors. When air is exhausted directly from the zone (art or vocational classrooms, science laboratories, kitchens, locker rooms, or even a classroom with a restroom connected to it), the DCV control strategy must avoid reducing intake airflow below the amount required to replace the air being exhausted.

HV15 *Exhaust Air Systems* (Climate Zones: all)

Zone exhaust airflows (for restrooms, janitorial closets, science laboratories, kitchens, art and vocational classrooms, locker rooms, etc.) should be determined based on the current version of ASHRAE Standard 62.1, but should not be less than the values required by local code unless approved by the authority having jurisdiction.

Central exhaust systems for restrooms, janitorial closets, and locker rooms should be interlocked to operate with the air-conditioning system, except during unoccupied periods. Such a system should have a motorized damper that opens and closes with the operation of the fan. The damper should be located as close as possible to the duct penetration of the building envelope to minimize conductive heat transfer through the duct wall and avoid having to insulate the entire duct. During unoccupied periods, it should remain closed and the exhaust fan turned off, even if the air-conditioning system is operating to maintain setback or setup temperatures. Consider designing exhaust ductwork to facilitate recovery of energy (see HV9) from Class 1 and Class 2 (e.g., restrooms) exhaust air, per the requirements of ASHRAE Standard 62.1.

Kitchens will generally have separate exhaust and make-up air systems according to the use of the kitchen and to the equipment manufacturers' suggestions. If showers are provided in locker rooms, exhaust must be increased during use and will generally require separate air intake (intake hood or make-up air unit). Science laboratories should have exhaust systems if noxious chemicals or preservatives are used. Make-up air will be necessary to prevent room pressure from becoming negative with respect to the outside.

HV16 Ductwork Design and Construction (Climate Zones: all)

Low-energy use ductwork design involves short, direct, and low pressure drop runs. The number of fittings should be minimized and should be designed with the least amount of turbulence produced. (In general, the first cost of a duct fitting is approximately the same as 12 ft of straight duct that is the same size as the upstream segment.) Unwanted noise in the ductwork is a direct result of air turbulence. Round duct is preferred over rectangular duct. However, space (height) restrictions may require flat oval ductwork to achieve the low turbulence qualities of round ductwork.

Air should be ducted through low-pressure ductwork with a system pressure classification of less than 2 in. of water. Rigid ductwork is necessary to maintain low pressure loss and reduce fan energy. Supply air should be ducted to diffusers in each individual space.

In general, the following sizing criteria should be used for duct system components:

- Diffusers and registers, including balancing dampers, should be sized with a static pressure drop no greater than 0.08 in. of water.
- Supply ductwork should be sized with a pressure drop no greater than 0.08 in. of water per 100 linear ft of duct run. Return ductwork should be sized with a pressure drop no greater than 0.04 in. of water and exhaust ductwork with a pressure drop no greater than 0.05 in. of water.
- Flexible ductwork should be of the insulated type and should be as follows:
    - Limited to connections between duct branch and diffusers
    - Limited to connections between duct branch and VAV terminal units
    - Limited to 5 ft (fully stretched length) or less
    - Installed without any kinks
    - Installed with a durable elbow support when used as an elbow
    - Installed with no more that 15% compression from fully stretched length

Hanging straps, if used, need to use a saddle to avoid crimping the inside cross-sectional area. For ducts 12 in. or smaller in diameter, use a 3 in. saddle; for those larger than 12 in. use a 5 in. saddle.

Long-radius elbows and 45° lateral take-offs should be used wherever possible. The angle of a reduction transition should be no more that 45° (if one side used) or 22.5° (if two sides are used). The angle of expansion transitions should be no more than 15° (laminar air expands approximately 7°).

Air should be returned or exhausted through appropriately placed grilles. Good practice is to direct supply air diffusers toward the exterior envelope and to locate return air grilles near the interior walls, close to the door.

Returning air to a central location (as in a multiple-zone, recirculating system) is necessary to reap the benefits of reducing ventilation air due to system population diversity (see HV11). Fully ducted return systems are expensive and must be connected to a single air handler (or the return ducts must be interconnected) to function as a multiple-zone recirculating system. Open plenum return systems are less expensive, but must be carefully designed and constructed to prevent infiltration of humid air from outdoors (Harriman 2001).

The ceiling plenum must also be well sealed to minimize air infiltration. Infiltration can be reduced by using a relief fan to maintain plenum pressure at about 0.05 in. of water higher than atmospheric pressure (see HV27), and lowering indoor humidity levels can reduce the risk of condensation (see HV8 and HV12). In addition, exhaust duct systems should be properly sealed to prevent infiltration.

Note:

- Plenum return systems in school buildings that have sloped roofs and eaves in cold, snowy climates requires special attention to insulation between the plenum and the roof. It must be continuous and well sealed. Leakage of warm air from the plenum to the roof can melt snow and form ice dams on the eaves. This can cause water to seep into the structure.
- Ductwork should not be installed outside the building envelope. Ductwork connected to rooftop units should enter or leave the unit through an insulated roof curb around the perimeter of the unit's footprint. Flexible duct connectors should be used to prevent sound transmission and vibration.
- Duct board should be airtight (duct seal level B, from ASHRAE Standard 90.1) and should be taped and sealed with products that maintain adhesion (such as mastic or foil-based tape).
- Duct static pressures should be designed, and equipment and diffuser selections should be selected, not to exceed noise criteria for the space (see HV29 for additional information on noise control).

HV17 Duct Insulation (Climate Zones: all)

The following ductwork should be insulated:

- All supply air ductwork
- All return air ductwork located above the ceiling and below the roof
- All outdoor air ductwork
- All exhaust and relief air ductwork between the motor-operated damper and penetration of the building exterior

In addition, all airstream surfaces should be resistant to mold growth and resist erosion, according to the requirements of ASHRAE Standard 62.1.

Exception: In conditioned spaces without a finished ceiling, only the supply air main ducts and major branches should be insulated. Individual branches and run-outs to diffusers in the space being served do not need to be insulated, except where it may be necessary to prevent condensation.

HV18 Duct Sealing and Leakage Testing (Climate Zones: all)

The ductwork should be sealed for Seal Class B from ASHRAE Standard 90.1. All duct joints should be inspected to ensure they are properly sealed and insulated, and the ductwork should be leak-tested at the rated pressure. The leakage should not exceed the allowable cfm/100 ft^2 of duct area for the seal and leakage class of the system's air quantity apportioned to each section tested. See HV22 for guidance on ensuring the air system performance.

HV19 *Fan Motor Efficiencies* (Climate Zones: all)

Motors for fans 1 hp or greater should meet National Electrical Manufacturers Association (NEMA) premium efficiency motor guidelines when available.

Fan systems should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. Depending on the HVAC system type, the efficiency level is expressed in terms of either a maximum horsepower (hp) per 1000 cfm of supply air or a maximum external static pressure (ESP) loss (for systems with integral, terminal fans).

HV20 *Thermal Zoning* (Climate Zones: all)

K-12 school buildings should be divided into thermal zones based on building size, orientation, space layout and function, and after-hours use requirements.

Zoning can also be accomplished with multiple HVAC units or a central system that provides independent control for multiple zones. The temperature sensor for each zone should be installed in a location that is representative of that entire zone.

When using a multiple-zone system (such as a VAV system) or a DOAS, avoid using a single air handler (or rooftop unit) to serve zones that have significantly different occupancy patterns. Using multiple air handlers allows air handlers serving unused areas of the building to be shut off, even when another area of the building is still in use. An alternate approach is to use the BAS to define separate operating schedules for these areas of the building, thus shutting off airflow to the unused areas while continuing to provide comfort and ventilation to areas of the building that are still in use.

HV21 *System-Level Control Strategies* (Climate Zones: all)

Control strategies can be designed to help reduce energy. Having a setback temperature for unoccupied periods during the heating season or a setup temperature during the cooling season can help to save energy by avoiding the need to operate heating, cooling, and ventilation equipment. Programmable thermostats allow each zone to vary the temperature setpoint based on time of day and day of the week. But they also allow occupants to override these setpoints or ignore the schedule altogether (by using the "hold" feature), which thwarts any potential for energy savings. A more sustainable approach is to equip each zone with a zone temperature sensor and then use a system-level controller that coordinates the operation of all components of the system. This system-level controller contains time-of-day schedules that define when different areas of the building are expected to be unoccupied. During these times, the system is shut off and the temperature is allowed to drift away from the occupied setpoint.

A pre-occupancy ventilation period can help purge the building of contaminants that build up overnight from the off-gassing of products and packaging materials. When it is cool at night, it can also help pre-cool the building. In humid climates, however, care should be taken to avoid bringing in humid OA during unoccupied periods.

Optimal start uses a system-level controller to determine the length of time required to bring each zone from the current temperature to the occupied setpoint temperature. Then, the controller waits as long as possible before starting the system, so that the temperature in each zone reaches occupied setpoint just in time for occupancy. This strategy reduces the number of hours that the system needs to operate, and saves energy by avoiding the need to maintain the indoor temperature at occupied setpoint even though the building is unoccupied.

CHW reset can reduce chiller energy use at part-load conditions. But it should be used only in a constant-flow (not variable-flow) pumping system, and it should be disabled when the outdoor dew point is above 55°F (for example) or if space humidity levels rise about 60% RH.

In a VAV system, SAT reset should be implemented to minimize overall system energy use. This requires considering the trade-off between compressor, reheat, and fan energy, as well as the impact on space humidity levels. If SAT reset is used in a humid climate, include one or more zone humidity sensors to disable reset if the RH in the space exceeds 60%.

HV22 Testing, Adjusting, and Balancing (Climate Zones: all)

After the system has been installed, cleaned, and placed in operation, the system should be tested, adjusted, and balanced in accordance with *ASHRAE Standard 111, Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems* or SMACNA's *Testing, Adjusting and Balancing* manual.

This procedure will help to ensure that the correctly sized diffusers, registers, and grilles have been installed, that each space receives the required airflow, and that the fans meet the intended performance. The balancing subcontractor should certify that the instruments used in the measurement have been calibrated within 12 months before use. A written report should be submitted for inclusion in the O&M manuals.

HV23 Commissioning (Climate Zones: all)

After the system has been installed, cleaned, and placed in operation, the system should be commissioned to ensure that the equipment meets the intended performance and that the controls operate as intended. See Appendix B, "Commissioning," for more information on Cx.

HV24 Filters (Climate Zones: all)

Particulate air filters are typically included as part of the factory-assembled HVAC equipment and should be at least MERV 8, based on *ANSI/ASHRAE Standard 52.2, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. Use a filter differential pressure gauge to monitor the pressure drop across the filters and send an alarm if the predetermined pressure drop is exceeded. Filters should be replaced when the pressure drop exceeds the filter manufacturer's recommendations for replacement, or when visual inspection indicates the need for replacement. The gauge should be checked and the filter should be visually inspected at least once each year.

If high-efficiency filters are to be used, consider using lower-efficiency filters during the construction period. When construction is complete, all filters should be replaced before the building is occupied.

HV25 Chilled-Water System (Climate Zones: all)

CHW systems can be an efficient way to move energy around the building, and with the load profile of many K-12 schools, they can be a great way to combine a thermal storage system (see AS4). CHW systems should generally be designed for variable flow through the building:

- Very small systems (<100 tons) may be designed for constant flow.
- Medium-sized systems (100–250 tons) may achieve variable flow by using two-way control valves on most of the cooling coils, with a few three-way valves to provide the required minimum flow through the chiller.
- Large systems (>250 tons) or systems with a significant water pressure drop (>75 ft of H_2O) are good candidates for variable primary flow.

Piping should be sized for a pressure drop of less than 3 ft of water per 100 ft of pipe. Using a smaller pipe size increases the pressure drop through the pipe, increases the velocity through the pipe, and may cause erosion to occur if velocity is too high. A larger pipe size results in additional pump energy savings, but increases the installed cost of the pipe. In systems that operate for longer hours, larger pipe sizes are often very economical.

VFDs on chillers can be beneficial in applications where condenser relief occurs for a significant number of hours. Air-cooled condensers are typically designed for 95°F ambient air condition, and water-cooled condensers are typically designed for 85°F entering water temperature. If a chiller will operate for a significant number of hours at temperatures at least 10°F below these conditions, a VFD should be considered. Not all chillers need to be equipped with a VFD; typically a VFD on the chiller that operates with the most amount of condenser relief will provide the most economical payback. Generally, climates that are hot and humid are not good candidates for VFDs on chillers.

CHW temperatures will vary depending on whether thermal storage is used. If thermal storage is used, the chiller must be selected for the most extreme temperatures, which typically occur during the charge mode.

To increase energy savings beyond 30%, use a CHW ΔT of 12°F–20°F. This will save pump energy, but it will also affect cooling coil performance. This can be overcome by lowering the chilled-water temperature to deliver the same air conditions leaving the coil. CHW temperature setpoints should be selected based on a life-cycle analysis of pump energy, fan energy, and desired air conditions leaving the coil.

HV26 *Water Heating Systems* (Climate Zones: all)

Condensing boilers can operate at up to 97% efficiency and can operate efficiently at part load. To achieve these high-efficiency levels, condensing boilers require that return water temperatures be maintained at 70°F–120°F, where the boiler efficiency is 97%–91%. This fits well with hydronic systems that are designed with ΔTs greater than 20°F (optimal ΔT is 30°F–40°F). The higher ΔTs allow smaller piping and less pumping energy. Because condensing boilers work efficiently at part load, VFDs can be used on the pumps to further reduce energy use.

Condensing boiler capacity can be modulated to avoid losses caused by cycling at less than full load. This encourages the installation of a modular (or cascade) boiler system, which allows several small units be installed for the design load, but allows the units to match the load for maximum efficiency of the system.

HV27 *Relief versus Return Fans* (Climate Zones: all)

Relief (rather than return) fans should be used when necessary to maintain building pressurization during economizer operation. Relief fans reduce overall fan energy use in most cases, as long as return dampers are sized correctly. However, if return duct static pressure drop exceeds 0.5 in. of water, return fans may be needed.

Cautions

HV28 *Heating Sources* (Climate Zones: all)

Many factors come into play in making a decision whether to use gas or electricity for heating, including availability of service, utility costs, operator familiarity, and the impact of source energy use.

Forced-air electric resistance and gas-fired heaters require a minimum airflow rate to operate safely. These systems, whether stand-alone or incorporated into an air-conditioning or heat pump unit, should include factory installed controls to shut down the heater when there is inadequate airflow that can result in high temperatures.

Ducts and supply-air diffusers should be selected based on discharge air temperatures and airflow rates.

HV29 *Noise Control* (Climate Zones: all)

Much of the education that takes place in K-12 classrooms hinges on oral communication. Less than optimal acoustical conditions in the classroom affect the academic performance of all students, but they pose a particular challenge for students learning in a non-native language, coping with learning disabilities, or hindered by impaired hearing.

The *ASHRAE Handbook–HVAC Applications* and *ANSI/ASA Standard S12.60, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools* are two potential sources for recommended background sound levels in the various spaces that make up K-12 school buildings.

Avoid installation of the HVAC equipment directly above classrooms. Consider locations above less critical spaces, such as storage areas, restrooms, and corridors, or in acoustically treated closets adjacent to the space. Acoustical requirements may necessitate attenuation of the noise associated with the supply and return air, or noise radiated from the HVAC equipment. Acoustical concerns may be particularly critical in short, direct runs of ductwork between the fan and supply or return outlet.

Refer to ASHRAE's *Practical Guide to Noise and Vibration Control for HVAC Systems* for specific guidance by system type.

HV30 *Proper Maintenances* (Climate Zones: all)

Regularly scheduled maintenance is an important part of keeping the HVAC system in optimum working condition. Neglecting preventive maintenance practices can quickly negate any energy savings expected from the system design.

Filters should be replaced when the pressure drop exceeds the filter manufacturer's recommendations for replacement, or when visual inspection indicates the need for replacement. ERVs need to be cleaned periodically to maintain performance. Dampers, valves, louvers, and sensors must all be periodically inspected and calibrated to ensure proper operation. This is especially important for OA dampers and CO_2 sensors. Inaccurate CO_2 sensors can cause excessive energy use or poor IAQ, so they need to be calibrated as recommended by the manufacturer.

A BAS can be used to notify O&M staff when preventive maintenance procedures should be performed. This notification can be triggered by calendar dates, run-time hours, the number of times a piece of equipment has started, or sensors installed in the system (such as a pressure switch that indicates when an air filter is too dirty and needs to be replaced).

HV31 *Zone Temperature Control* (Climate Zones: all)

The number of spaces in a zone and the location of the temperature sensor (thermostat) will affect the control of temperature in the various spaces of a zone. Locating the thermostat in one room of a zone with multiple spaces provides feedback based only on the conditions in that room. Locating a single thermostat in a large open area may provide a better response to the conditions of the zone with multiple spaces. Selecting the room or space that will best represent the thermal characteristics of the space due to both external and internal loads will provide the greatest comfort level.

To prevent misreading of the space temperature, zone thermostats should not be mounted on an exterior wall. Where this is unavoidable, use an insulated sub-base for the thermostat.

In spaces with high ceilings, consider using ceiling fans or high/low air distribution to reduce temperature stratification during the heating season. Six primary factors must be addressed when defining conditions for thermal comfort:

- Metabolic rate
- Clothing insulation
- Air temperature
- Radiant temperature
- Air speed
- Humidity

Appropriate levels of clothing, the cooling effect of air motion, and radiant cooling or heating systems, for example, can increase occupant comfort energy efficiently.

HV32 *Operable Windows* (Climate Zones: 2B 3 4 5 6 7 8)

Compared to buildings with fixed-position windows, buildings with properly applied and properly utilized operable windows can provide advantages in schools, including energy conservation and energy conservation education (see also EN22). Natural ventilation, natural cooling, and passive solar heating can have positive sustainability effects. Improper design and operation can have negative effects. Mechanical systems should be shut off when windows are opened. Operable window systems can be controlled manually or by interlock. Manual control provides the opportunity for energy-efficiency education in the classroom, but automatic controls (such as interlocks) are likely to save more energy.

A bottom window and a top window should be opened at the same time. This allows the stack effect to set up a convection current of airflow when the difference between the indoor and outdoor temperatures is 10°F or more.

Table 5.11 shows recommended setpoints for using operable windows. Using operable windows without proper sensor calibration can create moisture or comfort problems and may reduce energy savings.

Table 5.11. Operable Windows Recommended Set Points

Controller Type	Recommended Climate Zones	Cooling Setpoint	Heating Setpoint
Measuring Dry-Bulb Temperature Only	B and C zones	Window open when space temperature > outdoor temperature Window closed when space temperature < outdoor temperature	Window open when space temperature < outdoor temperature Window closed when space temperature > outdoor temperature
Measuring Temperature and Humidity	A zones	Window open when space temperature and humidity > outdoor temperature and humidity Window closed when space temperature and humidity < outdoor temperature and humidity	Window open when space temperature < outdoor temperature Window closed when space temperature > outdoor temperature

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SERVICE WATER HEATING (SWH)

Good Design Practice

WH1 Service Water Heating Types (Climate Zones: all)

This Guide assumes that the SWH equipment uses the same type of fuel source as is used for the HVAC system. This Guide does not cover systems that use oil, hot water, steam, or purchased steam for generating SWH, nor does it address the use of solar or site-recovered energy (including heat pump water heaters). These systems are alternative means that may be used to achieve 30% (or greater) energy savings over ASHRAE Standard 90.1-1999 and, where used, the basic principles of this Guide would apply.

The SWH equipment included in this Guide are the gas-fired water heater and the electric water heater. Natural gas and propane fuel sources are available options for gas-fired units.

Many factors come into play in making a decision whether to use gas or electricity, including availability of service, utility costs, operator familiarity, and the impact of source energy use. Efficiency recommendations for both types of equipment are provided to allow for choice.

WH2 System Descriptions (Climate Zones: all)

Gas-fired storage water heater. A water heater with a vertical or horizontal water storage tank. A thermostat controls the delivery of gas to the heater's burner. The heater requires a vent to exhaust the combustion products. An electronic ignition is recommended to avoid the energy losses from a standing pilot.

Gas-fired instantaneous water heater. A water heater with minimal water storage capacity. The heater requires a vent to exhaust the combustion products. An electronic ignition is recommended to avoid the energy losses from a standing pilot.

Electric resistance storage water heater. A water heater consisting of a vertical or horizontal storage tank with one or more immersion heating elements. Thermostats controlling heating elements may be of the immersion or surface-mounted type.

Electric resistance instantaneous water heater. A compact, under-cabinet, or wall-mounted type water heater with insulated enclosure and minimal water storage capacity. A thermostat controls the heating element, which may be of the immersion or surface-mounted type. Instantaneous, point-of-use water heaters should provide water at a constant temperature regardless of input water temperature.

WH3 Sizing (Climate Zones: all)

The water heating system should be sized to meet the anticipated peak hot-water load. Calculate the hot-water demand based on the sum of the building fixture units according to local code.

Local and state plumbing codes for water closets vary and range from 1 per 20–25 elementary female students to 1 per 30–45 secondary female students, and from 1 per 30 elementary male students to 1 per 40–90 secondary male students. Lavatories in the restrooms are generally in the ratio of 1 per 2 water closets installed in a general restroom. In many elementary schools, wet areas are provided in K-2 classrooms with hot water for hand washing. Some state codes and educational specifications may require sinks with hot water in laboratories, workshops, vocational classrooms, and art rooms.

Hot-water temperature requirements for restrooms and academic areas of a school vary by local and state code, within the range of 100°F–120°F. Hot water is also a requirement in the school kitchen, with a delivered temperature of 120°F–140°F. Use booster heaters on the dishwashers to bring the temperature to the 160°F–180°F required for sanitation.

In elementary schools, showers are normally specified in health/nurse rooms. In secondary schools, showers are normally specified for physical education locker rooms. In larger secondary schools, showers may be required for team sport areas. The temperature of the hot water provided to the showers should be 100°F–110°F.

In designing and evaluating the most energy-efficient hot-water system for a school and the associated life-cycle costs, consider installing tankless water heaters in most locations. Only areas where large volumes of hot water are required (such as the cafeteria, gymnasium, and culinary vocational classrooms) should large water heaters or smaller circulating hot-water systems be installed.

WH4 *Equipment Efficiency* (Climate Zones: all)

Efficiency levels are provided in the climate-specific tables in Chapter 3 for the four types of water heaters listed in WH2.

The gas-fired storage water heater efficiency levels correspond to condensing storage water heaters. High-efficiency, condensing gas storage water heaters (energy factor higher than 0.90 or thermal efficiency higher than 0.90) are alternatives to the use of gas-fired instantaneous water heaters.

For gas-fired instantaneous water heaters, the energy factor and thermal efficiency levels correspond to commonly available instantaneous water heaters.

Electric water heater efficiency should be calculated as 0.99 – 0.0012 × water heater volume (volume equals zero for instantaneous water heaters).

Instantaneous electric water heaters are an acceptable alternative to high-efficiency storage water heaters. Electric instantaneous water heaters are more efficient than electric storage water heaters, and point-of-use versions will minimize piping losses. However, their impact on peak electric demand can be significant and should be taken into account during design. Where unusually high hot-water loads (e.g., showers or laundry facilities) are present during peak electrical use periods, electric storage water heaters are recommended over electric instantaneous ones.

WH5 *Location* (Climate Zones: all)

The water heater should be close to the hot water fixtures to avoid the use of a hot-water return loop or of heat tracing on the hot water supply piping. Where electric resistance heaters are used, consider point-of-use water heaters with a low number of fixtures or where they can eliminate the need for a recirculating loop.

WH6 *Pipe Insulation* (Climate Zones: all)

All SWH piping should be installed in accordance with accepted industry standards. Insulation levels should be in accordance with the recommendation levels in the climate-specific tables in Chapter 3, and the insulation should be protected from damage. Include a vapor retardant on the outside of the insulation.

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ADDITIONAL SAVINGS

AS1 *Electrical Distribution System* (Climate Zones: all)

Energy-efficient distribution transformers should be provided in all construction/repair projects: new construction, renovation, or replacement. Minimum transformer specifications as of January 1, 2007, are classified by DOE as TP-1 and are the lowest efficiency available. Energy-efficient transformers that are 30% more efficient than the minimum TP-1 are classified by DOE as CSL-3.

The size of an educational building is a contributing factor in the determination of the electrical voltage service brought into the building. Electrical service from the utility in smaller schools is usually 120/208 three-phase voltage and in larger schools 277/480 three-phase voltage. When the 277/480 volt service is provided, 120/208 volt dry step down transformers are placed in key locations in the building to provide the power to the electrical outlets throughout. Electrical distribution systems in today's schools contribute to the energy inefficiency. The following good practices will help improve the energy efficiency of the electrical distribution system.

Electrical Service Voltage. School facilities smaller than 40,000 ft^2 should design the incoming electrical service from the utility for 120/208 V. Schools facilities larger than 40,000 ft^2 should have the incoming electrical service designed from the utility at 277/480 V. This design will require the placement of internal step down dry transformers 277/480 V to 120/208 V to provide the needed power for the plug load.

Energy-Efficient Transformers. DOE recognizes that current step-down transformers contribute to energy waste throughout the country. The CSL-3 standard has been established to improve the energy efficiency of distribution transformers. This standard recognizes the low loading, especially in schools, and the no-load losses with current transformer design. The standard CSL-3 design eliminates any impact for normal harmonics created by the loads in the school. Concentrating all larger computer loads on one transformer can be handled by a variation in the CSL-3 design and still keep the required efficiencies and no-load losses. The standard includes specifics on the no-load losses for specific sized transformers and specific percent efficiencies at given loadings. For example, a CSL-3 75 KVA 277/480 to 120/208 volt transformer maximum no load loss is 170 W/h versus the current industry average of more than 850 W/h. This same transformer will meet or exceed 98.4% efficiency at one-sixth loading. The efficiency of the standard transformers currently specified at one-sixth loading is 80% to 85%. This is an unregulated load at this time.

Specification of Energy-Efficient Transformers. Energy-efficient transformers should be specified using DOE's CSL-3 Standard as the basis. Specifications must include maximum no-load losses for specified transformers sizes and percent efficiency at 16.7% loading. A statement should be included in the specifications that requires the bid submission to include test data for the transformers being provided.

Electrical distribution equipment is usually provided by one supplier. This means the cost of the transformer is "buried" in the electrical distribution equipment price. The following statement should be included in the bid specifications: "The bid price for the dry distribution transformers specified (277/480 to 120/208 V) must be identified (priced) separately within the electrical bid and cannot be included in the bid pricing for other electrical distribution equipment that falls under Section 16 of the Standard AIA Specification Structure. If specified transformers are not separately identified in the bid pricing then the entire bid will be disqualified."

AS2 Plug and Phantom Loads (Climate Zones: all)

Plug Loads. Plug loads are devices or appliances that plug into a school's electrical system. A school typically has a 120/208 V electrical system and includes many loads. A load is anything that draws power from the system and requires electricity to work. Plug loads found in schools include computers, DVD players, VCRs, overhead and LCD projectors, boom boxes, CD players, printers, scanners, copiers, fax machines, radios, microwaves, coffee pots, popcorn poppers, fish tanks, desktop lights, stoves, refrigerators of all sizes, vending machines, smart boards, vocational equipment and tools, soda machines, drinking fountains, and many other devices for educational purposes and for the comfort of the students, faculty, and staff.

Technology Case Study: Twenhofel Middle School Independence, KY

Twenhofel Middle School in Kentucky installed both energy-efficient transformers (CSL-3) and typical specified transformers (CSL-1). Each of the three grade wings of the school had distribution transformers, the 6th grade wing had the energy-efficient transformer, and the other two wings had typical transformers. The following were the results:

1. The electric use in the 6th grade wing was continuous lower than the other wings
2. Testing of the transformers revealed that the loading for these transformers during the day were very low—between 2 and 3%.
3. The efficiency of the transformers at this loading was 79.5% for the typical transformer and 91.5% for the energy-efficient transformer. This meant an improvement in efficiency of more than 15% in addition to the no load loss improvement between 500–700 W/h.

The following illustrates the potential energy savings when specifying and installing energy efficient transformers, at current use of distribution transformers in schools and average electrical energy cost across the nation.

- Typical 73,000 ft^2 elementary school—$9000/year and more than $400,000 over a 50-year building life
- Typical middle school—$13,000/year and more than $600,000 over a 50-year building life
- Typical high school—$20,000/year or more than $1 million over a 50-year building life

Note: The 50-year life figures do not include any rate increase during the period.

Technology Case Study: North Thurston Public Schools Lacey, WA

Energy Star Power Management features—standard in Windows and Macintosh operating systems—place inactive monitors and computers (CPU, hard drive, etc.) into a low-power sleep mode. A simple touch of the mouse or keyboard “wakes” the computer and monitor in seconds.

Monitor power management (MPM) can save $10–30 per monitor annually by placing your inactive monitors into a low-power sleep mode.

Computer power management (CPM) places inactive computers (CPU, hard drive, etc.) into a low-power sleep mode, which can save $15–45 per desktop computer annually.

http://www.energystar.gov/index.cfm?c=power_mgt.pr_power_management

Read about how North Thurston Public Schools is saving $45,000 annually by activating computer and monitor sleep settings: http://www.energystar.gov/ia/products/power_mgt/North_Thurston_Case_Study.pdf.

Phantom Loads. A VCR that has been flashing "12:00 a.m." since it was installed in a classroom is a prime example of an electronic device in that consumes energy when the switch indicates it is off. This use of electrical energy is classified as a phantom load. Phantom loads are also known as standby power or leaking electricity. Phantom loads usually coincide with any electronic or electrical device or appliance. Equipment with electronic clocks or timers or remote controls, portable equipment and office equipment, with wall cubes (a small box that plugs into an AC outlet to charge cell phones or provide power to computers) all have phantom loads. Phantom loads can consume up to 5% of an electrical plug load.

Control on Plug Loads. Plug loads contribute up to 25% of the electrical load in a school. This estimation comes from plug load surveys conducted in schools over the past several years. Plug loads density can be 0.6–1.0 W/ft^2. A large contributor to this load is equipment and appliances left on after use, and equipment that has a phantom load when not in use. To reduce this load potential, consider controlling the top outlet of each duplex outlet with the occupancy sensor used to control the lighting in the room. The inclusion of this feature in future designs would reduce the plug load density from the current 0.6–1.0 to 0.4–0.6 W/ft^2. For a 100,000 ft^2 school, this would mean a reduction of 20–40 kW/h. Creating a personal appliance policy in the school district and conducting constant energy awareness training on equipment and appliance use should be undertaken.

Control of Phantom Loads. The best direct way to control phantom loads is to unplug items such as TVs, VCRs, and other similar items when not in use. In lieu of directly unplugging the item, all these items can be plugged into a power strip that is switched off at the end of each day, over the weekend, and during holidays and vacations.

ENERGY STAR Appliances/Equipment. A school board policy should be established that requires all electrical equipment and appliances placed in a school to have the ENERGY STAR Label (where there is an ENERGY STAR rating for the equipment or appliance). See Appendix D for a list of items with ENERGY STAR ratings.

The recommendations presented in Table 5.12 for the purchase and operation of plug load equipment are an integral part of this Guide, but the energy savings from these recommendations will be in addition to the targeted 30% savings.

Table 5.12. Recommendations for Efficient Plug Load Equipment

Equipment/Appliance Type	Purchase Recommendation	Operating Recommendation
Desktop Computer	ENERGY STAR only	Implement sleep mode software
TV/VCR	Purchase flat screens with sleep modes	Many of these items are only used during peak times and should be unplugged with occupancy sensors
Laptop Computer (use where practical instead of desktops to minimize energy use)	ENERGY STAR only	Implement sleep mode software
Computer Monitors	Energy Star flat screen monitors only	Implement sleep mode software
Printer	ENERGY STAR only	Implement sleep mode software
Copy Machine	ENERGY STAR only	Implement sleep mode software
Fax Machine	ENERGY STAR only	Implement sleep mode software
Water Cooler	ENERGY STAR only	N/A
Refrigerator	ENERGY STAR only	N/A
Vending Machines	ENERGY STAR only	Delamp display lighting
TV/VCR	ENERGY STAR only	

AS3 *Ground-Source Heat Pumps* (Climate Zones: all)

A variation of the WSHP system (see HV2), the GSHP takes advantage of the Earth's relatively constant temperature and uses the ground instead of a cooling tower and boiler. GSHP systems do not actually get rid of heat, but store it in the ground for use at a later time. During the summer, the heat pumps extract heat from the building and transfer it to the ground. When the building requires heating, this stored heat can be recaptured from the ground. In a perfectly balanced system, the amount of heat stored over a given period of time would equal the amount of heat retrieved.

GSHP systems offer the potential for saving energy because they can reduce or eliminate the energy needed to operate a cooling tower or boiler. Eliminating the cooling tower also has architectural and maintenance advantages, and eliminating the boiler frees up floor space in the building.

Although eliminating both the cooling tower and boiler will likely result in the greatest overall energy savings, for most applications this requires the largest (and more expensive) geothermal heat exchanger to account for the imbalance between heat stored and heat extracted.

For example, in a cooling-dominated climate, a large amount of heat must be rejected to the ground during the cooling season, but a much smaller amount of heat is extracted from the ground during the heating season. This imbalance can cause the temperature of the ground surrounding the geothermal heat exchanger to increase over time.

Conversely, in a heating-dominated climate, a relatively small amount of heat is rejected to the ground during the cooling season, but a much larger amount of heat must be extracted from of the ground during the heating season. In this case, the ground temperature can decrease over time. In either case, future operation of the heat pump is compromised by this change.

In many areas of the country, this imbalance requires the geothermal heat exchanger to be larger to prevent the ground temperature from changing over time. The first cost to install such a large heat exchanger often dissuades people from considering this approach. Using a hybrid approach, however, can often make GSHP systems more economical, opening up the possibility to reap the potential energy savings.

This hybrid approach involves adding a small cooling tower to the loop for a system that is installed in a cooling-dominated climate, or adding a small boiler to a system in a heating-dominated climate. In either case, the geothermal heat exchanger is sized based on the smaller of the two loads: for the total heat absorbed in a cooling-dominated climate or the total heat rejected in a heating-dominated climate. Then, a small cooling tower (or boiler) is added to reject (or add) the remaining heat.

This approach reduces the required size of the geothermal heat exchanger by avoiding the imbalance. The overall energy savings may not be as great as in a system with a larger heat exchanger, but this approach often results in a more acceptable return on investment.

AS4 *Peak Demand Reduction (Thermal Storage, Thermal Mass)* (Climate Zones: all)

Adding thermal storage to an HVAC system can reduce the utility costs associated with cooling by shifting operation of the chiller from times of high-cost electricity (daytime) to times of low-cost electricity (nighttime). This avoids, or reduces, the electricity required to operate the chiller during the daytime hours. Operation of the chiller is shifted to the off-peak period, during which the cost of electricity and the demand charge are lower. The chiller is used during that period to cool or freeze water inside storage tanks, storing the thermal energy until the on-peak period.

During the nighttime hours, the outdoor dry-bulb and wet-bulb temperatures are typically several degrees lower than during the day. This lowers the condensing pressure,

Technology Case Study:
The Dalles Middle School
The Dalles, OR

Figure S7.1. Water source heat pump.

The Dalles Middle School is located in a rural area along the Columbia River on the eastern slopes of the Cascades. The school had a subsurface geological problem that needed to be addressed. A landslide area adjacent to the school site was being dewatered through wells at a flow rate of about 130 gal/min. As part of the $12.5 million project to construct a new 96,500 ft^2 school, a geothermal system was installed based on this subsurface problem. Storage tanks and pipes were installed so that the water previously pumped directly to the Columbia River was now piped through GSHPs to provide either cooling or heating before being pumped to the river.

Photo and data provided by BOORA Architects, Oregon Energy Office, and Larry Schoff.

allowing the chiller to regain some of the capacity and efficiency it lost by producing colder fluid temperatures to recharge the storage tanks.

Another potential benefit of thermal storage is a reduction in the size and capacity of the chiller. When thermal storage is used to satisfy all or part of the design cooling load, the chiller may be able to be downsized as long as it has enough time to recharge the storage tanks.

An additional approach to reducing peak cooling demand is to take advantage of the building's thermal mass. Many school buildings are constructed of concrete or masonry walls. The thermal mass of these materials can absorb excess solar heat and stabilize indoor temperatures.

The principle is to precool the building during the nighttime (or morning off-peak) hours with cool OA. This cools the building's thermal mass and reduces the cooling load during on-peak hours.

In many climates, masonry walls are more efficient when insulation is located on the outside. This allows the wall to absorb excess heat from inside the building, and the insulation minimizes heat transfer to the outdoors. However, this is not common practice for most builders, and insulated masonry increases the width of a wall, making it difficult to finish at the edges of windows, roofs, and doors. Fortunately, new technologies have lowered the cost and increased options for insulated masonry.

AS5 Thermal Displacement Ventilation (Climate Zones: all)

Thermal displacement ventilation (TDV) systems are different from conventional overhead air delivery systems. TDV systems deliver air near the floor, at a low velocity, and at a temperature of about 65°F (compared to around 55°F with overhead air delivery). The goal of TDV systems is to cool the occupants, not the space. 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.

Air quality improves because contaminants from occupants and other sources tend to rise out of the breathing zone rather than being mixed in the space. Similarly, cooling loads decrease 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. (This is especially true in classrooms designed for 100% OA.)

TDV is most appropriate for spaces with ceilings higher than 10 ft to permit temperature stratification. However, heating performance may be worse than with systems that deliver air at greater velocities, since mixing (not stratification) is desirable for heating. In non-arid climates, the supply air must be sufficiently dehumidified before it is reheated, or mixed with warm return air, to achieve the desired 65°F supply-air temperature.

AS6 Photovoltaic Systems

PV systems have become an increasingly popular option for energy production and for a teaching opportunity in schools. Currently, most PV systems in schools are relatively small compared to the total energy use of the school; this is due mainly to the initial cost of the PV system. Most PV systems in K-12 schools range from 1–50 kW.

One school using a larger system is Williamstown Elementary School in Williamstown, Massachusetts. Williamstown Elementary has a 24 kW roof-mounted PV system. It is estimated to produce roughly 30,000 kWh of electricity per year, which equates to 5%–10% of the school's annual energy use.

The actual energy production can be monitored at the Web site for the Massachusetts Technology Collaborative Renewable Energy Trust by viewing the trust funded projects and accessing the Williamstown Elementary project: http://www.mtpc.org/renewableenergy/index.html.

The Head-Royce School in Oakland, California, also uses a large PV system to generate significant energy savings. The school installed a 53 kW PV system on the roof of the gymnasium that provides a 25% savings in the electricity bill for the school and gymnasium.

The smaller PV systems are typically used mostly as teaching devices. They are usually installed in plain view to make them visible to the students, teachers, and the surrounding community. It is an attempt to inform the public of the importance of renewable energy sources and the technology involved.

Fossil Ridge High School in Fort Collins, Colorado, uses a smaller PV system. The 5.2 kW PV system is mounted outside the south entrance of the school on frames in front of the windows. The PV panels act as overhangs for the windows. Another school that uses a small PV system is Zeeland West High School in Zeeland, Michigan. This 1 kW

Technology Case Study: Elmira High School Elmira Oregon

Elmira High School in Elmira, Oregon, is a good example of how a school uses PV in its curriculum with a 0.6-kW PV system. Elmira is one of 15 schools in Oregon that is participating in a pilot PV program started by the Bonneville Power Administration (BPA) and Western SUN. The University of Oregon has put together a series of lesson plans for the schools that are participating in the program. These lesson plans are available in the educational resources on the University of Oregon Web site (http://solardata.uoregon.edu/).

- Lesson I—Solar cells introduces the students to the basic physics and chemistry that occur in a solar cell.
- Lesson II—Solar electric arrays shows the components of a solar electric system and the concept of a PV IV curve.
- Lesson III—Photovoltaics in arrays; solar cells generating electricity teaches the students about some of the variables that influence the effectiveness of the PV arrays in generating electricity.

Elmira can gather real-time information on the PV arrays at BPA's Energy Efficiency (EE) Web site (http://www.bpa.gov/Energy/N/), as one of the 15 solar schools with EE metering data in the Technologies section of the site.

system is mounted on poles on the ground, which aids in using the PV system as a teaching device.

There are many unique funding opportunities for PV systems in schools. In addition to the many rebate programs offered by state and local utility companies, there are often significant incentives, loans, grants, and buy-back programs for PV systems for K-12 schools. The following link shows some incentives and rebates that are available to schools in most states: http://www.dsireusa.org/Index.cfm?EE=0&RE=1. Some state and local utility companies offer rebates that range from \$2.00–\$6.00/W for school PV systems.

Technology Case Study: Twenhofel Middle School Independence, KY

Twenhofel Middle School in Independence, Kentucky, uses the green building techniques as a teaching aide. The students can monitor most of the systems that are used in the school through the online monitoring program available on the Internet (http://www.twhvac.kenton.kyschools.us/). The Web site allows the students to monitor the electrical energy, PV system, daylighting system, geothermal heating/cooling system, and the rainwater harvesting system. The program makes students aware of their daily energy use and is an opportunity for a hands-on learning experience with renewable energy. In the science classes, the students use the monitoring program to track the effects on daylighting from the sun, which teaches the students the patterns of the sun and earth throughout the course of a year.

The school encourages the students to conserve energy with a monthly contest between the 6th–8th grade students to see which grade can conserve the most energy over the course of a month. The students track their progress in the monthly contest every morning via a television mounted in the lobby.

Figure S9.1. Clerestory windows and 24 kW PV system.

AS7 *Solar Hot-Water Systems*

Because of the high hot-water demands associated with cafeterias, solar hot-water systems are often viewed as important strategies in reducing energy bills. It can be even more cost-effective in middle schools and high schools, which have additional significant load for gym class showers and sports programs. Several types of systems could be used for additional savings. Two of the more common are drainback and closed-loop systems.

Use *drainback solar hot-water systems* in small applications where the piping can be sloped back toward a collection tank. By draining the collection loop, freeze protection can be accomplished when the pump shuts down, either intentionally or non-intentionally.

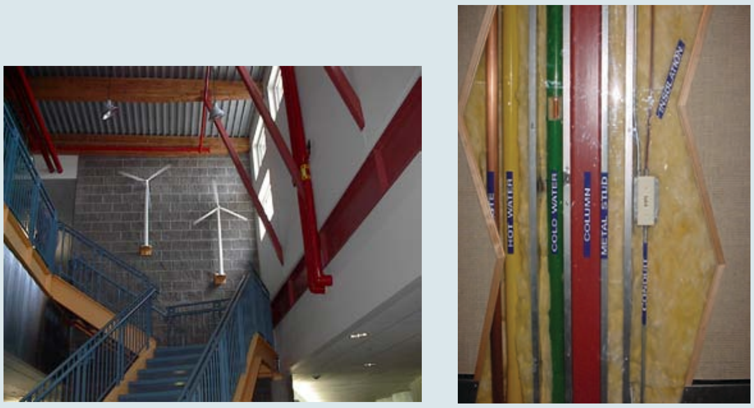
Select a *closed-loop*, *freeze-resistant solar system* if piping layouts make drainback options impractical. In closed-loop systems, a small pump circulates antifreeze protected fluids through the collection loop when there is adequate solar radiation and the differential between the collector fluid temperature and when the tank temperature justifies continuation of the collection mode.

AS8 *Energy-Efficient Schools as Teaching Tools*

Schools that incorporate energy efficiency and renewable energy technologies make a strong statement about the importance of protecting the environment. They also provide

Technology Case Study: Zach Elementary School Fort Collins, CO

Zach Elementary School in Fort Collins, Colorado, has left building systems and some piping exposed to teach students about the energy efficiency features in the school. All the electricity used in the school is purchased from wind power. Miniature wind turbines are mounted to the walls inside the school. The turbines are used to increase the awareness of the growing wind energy presence in Fort Collins. The school has also placed cutouts in some of the walls to allow the students to see inside and to learn about the construction techniques used to make the building energy efficient.



(a) (b)

Figure S10.1. (a) Example wind turbines and (b) exposed piping and insulation.

hands-on opportunities for students and visitors to learn about these technologies and the importance of energy conservation. The efforts to make a school building energy efficient are no longer being hidden within the walls and inside mechanical rooms. They are being used as teaching aids in the schools, allowing teachers to introduce curriculum that focuses on energy usage and environmental issues.

PV systems are a common area of interest for energy-efficient teaching tools. The PV systems allow real-time information that can be added to the school's curriculum.

Many schools that have installed PV systems have instituted programs for the students that allow them to monitor the real-time system performance. The monitoring programs are typically available through kiosks in the school or via the Internet. Examples of these monitoring systems are available at the following Web sites.

- The Massachusetts Technology Collaborative Renewable Energy Trust (http://www.mtpc.org/renewableenergy/index.html)
- The Missouri Department of Natural Recourses, Missouri Schools Going Solar (http://www.sunviewer.net/portals/MSGS/)
- The Energy Whiz program (http://www.energywhiz.com/index.htm)
- Individual schools including the following:
    - North Charleston Elementary School (http://northcharleston.greentouchscreen.com/)
    - Desert Edge High School (http://desertedge.greentouchscreen.com/)
    - Turner Falls High School (http://66.189.87.227/tfhs01/tfhsweb/home.html)
    - The Match School (http://www.matchschool.org/solar/home.html)
    - Williamstown Elementary School (http://buildingdashboard.com/clients/wtown/)

Energy-efficient teaching aids include more than just PV systems. Some schools have left HVAC equipment and plumbing exposed to allow the students to see and learn from the systems.

Resources for educational and training information on energy, energy efficiency, and renewable energy are available from the Department of Energy (DOE) on their Energy Education Web site (http://www1.eere.energy.gov/education/). The "Get Smart About Energy" page (http://www.eere.energy.gov/education/lessonplans/) offers more than 350 lesson plans and activities for grades K-12.

Appendix A
Envelope Thermal Performance Factors

Each climate zone recommendation table presents a prescriptive construction option for each opaque envelope measure. Table A.1 presents U-factors for above-grade components, C-factors for below-grade walls, and F-factors for slab-on-grade floors that correspond to each prescriptive construction option. Alternate constructions would be an equivalent method for meeting the recommendations of this guide provided they are equal to or better than the thermal performance factors listed in Table A1.

Table A1. Envelope Thermal Performance Factors

Opaque Construction Options

Roof Assemblies

Insulation Entirely Above Deck	
R	U
25	0.039
Metal Building	
R	U
19	0.065
13+13	0.055
13+19	0.049
19+19	0.046
Attic and Other	
R	U
30	0.032
38	0.027
60	0.017

Walls, Above Grade

Mass Walls	
R	U
5.7 c.i.	0.151
7.6 c.i.	0.123
9.5 c.i.	0.104
11.4 c.i.	0.090
13.3 c.i.	0.080
15.2 c.i.	0.071
Metal Building	
R	U
16	0.093
19	0.084
19+5.6 c.i.	0.057
19+11.2 c.i.	0.043
Steel Framed	
R	U
13	0.124
13+3.8 c.i.	0.084
13+7.5 c.i.	0.064
13+21.6 c.i.	0.034
Wood Framed and Other	
R	U
13	0.089
13+3.8 c.i.	0.064
13+7.5 c.i.	0.051
13+10 c.i.	0.045

Walls, Below Grade

Below Grade Walls	
R	C
7.5 c.i.	0.119
15 c.i.	0.063

Floors

Mass	
R	U
4.2 c.i.	0.137
6.3 c.i.	0.107
8.3 c.i.	0.087
10.4 c.i.	0.074
12.5 c.i.	0.064
16.7 c.i.	0.051
Steel Framed	
R	U
19	0.052
30	0.038
38	0.032
Wood Framed and Other	
R	U
19	0.051
30	0.033

Slabs

Unheated	
R-in	F
10-24	0.54
15-24	0.52
20-24	0.51
Heated	
R-in.	F
7.5-12	1.02
7.5-24	0.95
10-24	0.90
15-24	0.86
15-Full	0.44

Appendix B
Commissioning

A building can have the best possible design for achieving energy savings, but unless the building is built as designed and is operated according to the design intent, energy savings will not be achieved. A CxA ensures the energy- and water-saving methods and devices selected by the design team are incorporated in the building plans and specifications, that everything is built and tested accordingly, and that school personnel, including those occupying the building, are provided the necessary documentation and training to properly operate the building after it is occupied. The CxA can be an independent member of the design firm, the school's facility staff, or a third-party consultant. Some prefer to use third-party consultants for this role to ensure that the work is done independently of the design team to ensure that the results are not biased.

The Cx process is applicable to all buildings, but large and complex buildings require a correspondingly greater level of effort than is required for small, simple buildings. See Table B1 for more information.

Table B1. Commissioning Activities and Related Responsibilities

Item	Activity	Responsibility
1.	Create Owner's Project Requirements (OPRs)	CxA/owner
2.	Create project specific Cx plan (use this model, modify where necessary)	Owner/CxA
3.	Create the Basis of Design	Architect/engineer
4.	Review OPRs and Basis of Design	CxA
5.	Review schematic and design development documents, including load calculations	CxA
6.	Review construction documents before completion	CxA
7.	Incorporate Cx requirements into construction documents	Designers
8.	Review submittals for commissioned systems	Designer; CxA
9.	Develop project-specific construction checklists	CxA
10.	Implement construction checklists	Contractors
11.	Create and maintain Cx issues log	CxA
12.	Perform targeted inspections during rough-in phase	CxA/AE/O&M
13.	Witness pipe flushing and testing, duct testing	CxA
14.	Field-verify contractors' completed construction checklists	CxA/O&M
15.	Performance testing and demonstrations	Contractors
16.	Validate test and balance report	CxA
17.	Conduct periodic Cx meetings	CxA
18.	Develop functional performance test procedures	CxA
19.	Assist in contractor troubleshooting	CxA
20.	Identify air quality issues	CxA
21.	Direct and witness functional performance testing	CxA/O&M
22.	Issue final Cx report	CxA
23.	Develop systems manuals from O&M manuals including re-commissioning procedures	CxA
24.	Project manager coordinate and document owner training performed by contractors	Project manager
25.	Confirm training performed by contractors is per contract and adequate	CxA/O&M
26.	Recommend final system acceptance	CxA/O&M
27.	Perform post-occupancy review two months after occupancy	CxA/project manager/ facilities personnel/O&M
28.	Perform post-occupancy review and warranty inspections 10 months after occupancy per contract documents	CxA/project manager/ facilities personnel/ O&M/architect
29.	Create lesson-learned document for distribution to all project managers/planners	CxA

Note: Designer is an inclusive term that indicates project architect and engineers and other design consultants, such lighting, acoustics, landscape architects.

Appendix C
Climate Zones for Mexico and Canada

The following tables show the climate zone numbers for a wide variety of Mexican and Canadian locations. Additional information on international climatic zones can be found in ASHRAE Standard 90.1-2004, Normative Appendix B, "Building Envelope Climate Criteria." The information is from Tables B-2 and B-3 in that appendix.

Table C1. Mexican Climate Zones

Country		Country	
City	Zone	City	Zone
Mexico		**Mexico**	
Mexico City (Distrito Federal)	3	Tampico (Tamaulipas)	2
Guadalajara (Jalisco)	1	Veracruz (Veracruz)	4
Monterrey (Nuevo Laredo)	3	Merida (Yucatan)	1

Table C2. Canadian Climatic Zones

Province	
City	Zone

Alberta (AB)	
Calgary International Airport (A)	7
Edmonton International A	7
Grande Prairie A	7
Jasper	7
Lethbridge A	6
Medicine Hat A	6
Red Deer A	7

British Columbia (BC)	
Dawson Creek A	7
Ft Nelson A	8
Kamloops	5
Nanaimo A	5
New Westminster BC Pen	5
Penticton A	5
Prince George	7
Prince Rupert A	6
Vancouver International A	5
Victoria Gonzales Hts	5

Manitoba (MB)	
Brandon CDA	7
Churchill A	9
Dauphin A	7
Flin Flon	7
Portage La Prairie A	7
The Pas A	7
Winnipeg International A	7

New Brunswick (NB)	
Chatham A	7
Fredericton A	6
Moncton A	6
Saint John A	6

Newfoundland (NF)	
Corner Brook	6
Gander International A	7
Goose A	7
St John's A	6
Stephenville A	6

Northwest Territories (NW)	
Ft Smith A	8
Inuvik A	8
Yellowknife A	8

Nova Scotia (NS)	
Halifax International A	6
Kentville CDA	6
Sydney A	6
Truro	6
Yarmouth A	6

Nunavut	
Resolute A	8

Ontario (ON)	
Belleville	6
Cornwall	6
Hamilton RBG	5
Kapuskasing A	7
Kenora A	7
Kingston A	6
London A	6
North Bay A	7
Oshawa WPCP	6
Ottawa International A	6
Owen Sound MOE	6
Petersborough	6
St Catharines	5
Sudbury A	7
Thunder Bay A	7
Timmins A	7
Toronto Downsview A	6
Windsor A	5

Prince Edward (PE)	
Charlottetown A	6
Summerside A	6

Quebec (PQ)	
Bagotville A	7
Drummondville	6
Granby	6
Montreal Dorval Int'l A	6
Quebec A	7
Rimouski	7
Septles A	7
Shawinigan	7
Sherbrooke A	7
St Jean de Cherbourg	7
St Jerome	7
Thetford Mines	7
Trois Rivieres	7
Val d'Or A	7
Valleyfield	6

Saskatchewan (SK)	
Estevan A	7
Moose Jaw A	7
North Battleford A	7
Prince Albert A	7
Regina A	7
Saskatoon A	7
Swift Current A	7
Yorkton A	7

Yukon Territory (YT)	
Whitehorse A	8

Appendix D
ENERGY STAR® Appliances

The following equipment and appliances that are typically used in K-12 schools and are within the scope of the applicable ENERGY STAR program will have the ENERGY STAR label. For more information, visit the ENERGY STAR Web site at www.energystar.gov.

1. Appliances
   - battery chargers
   - clothes washers
   - dehumidifiers
   - dishwashers
   - refrigerators and freezers
   - room air conditioners
   - room air cleaners
   - water coolers

2. Heating and Cooling
   - air-source heat pumps (see also the energy-efficiency requirements in Chapter 3)
   - boilers (see also the energy-efficiency requirements in Chapter 3)
   - central air conditioners (see also the energy-efficiency requirements in Chapter 3)
   - ceiling fans
   - dehumidifiers
   - furnaces (see also the energy-efficiency requirements in Chapter 3)
   - geothermal heat pumps (see also the energy-efficiency requirements in Chapter 3)
   - programmable thermostats
   - room air conditioners
   - ventilating fans

3. Electronics
   - cordless phones
   - combination units (TV/VCR/DVD)
   - DVD products
   - audio

- televisions
- VCRs

4. Office Equipment
    - computers
    - copiers
    - fax machines
    - laptops
    - mailing machines
    - monitors
    - multifunction devices
    - printers
    - scanners

5. Lighting
    - CFLs
    - ceiling fans

6. Commercial Food Service
    - commercial fryers
    - commercial hot food holding cabinets
    - commercial solid door refrigerators and freezers
    - commercial steam cookers

7. Other Products
    - traffic signals
    - transformers
    - vending machines

Appendix E
Additional Resources

ORGANIZATIONS—GENERAL

American Institute of Architects (AIA)

1735 New York Ave., NW
Washington, DC 20006-5292
800-AIA-3837 or 1-202-626-7300
http://www.aia.org/

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

1791 Tullie Circle, NE
Atlanta, GA 30329
800-527-4723 or 1-404-636-8400
http://www.ashrae.org/
ASHRAE Standing Standards Project Committee 90.1 (SSPC 90.1)
ASHRAE Technical Committee on Educational Facilities (TC 9.7)

Illuminating Engineering Society of North America (IESNA)

120 Wall Street, Floor 17
New York, NY 10005
1-212-248-5000
http://www.iesna.org/

U.S. Department of Energy (DOE)

1000 Independence Ave., SW
Washington, DC 20585
800-dial-DOE (1-800-342-5363) or 1-202-586-5000
http://www.energy.gov/

U.S. Green Building Council (USGBC)

1800 Massachusetts Ave., NW, Suite 300
Washington, DC 20036
800-795-1747 or 202-742-3792
http://www.usgbc.org/

ORGANIZATIONS—HIGH PERFORMANCE SCHOOLS

Collaborative for High Performance Schools (CHPS)

142 Minna Street, Second Floor
San Francisco, CA 94105
887-642-CHPS
http://www.chps.net/

National Clearinghouse for Educational Facilities (NCEF)

1090 Vermont Ave., NW, Suite 700
Washington, DC 20005-4905
888-552-0624 or 202-289-7800
http://www.edfacilities.org/

National Institute of Building Sciences (NIBS)

1090 Vermont Ave., NW, Suite 700
Washington, DC 20005-4905
202-289-7800
http://www.nibs.org/

Sustainable Building Industry Council (SBIC)

1112 16th Street, NW, Suite 240
Washington, DC 20036
202-628-7400
http://www.sbicouncil.org/

COMMISSIONING

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ASHRAE. 2007. *ASHRAE Handbook—HVAC Applications*. Chapter 38, "Operation and Maintenance Management." Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

CHPS. 2004. Best Practices Manual, Volume IV—Maintenance and Operation (M&O). Collaborative for High Performance Schools, San Francisco (www.chps.net).

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Advanced Energy Design Guide for K-12 School Buildings

This Guide was prepared under ASHRAE Special Project 111.

The ASHRAE *Advanced Energy Design Guide for K-12 School Buildings* is the third in a series designed to provide recommendations for achieving 30% energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999. The energy savings target of 30% is the first step in the process toward achieving a net zero energy building, which is defined as a building that, on an annual basis, draws from outside resources equal or less energy than it provides using on-site renewable energy sources. ANSI/ASHRAE/IESNA Standard 90.1-1999, the energy-conservation standard published at the turn of the millennium, provides the fixed reference point for all of the Guides in this series. The primary reason for this choice as a reference point is to maintain a consistent baseline and scale for all of the 30% AEDG series documents.

This Guide focuses on elementary, middle, and high school buildings. These buildings have a wide variety of heating and air-conditioning equipment, which is reflected in the recommendations contained in this Guide. There is also extensive information about lighting systems, including daylighting—an important energy-saving measure.

The *Advanced Energy Design Guide for K-12 School Buildings* will help school boards, school administrators, design professionals, and contractors build, operate, and maintain more energy-efficient schools.

The recommendations in this Guide will allow those involved in designing or constructing school buildings to easily achieve advanced levels of energy savings without having to resort to detailed calculations or analyses. All of the energy-saving recommendations for each of the eight U.S. climate zones are summarized in a single table, thus facilitating the Guide's use. Additional recommendations point to other opportunities to incorporate greater savings into the design of the building.

Those looking for help in implementing the recommendations of this Guide will find an expanded section of tips and approaches in the "How to Implement Recommendations" chapter of the Guide. To further facilitate its use, the Guide cross-references the how-to information with the numbered tips and the color-coded climate zone maps inside. Examples of advanced K-12 school building energy designs are also provided in numerous case studies to illustrate the recommendations and to demonstrate the flexibility offered in achieving the advanced energy savings levels provided within the Guide.

For more information on the entire Advanced Energy Design Guide series, please visit www.ashrae.org/aedg.

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