
Building Enclosure and Insulation

OVERVIEW

The design of the school building enclosure, or envelope, entails many considerations. The materials—both indoors and out—must be durable, resistant to vandalism, easy to clean, and inexpensive. They must be strong enough to meet seismic codes, yet appear inviting. Add energy efficiency and sustainability to this list and the job of the design team is even more complex.

This chapter provides technical guidelines for the school building enclosure, including:

- Guideline IN1: Wall Insulation
- Guideline IN2: Roof Insulation
- Guideline IN3: Cool Roofs
- Guideline IN4: Radiant Barriers
- Guideline IN5: Reduce Infiltration
- Guideline IN6: Slab on Grade Insulation
- Guideline IN7: Fenestration Performance
- Guideline IN8: Moisture Control
- Guideline IN9: Acoustic Design

The construction of the building enclosure, especially its color, levels of insulation, and thermal mass, has a significant effect on energy efficiency and occupant comfort. The building enclosure also affects acoustic comfort since it can attenuate site and traffic noise. The selection of materials for the

construction of the building enclosure affects school resource efficiency, including transport energy, the volume, and type of raw materials that must be extracted from the earth, and the energy required for manufacturing and packaging. Building shell construction also affects thermal comfort. Even when heating and cooling systems are large enough to make up for poorly insulated components, the building's surface temperature may be cold or hot (depending on season), and this affects the radiant temperature of the space.

Heat Transfer through the Building Enclosure

Heat transfer through envelope components is quite complex and dynamic. The direction and magnitude of heat flow is affected by solar gains from the sun, outdoor temperature, and indoor temperature. Building envelope components have three important characteristics that affect their performance: their U-factor or thermal resistance (R-value); their thermal mass or ability to store heat, measured as heat capacity (HC); and their exterior surface condition/finish (for example, are they light in color to reflect the sun or dark to absorb solar heat?). These concepts are explained in greater detail below. Also discussed below is the use of radiant barriers and cool roofs to reduce heat transfer in certain situations.

U-factor

The U-factor is the rate of steady-state heat flow. It is the amount of heat in British thermal units (Btu) that flows each hour through 1 ft² of surface area when there is a 1°F temperature difference between the inside and outside air. Heat flow can be in either direction, as heat will flow from the warmer side to the cooler side. Insulation and most other building materials affect heat flow equally in both directions; some construction elements such as radiant barriers may reduce heat flow entering the building but have little impact on heat leaving the building.

Steady-state heat flow assumes that temperatures on both sides of the building envelope element (while different) are held constant for a sufficient period so that heat leaving one side of the assembly is equal to heat entering the opposite side. The concept of steady-state heat flow is a simplification because, in the real world, temperatures change constantly. However, U-factor can predict average heat flow rates over time and is commonly used to explain the thermal performance of construction assemblies.

Because they are easy to understand and use, the terms for steady-state heat flow (R-values and U-factors) are part of the basic vocabulary of building energy performance.

With metal framing, thermal bridges have a significant impact on the performance of the overall assembly, sometimes reducing the insulation effectiveness to less than half. The U-factor accounts for thermal bridges and the conductance of every element of the construction assembly, including the air film conductance on the interior and exterior surfaces. The air film conductance quantifies the rate at which heat is transferred between the surface of the construction assembly and the surrounding environment. This conductance depends on the orientation and roughness of the surface and the wind speed across the surface.

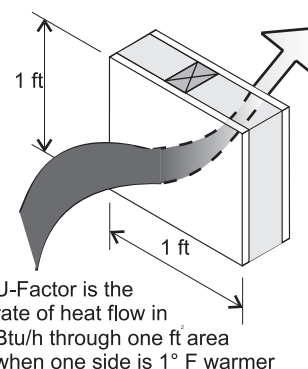


Figure 103—Concept of U-Factor

For light frame walls, U-factors provide an adequate description of heat transfer. For heavy concrete and masonry walls, however, this is only true under constant temperature conditions. The dynamic heat storage properties of concrete and masonry alter the thermal behavior of the wall, and the U-factor becomes less accurate as a predictor of heat flow (see discussion of HC below).

Heat transfer through slab-on-grade floors is a complex process. Most of the heat loss occurs at the slab perimeter. The “F factor” is a term analogous to U-factor that represents the rate of heat transfer from the perimeter of the slab to outdoors, except that F-factor is the rate of heat loss per linear foot rather than per square foot as with U-factor. The heat loss through the slab is proportional to the slab perimeter. Since the heat loss through slab-on-grade is a complex process, published values for F-factors should be used.

R-values

R-values are also used to describe steady-state heat flow but in a slightly different way. The R-value is a material property that is proportional to resistance to heat flow. A larger R-value has greater thermal resistance, or more insulating ability, than a smaller R-value. The opposite is true with U-factors: lower values mean more insulating ability.

R-values are widely recognized in the building industry and are used to describe insulation effectiveness. The insulation R-value does not describe the overall performance of the complete assembly, however. It only describes the thermal resistance of the insulation material. In contrast, the U-factor is a measure of the thermal performance of the entire construction assembly. The performance of the entire wall assembly can be significantly lower when metal framing or other elements penetrate the insulation.

Ratings for R-values of insulating materials are typically specified at 75°F. The insulating properties of the material are dependent on temperature. A specified insulation will have a higher R-value at low temperatures and a lower R-value at higher temperatures. This effect can be significant: for example, fiberglass batt insulation has an R-value (in IP units) of 3.2 per inch at 75°F, but 2.7 per inch at 115°F,

which might be an attic temperature on a hot day. Insulation must also not be compressed near structural members, and must remain dry, to maintain its rated R-value. Insulation that is blown into a cavity may settle over time, reducing its effective R-value.

Most construction assemblies include more than one material in the same layer. For example, a wood stud wall includes cavity areas where the insulation is located and other areas where there are solid wood framing members. The wood areas have a lower R-value and conduct heat more readily than the insulated areas. Framing members must be considered when calculating the U-factor of a wall, roof, or floor assembly. See the Design Tools section below for more details.

Thermal Mass

Thermal mass is another important characteristic that affects the thermal performance of construction assemblies. Heavy walls, roofs, and floors have more thermal mass than light ones. Thermal mass both delays and dampens heat transfer (see Figure 104). The time lag between peak outdoor temperature and interior heat transfer is between four and 12 hours depending on the heat capacity of the construction and other characteristics.

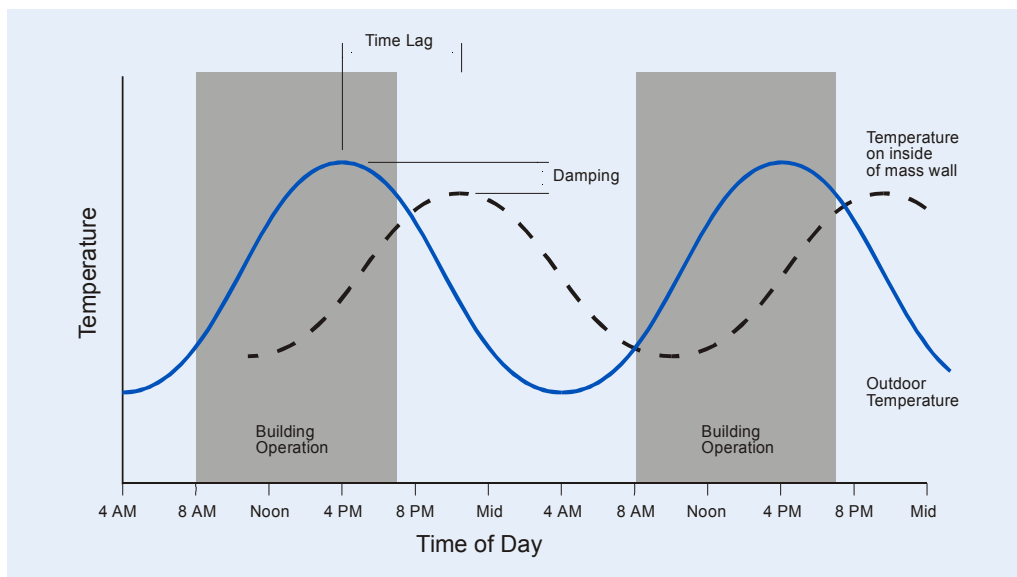


Figure 104—Temperature Swing

Thermal mass that is exposed to interior air has other benefits as well. If the mass is allowed to cool at night, it will absorb heat during the morning and reduce the cooling load. If the interior thermal mass is exposed to sunlight, it will warm during the day and release the heat at night. Thermal mass used this way is a basic principle of passive solar design and may be appropriate in the mountain climates of California.

Figure 105 shows examples of mass walls commonly used in school construction.

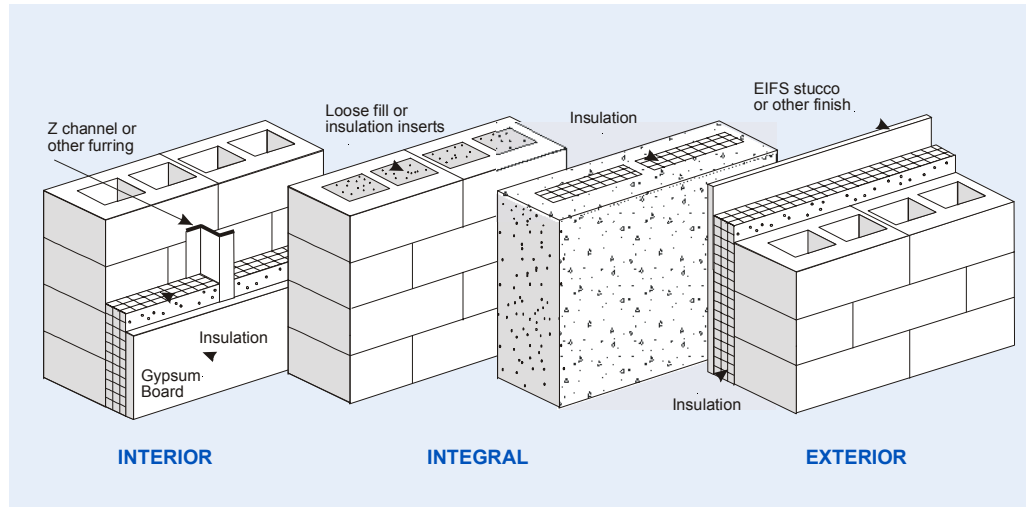


Figure 105—Mass Wall Constructions

Heat Capacity

HC is the metric used to quantify thermal mass. HC is the amount of heat in Btu that must be added to 1 ft² of surface area to uniformly elevate the temperature of the construction by 1°F. The units are Btu/ft²·°F. HC is the sum of the heat capacity of each individual layer in the wall. The heat capacity of each layer is the density of the material times its thickness times its specific heat (all in consistent units). HC can be approximated by multiplying the weight of 1 ft² of wall, roof, or floor by 0.2. For example, a wall with a weight of 100 lb/ft² has an HC of approximately 20 Btu/ft²·°F.

Many energy standards (including California Title 24) consider HC as a factor in the overall performance of a building envelope component. The California Nonresidential Standards, for instance, have separate U-factor criteria for different HC ranges.

Concrete is not a very good insulating material. However, some varieties are better than others. There is a class of materials called aerated concrete that has air bubbles entrained in the concrete, which makes the concrete lighter and also improves its insulating ability. Low-density aggregates such as perlite or vermiculite can be used to produce lightweight concrete.

Cool Roofs

Heat transfer is also affected by the exterior surface, which is particularly important for roofs. In fact, the term “cool roof” is used to describe those with favorable surface characteristics. Cool roofs have two key features. First, they have a high solar reflectance, which usually means that they are light in color. The high reflectance means that solar radiation is reflected rather than absorbed by the roof surface, keeping the surface temperature lower and reducing heat gain. Second, cool roofs have a high or normal emittance. Emittance is a little harder to understand than reflectance, but it can be just as important to energy performance. Emittance is that percentage of absorbed solar energy that would be radiated to

the sky from a surface. Galvanized metal and other metallic finishes have a low emittance, which means that when they warm up, they cannot easily release their heat by radiating it back to the sky.

Radiant Barriers

One last feature of construction assemblies that deserves discussion is radiant barriers. Many construction assemblies have a large cavity. An attic, for instance, is a cavity separating the roof from the ceiling. Radiant barriers are not typically installed in walls. In construction assemblies that have a cavity, much of the heat transfer from the warmer surface to the colder surface is due to radiation. A radiant barrier can reduce this component of heat transfer. A radiant barrier is a shiny metallic surface on one or more sides of the cavity that has a low emittance. Radiant barriers are commonly installed in attics.

Fenestration Products

High performance fenestration products, that include features such as double-glazing and low-emissivity (“low-e”) coatings, are an effective way to reduce both solar heat gains and winter thermal losses in modern construction. Fenestration has three principal energy performance characteristics, which have been identified by the National Fenestration Rating Council (NFRC) to be tested and labeled on manufactured windows: visible light transmittance, solar heat gain coefficient, and U-factor. Site-built windows and skylights may not have this information available.

- Visible light transmittance (VLT) is the fraction of light that is transmitted through the glazing. Light is that portion of solar radiation that is visible, meaning it has a wavelength between about 380 and 780 nanometers. Single clear glass has a VLT of about 0.9, while highly reflective glass can have a VLT as low as 0.05. The quantity of light that enters through a window or skylight is directly proportional to VLT. In general, the VLT should be as high as possible, provided it doesn’t create glare or other visibility problems.
- Solar heat gain coefficient (SHGC) is the fraction of solar radiation incident on a window or skylight that is either transmitted, or absorbed and re-emitted, to the interior space. A window that entirely blocks all solar heat would have an SHGC of zero, while a perfectly transmissive glazing has an SHGC of one. A lower SHGC results in lower cooling loads for the space. Windows used for daylighting should ideally have a high VLT and a low SHGC. However, glazing materials with a low SHGC (like dark gray and bronze tints) may also have a low VLT, so the challenge is to identify spectrally “selective” low-e products and blue/green tints. Only 38% of solar energy that strikes the windows is visible light. The remainder is in the form of infrared heat and UV rays that can degrade fabrics and interior surfaces. Low-e windows have a very thin metallic oxide coating on the window surface that lets visible light in, but keeps infrared heat and UV light out.
- Relative Solar Heat Gain (RSHG) is a term used in the Title 24 Nonresidential Energy Efficiency Standards. It is very similar to SHGC, but also incorporates the effects of exterior overhangs on solar heat transmission. A window that does not have a low SHGC may still comply with the

standard if an overhang is used to block solar heat transmission during summer months, when space cooling loads are highest. The RSHG of a window shaded by an external overhang is determined by multiplying the SHGC by an overhang factor. If no overhang is present, the RSHG equals the SHGC. Details on this calculation procedure are provided in the 2005 Title 24 Nonresidential Compliance Manual. Overhangs are recommended on south-facing windows. For other orientations, the effects of overhangs on peak cooling loads and annual energy consumption are best analyzed using an energy simulation program.

- Interior shading devices will also reduce the solar heat transmission through windows. However, these are not considered when determining the energy performance of the building enclosure.
- U-factor measures the heat flow through a window assembly due to the temperature difference between the inside and outside. The lower the U-factor, the lower the rate of heat loss and of heating energy consumption. The fenestration frame and glazing edge spacers degrade the U-factor of an insulated glass assembly. So two U-factors are frequently specified: the center of glass (COG) value, which is the U-factor measured at the center of the assembly, and the whole-window value, which is the overall U-factor of the glazing plus the spacer and frame system. (The whole-unit value will be higher than the COG value.) An NFRC rating procedure provides a whole-window U-factor, which includes the effects of the framing. For double-glazed windows, typical whole-window U-factors are between 0.3 and 0.7 Btu/h-ft²-°F.

Window frames are commonly available in metal, wood, vinyl, and fiberglass. Metal frames conduct the most heat and must have a thermal break for good performance. Insulated vinyl and fiberglass frames have the best energy performance.

Applicable Codes

The California Nonresidential Energy Efficiency Standards (Title 24) apply to schools, and these standards require that roofs, walls, and floors have a minimum level of insulation. The criteria are expressed both in terms of a minimum R-value and a maximum U-factor. The California 2005 Title 24 standards provide a set of pre-calculated U-factors for common construction assemblies. These are included in Joint Appendix IV of the standards, and must be used when using the envelope tradeoff or whole building performance methods to demonstrate code compliance. For unusual constructions not included in Joint Appendix IV, the U-factor may be calculated using acceptable methods shown in Table 22.

The requirements vary by climate region and are summarized in Table 21. Roofs must be insulated with at least R-11 insulation in the south coast region, while a minimum of R-19 is required in the other California climate regions. Walls require R-11 along the coast, but R-13 for the valley, desert, and mountains. R-19 floor insulation is required in the mountains and R-11 in the other climate regions. For relocatable classrooms, a construction that meets the most stringent requirements in Table 21 complies with the standard.

Table 21—Title 24 Standards for Building Envelope

		South Coast		North Coast		Central Valley		Desert		Mountains	
Roofs	R-value	11		19		19		19		19	
	U-value	0.076		0.051		0.051		0.051		0.051	
Walls	R-value	11		11		13		13		13	
	Wood frame	0.110		0.110		0.102		0.102		0.102	
	Metal frame	0.224		0.224		0.217		0.217		0.217	
	Metal Building	0.123		0.123		0.113		0.113		0.113	
	Mass ($7 \leq HC < 15$)	0.430		0.430		0.430		0.430		0.330	
	Mass ($15 \leq HC$)	0.690		0.650		0.650		0.410		0.360	
	Other	0.110		0.110		0.102		0.102		0.102	
Floors	R-value	11		11		11		11		19	
	Mass ($7.0 \leq HC$)	0.139		0.139		0.090		0.139		0.090	
	Other	0.071		0.071		0.071		0.071		0.048	
Windows	U-value	0.77		0.77		0.47		0.47		0.47	
	Relative Solar Heat Gain	Non-North	North	Non-North	North	Non-North	North	Non-North	North	Non-North	North
	0%–10% WWR	0.61	0.61	0.61	0.61	0.47	0.61	0.46	0.61	0.49	0.72
	11%–20% WWR	0.61	0.61	0.55	0.61	0.36	0.51	0.36	0.51	0.43	0.49
	21%–30% WWR	0.39	0.61	0.41	0.61	0.36	0.57	0.36	0.47	0.43	0.47
	31%–40% WWR	0.34	0.61	0.41	0.61	0.31	0.57	0.31	0.40	0.43	0.47
Skylight U-factor	Glass w/ curb	1.18		1.42		1.18		1.18		1.18	
	Glass w/o curb	0.68		0.82		0.68		0.68		0.68	
	Plastic w/curb	1.32		1.56		1.32		1.32		1.04	
Skylight SHGC Glass	0%–2%	0.79		0.79		0.46		0.46		0.68	
	2.1%–5%	0.40		0.40		0.36		0.36		0.46	
Skylight SHGC Plastic	0%–2%	0.77		0.79		0.77		0.71		0.77	
	2.1%–5%	0.62		0.65		0.62		0.58		0.58	

Source: California 2005 Nonresidential Energy Efficiency Standards (Title 24)

Fenestration has a large impact on heating and cooling loads. The standards allow total fenestration area to be no more than 40% of the total exterior wall area. Most classroom buildings use less than this limit. The Fenestration Performance Guideline provides thermal performance requirements for windows and skylights. These products must be rated by National Fenestration Rating Council test procedures.

The 2005 Title 24 Nonresidential Standards now require cool roofs for low-sloped buildings. The cool roofs guideline provides information on cool roof applications that are compliant with the new standard.

Design Tools

The thermal performance of construction assemblies can be calculated in many ways. The appropriate method depends on the type and complexity of construction. The basic calculation methods include:

- *Series Calculation Method.* This is the easiest way of calculating U-factor, but its use is limited to constructions that have no framing and are made of homogenous materials.
- *Parallel Path Calculation Method.* This simple extension of the series calculation method can be used for wood-framed assemblies.
- *Effective R-value (Isothermal Planes).* This method uses principles similar to the series and parallel path calculation methods, and is appropriate for construction assemblies such as concrete masonry and metal-framed walls/roofs where highly conductive materials are used in conjunction with insulated or hollow cavities.
- *Two-Dimensional Calculation Method.* Two dimensional heat flow analysis may be used to accurately predict the U-factor of a complex construction assembly. Two dimensional heat flow analysis is also the best method for determining whole-window U-factors. Calculating two-dimensional heat flow involves advanced mathematics and is best performed with a computer.
- *Testing.* This is the most accurate way to determine the U-factor for all types of construction, except slabs-on-grade. But because a large variety of possible construction assemblies exist, it is costly and time consuming and impractical to test them all. Calculation methods are usually more cost-effective.

Table 22 provides guidelines on which method can be used with different types of construction assemblies. For California, these U-factor calculation methods only apply for construction assemblies not covered in Joint Appendix IV of the Title 24 standards.

Table 22—Procedures for Determining U-Factors for Opaque Assemblies

	Series Calculation Method	Parallel Path Calculation Method	Effective R-value (Isothermal Planes)	Two- dimensional Calculation Method	Testing
Roofs					
Insulation above Deck	✓			✓	✓
Attic (wood joists)		✓		✓	✓
Attic (steel joists)			✓	✓	✓
Other				✓	✓
Walls					
Mass			✓	✓	✓
Wood Framed		✓		✓	✓
Steel Framed			✓	✓	✓
Other				✓	✓
Below-Grade Walls					
Mass			✓	✓	✓
Other				✓	✓
Floors					
Mass	✓		✓	✓	✓
Steel Joist			✓	✓	✓
Wood Framed		✓	✓	✓	✓
Other				✓	✓

Computer Programs

The calculation methods described above are implemented in a number of design tools and computer programs.

- *The EZFrame program*, available from the California Energy Commission (CEC), can be used to calculate the U-factor of metal framed wall and roof constructions and accounts for many features such as the gauge of the steel used for framing members, the percent of knockouts in the web, and insulating tape between the framing members and the sheathing. The cost is \$14. For more information, contact the CEC. Tel: (916) 654-5106 or (800) 772-3300. Web site: www.energy.ca.gov/efficiency/computer_prog_list.html. (The list of approved programs for the upcoming 2005 Title 24 standards is under development at the time of press.).
- *The Therm program*, available from Lawrence Berkeley National Laboratory is designed primarily to analyze window frames, but can be used for any type of two-dimensional heat transfer analysis. This program can be downloaded from windows.lbl.gov/software/therm/therm_getacopy.htm.
- *The WINDOW 5.2 program*, available from Lawrence Berkeley National Laboratory can be used to analyze thermal performance of window assemblies. It uses two-dimensional heat transfer calculation methods consistent with NFRC rating procedures. It has the flexibility to analyze combinations of glazing products, frames, spacers and gas fills, at different orientations (tilts). It also can provide surface temperature predictions for different environmental conditions, which is useful when considering thermal comfort. For more information, see windows.lbl.gov/software/window/window.html.

- General-purpose energy simulation programs such as DOE-2 and EnergyPlus can be used to calculate the energy savings of various construction assemblies. With these programs, the dynamics of heat transfer are modeled. In fact, EnergyPlus models the temperature gradient in constructions. DOE-2, on the other hand, uses a more simple response factor method.

Pre-Calculated Data

The U-factor of common constructions has been calculated and values are published in a number of sources.

- Joint Appendix IV of the 2005 California Nonresidential Manual has a wealth of useful data, including R-values of common materials, pre-calculated U-factors, and other data. The manual can be downloaded from www.energy.ca.gov/title24/nonresidential_manual/index.html.
- Appendix A of ANSI/ASHRAE/IESNA Standard 90.1-2001 has published values in both inch-pound and metric (SI) units. Constructions include walls, roofs, floors, slabs, and below-grade walls. These values are also contained in the EnvStd 4.0 computer program, which can be downloaded from www.archenergy.com/products.

Indoor Air Quality and Moisture

It is extremely important to provide an exterior weather barrier with drainage plane to prevent moisture from entering construction cavities. Wet or damp construction cavities, attics, and plenums are a major source of mold and can contribute significantly to indoor air quality (IAQ) problems. In addition, moisture can damage the structure and degrade the performance of insulation, increasing energy and operating costs. For example, the California Air Resources Board reports that most of the IAQ complaints that they receive with regard to schools are related to leaky roofs that have resulted in the growth of mold in a plenum or attic space.

Water vapor can also enter construction cavities through a process of moisture migration. Moisture migrates from the warm and humid side of the construction assembly to the cold dry side of the construction assembly. The vapor cools as it moves through the wall and may condense into water molecules that can accumulate to cause damage and create mold. To prevent water vapor migration, framed walls, floors, and roofs should have a vapor barrier on the warm moist side. For California climates, this means that the vapor barrier should be on the interior side. Vapor barriers also are available as part of most insulation products and consist of an asphalt-impregnated paper or metal foil. Care should be taken during construction to ensure that this vapor barrier is continuous, tightly secured at the framing members, and not damaged. Special care should be taken in lockers, showers, food preparation areas, and other spaces that are likely to have high humidity.

In addition to correctly installing a vapor retarder, it is important to provide adequate ventilation to dry spaces where moisture can build up. Most building codes require that attics and crawl spaces be ventilated, and some require a minimum 1-in. clear airspace above the insulation for ventilation of vaulted ceilings. Even the wall cavity may need to be ventilated in extreme climates. An infiltration

barrier should be installed under slabs with ventilated gravel in areas with soil gas contaminants like radon or methane.

Insulation Protection

Insulation should be protected from sunlight, moisture, landscaping equipment, wind, and other physical damage. Rigid insulation used at the slab perimeter of the building should be covered to prevent damage from gardening or landscaping equipment. Rigid insulation used on the exterior of walls and roofs should be protected by a permanent waterproof membrane or exterior finish. In cold climates, mechanical or other equipment should not be installed in attics, since it can generate heat and cause uneven snow melting and ice dams. For moderate climates, access to equipment installed in attic spaces should be provided in a way that will not cause compression or damage to the insulation, which may mean using walking boards, access panels, and other techniques to prevent damage to the insulation.

In situations where insulation is left exposed (including return air plenums), fiberglass insulation products should be encapsulated in a manner that prevents fibers from becoming airborne. To maintain a continuous vapor barrier, all seams should be sealed with tape or mastic. In this application, simply stapling the insulation is not adequate.

Acoustic Performance

Acoustic design is a cross-cutting issue: the choice of interior surfaces and finishings, HVAC equipment location and selection, ductwork, diffuser selection and site layout are all important design considerations. The design of the building enclosure and choice of insulation also affect the acoustic performance of school facilities. The 2002 voluntary ANSI Standard S12.60 provides “best practice” recommendations for acoustic performance. Best practice design will yield a background noise level of 35 decibels (dBA) or lower. Decibels are a measure of the sound pressure level, measured on a logarithmic scale. By comparison, a whisper has a sound level of about 20 dBA, speech range of about 50–70 dBA, and a loud rock concert of 120 dBA. For a teacher to be intelligibly heard, the teacher’s voice must be at least 10 dB higher than the background noise level in the classroom.

For the building enclosure, one means of reducing noise levels in the classroom is to reduce the sound transmission from adjacent spaces and from outdoors. The ability of a wall assembly to limit sound transmission between spaces is known as the *sound transmission class* (STC). This is a measure of the noise reduction in decibels, weighted over frequencies common in human speech (125 Hz–4000 Hz). So this rating does not account for low-frequency noise such as that generated by HVAC equipment or musical instruments. Best practice for construction assemblies requires an STC of 50–60. The higher the rating is, the better the sound reduction. For example, an exterior noise source of 80 decibels will result in an interior sound level of 30 decibels, when transmitted through a wall with an STC rating of 50. Modern construction that uses lightweight materials for interior walls provides only limited sound reduction. Providing a layer of gypsum board on both sides of a stud wall, with staggered joints, will reduce sound transmission. Other options for reducing sound transmission are to use metal studs, to

include an air space in the cavity or to increase the wall mass. A simple test is to turn on a television in a classroom at a level that can be easily heard, and to check if the sound can be heard or program content understood in adjacent classrooms. Make sure that partition walls extend up to the structural deck and do not terminate at suspended ceilings.

Design the exterior building enclosure to block external noise such as that generated from traffic or mechanical equipment. Adding mass to exterior walls, such as increasing the thickness of a concrete masonry unit wall, will reduce sound transmission from the outside. Using high performance windows and designing to minimize air infiltration will also help to minimize impacts of external noise.

Material Efficiency and Other Environmental Considerations

One of the most effective ways to achieve material efficiency in a building is to reuse all or part of an existing building enclosure. This reduces solid waste produced by a project and avoids the environmental burdens associated with production and delivery of materials for a new building enclosure. Saving the building enclosure, however, may not be appropriate if the existing structure is not energy efficient and cannot be adequately upgraded to meet high performance objectives.

When designing a new building enclosure, material efficiency can be achieved by:

- Using panelized, pre-cut, and engineered construction products.
- Designing with standard dimensions to reduce on-site waste.
- Designing a compact building (this also reduces impervious surface on the site, but may conflict with daylighting objectives).
- Planning for future adaptability to extend the life of the building.
- Choosing durable materials and systems.

In addition, building enclosure and insulation materials exist that are recyclable, include recycled or resource-efficient content, or have other environmentally preferred characteristics. The materials may, for example, avoid introducing toxins into the building or natural environment, or they may be produced using sustainable methods. In addition to the design strategies above, refer to the following Table 23 for some easily achievable strategies that will improve the sustainability of the building enclosure and insulation.

When weighing options for environmentally friendly insulation, it is important to specify products that have been independently tested or certified. Scientific Certification Systems (SCS) verifies claims of the recycled content of insulation products. CHPS maintains a list of insulation products that have met the Section 01350/DHS Standard Practice standard for low VOC emissions, as tested by independent agencies. More information is available at the CHPS Web site (www.chps.net).

For specific product recommendations, also see GreenSpec: The Environmental Building News Product Directory and Guideline Specifications, available at www.buildinggreen.com/, and OIKOS's Redi Guide

(Resources for Environmental Design Index), available from Iris Communications, (800) 346-0104, www.oikos.com/.

Table 23—Strategies for Constructing Resource-Efficient Building Enclosures

Building Component	Strategies		Environmental Benefits & Considerations	
Foundation and Concrete Work	For concrete materials, specify fly ash as replacement, not addition. 10%–25% replacement is commonly specified, but higher percentages are possible, depending on application.		Formerly landfilled as industrial waste, fly ash is now used to replace energy-intensive Portland cement in concrete mix. Fly ash adds workability and strength. Consider using “high volume” fly ash concrete (with 50% fly ash).	
	Use autoclaved and/or aerated concrete for appropriate concrete applications.		Aerated concrete is lighter and has better insulating properties than standard concrete.	
	Prohibit dumping concrete waste anywhere intended to be pervious.		Prevents degradation of the site and permits infiltration.	
	Use steel rather than wood forms.		Although energy intensive, steel is reusable, contains recycled content and can be recycled at the end of service life.	
	If wood forms are used, reuse wood in framing and sheathing.		Reduces resources used. Reduces waste.	
	Use low and non-toxic form releases. Bio-based products are available.		Prevents soil contamination, and reduces human health risk. Promotes worker safety. Water-based products should be protected from freezing during storage.	
	Use expansion joint fillers with recycled content.		Appropriate use of recycled, relatively low-strength materials, such as waste cellulose from recycled newspapers.	
	Use rebar supports with recycled content. DOT-approved products are available with 100% recycled content, including engineered plastics and fiberglass.		Rebar supports in concrete form-work have minimal structural requirements; appropriate use of recycled waste plastic.	
	If using ICFs, use options with ozone-friendly foam ingredients. (ICFs are permanent forms with integral insulation that are not disassembled after the concrete is cured. Note: not all ICFs are alike; field R-values can differ significantly so rely on results from completed projects.)		ICFs can provide significant improvements in energy efficiency and can reduce the use of energy-intensive Portland cement. Using ozone-friendly options (with EPS foam) eliminates a source of global warming.	
	Use sill sealers to limit infiltration at the foundation.		Increases energy efficiency.	
Masonry Walls	Use sub-slab ventilation in areas with radon or potential soil gas submissions.		Improves indoor air quality.	
	Use mortar dropping control product to prevent blocking of weep holes. Product available with 100% recycled polyethylene.		Maintains air flow and allows moisture migration from behind masonry veneer facades. Improves building durability.	
	For CMUs: maximize recycled content. Typically available with 10% recycled content.		Reduces resources used to produce new CMU material. No difference in product performance or application. Products are high strength, high fire resistance, and highly durable.	
	For CMUs: use CMUs containing fly ash.		Formerly landfilled as industrial waste, fly ash is now used to replace energy-intensive Portland cement in concrete mix. Fly ash adds workability and strength.	
	For CMUs: consider using lightweight CMUs.		Reduces transportation-related impacts.	
	For CMUs: pull watermark line down below window framing to eliminate finishing details.		Reduces maintenance over the life of the building.	
	For CMUs: do not paint, order with color.		Avoids resources used to produce paint. Avoids use of VOC-emitting paints generally used to finish CMUs. The pigments typically used in colored CMU are nontoxic and contain none of the solvents associated with painting and re-painting. Products are low maintenance.	
	Use fireproofing available with recycled EPS foam and recycled newsprint.		Traditionally, products contained fiberglass and asbestos for this use. More benign products that make efficient use of recycled materials are preferable.	

Building Component	Strategies		Environmental Benefits & Considerations	
Wood Framing	Use advanced or intermediate framing systems where applicable and accounting for seismic requirements for building site. Example framing elements include 24 in. on-center framing, insulated headers, two stud corners with drywall clips, ladder partitions. References: <i>Builder's Guide</i> —Building Science Corporation, and <i>Efficient Wood Use in Residential Construction</i> —Natural Resources Defense Council.		This both allows for more insulation, less "cold" spots, and increased wood efficiency, thus improving both energy and materials efficiency.	
	Use engineered wood products in place of dimensional lumber such as floor joists and roof joists.		Engineered wood products are lighter weight and use fewer resources for the same function as dimensional timbers.	
	Use wood certified with Forest Stewardship Council (FSC) or Scientific Certification Service (SCS). A variety of certified dimensional and engineered wood products are available.		Prevents degradation to forest and wildlife habitat.	
Siding	Use fiber cement siding. Most available factory primed; suggest back priming. Proper painting is important for the siding's long-term durability.		Reduces virgin wood use and can be a durable option.	
Roofing	Use metal roofing.		Includes recycled content, is durable, and can be recycled at the end of service life.	
	Use non-PVC options for membrane roofing.		Avoids the environmental impacts of PVC manufacturing.	
	Consider a green or vegetated roof system for low-slope roofs. These roofs contain plants in a lightweight soil to absorb and slow runoff that would otherwise pour from rooftops. These roof systems typically consist of drainage, soil, and vegetation layers. Be sure to use native plants and grasses in green roof systems.		Can absorb and slow rainwater runoff to reduce peak loads on sewer systems. Helps reduce building heat gain and prevents urban heat islands. Plantings also absorb carbon dioxide. Helps conserve energy in the winter by insulating rooftops. Green roofs, however, require structural steel to support their weight. Because steel has high-embodied energy, this may offset some of the environmental benefits of using green roofs.	
Moisture and Waterproofing	Sealants and repellants: Limit use of sealants through proper detailing. Use least-toxic options. Avoid products containing methylene chloride, chlorinated hydrocarbons, aromatic and aliphatic solvents, styrene butadiene, or products containing bactericides and fungicides classified as phenol mercury acetates, phenol phenates, or phenol formaldehyde.		Combining good detailing and low toxicity will prevent air quality problems while promoting long service life of the building.	
	Do not rely on caulking for waterproofing. Proper flashing will prevent water from entering the building.		In addition to adding durability to shell, proper flashing prevents mold and mildew build up, reducing health risk.	
	If using a vapor retarder, select film available with up to 100% LDPE (plastic).		Utilizes plastic waste that would otherwise be landfilled. Reduces resources required to produce virgin-based material.	
	Use cellulose insulation produced with 100% recycled newsprint.		Utilizes paper waste that would otherwise be put in landfills.	
	If using rigid insulation with polyisocyanurate foam, use ozone-friendly option.		Prevents further degradation of the earth's atmosphere through global warming.	
Exterior Doors *	Use doors produced with reclaimed lumber.		Reduces pressure on timber supply, as well as degradation of forest habitat.	

* for window recommendations, see *Daylighting* chapter

Source: Adapted from *GreenSpec: The Environmental Building News Product Directory and Guideline Specifications*

References

Access Board, The. October 2003. "Listening for Learning 3: Counting the Costs of Noisy vs. Quiet Classrooms "

www.quietclassrooms.org/ada/adahandout3.htm

California Energy Commission. 2005. *Nonresidential Energy Efficiency Standards*

www.energy.ca.gov/title24/2005standards/index.html

New Buildings Institute. 2005. *Advanced Buildings Reference Guide*.

Seep, Benjamin, et al. 200, rev. 2003. "Classroom Acoustics I—a resource for creating learning environments with desirable listening conditions," *Classroom Acoustics Publications* Acoustical Society of America.

Seep, Benjamin, et. al. 2000. "Classroom Acoustics II," *Classroom Acoustics Publications* Acoustical Society of America. This document links good acoustical design with learning and teacher performance.

Additional Information

Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747

Phone: 516.576.2360, Fax: 516.576.2377

United States Access Board, 1331 F Street N.W., Suite 1000, Washington, DC 20004-1111. 800 872-2253 (v) 800 993-2822 (TTY) fax: 202 272-0081. Information is available online at

www.quietclassrooms.org.

Information on STC and typical performance of common construction assemblies can be found at:

www.stcratings.com.

EnergyPlus is a building energy simulation program for modeling building heating, cooling, lighting, ventilating, and other energy flows. The program provides capabilities for modeling the performance of emerging HVAC technologies, and provides thermal comfort predictions. More information can be obtained from the U.S. Department of Energy's Building Technologies Program, or online at

www.eere.energy.gov/buildings/energyplus/.

GUIDELINE IN1: WALL INSULATION

Recommendation

Insulate exterior walls at a level appropriate for each class of construction and climate.

Class of Wall	South Coast, North Coast Climates	Central Valley, Desert, Mountain
Wood-Framed Walls	Insulate 2x4 wood-framed walls with R-13 fiberglass batt insulation or use other insulating materials with a similar thermal resistance. When 2x6 wood framing is needed for structural (or other) reasons, insulate with at least R-19 fiberglass insulation.	Use 2x6 wood studs and advanced framing techniques to increase the percent of insulated cavity in walls. Insulate the cavities with R-19 batt insulation or other materials with a similar thermal resistance.
Steel-Framed Walls	Insulate 2x4 steel-framed walls with R-13 fiberglass batt insulation or other materials with a similar thermal resistance. When 2x6 framing is needed for structural (or other) reasons, insulate the cavities with at least R-19 fiberglass insulation.	Provide a continuous thermal barrier by installing a layer of continuous insulation on either the exterior or interior surface of the wall. Protect the insulation from physical damage and from moisture penetration.
Mass Walls	Shade mass walls from exposure to direct sun. Insulation is marginally cost effective in coastal climates.	Insulate mass walls either by furring on the interior surface, with an exterior insulation finish system (EIFS), or with an integral insulation system.



Figure 106—Insulation

Source: CertainTeed

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

Description

The construction of exterior walls affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood-framed, steel-framed, or mass) is usually determined by requirements for fire separation between spaces, durability, or other issues. The recommended insulation levels for these classes are based on life-cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates and less in more temperate climates.

Concepts of thermal heat transfer are presented in this chapter's Overview and should be reviewed, since they apply to walls as well as other building enclosure components.

Applicability

These recommendations apply to all exterior walls in all spaces that are heated or cooled. Design decisions that affect wall thickness must be considered in the schematic design phase of the project.

Applicable Codes

For both metal-framed and wood-framed walls, the California Building Code requires R-11 insulation in the north and south coast climates, and R-13 insulation in the other climate zones. Criteria for framed walls are provided as both a minimum R-value and a maximum U-factor. Only U-factor criteria are provided for mass walls and less insulation is required than for framed walls. See the Overview to this chapter.

Fire protection codes (the California Building Code) require noncombustible construction for certain classes of schools, which prohibits wood framing. In some instances, walls must provide a 4-hour fire separation near property lines and in other applications, which generally requires mass walls.

Structural and seismic safety requirements often dictate the thickness and spacing of framing members. For masonry walls, they usually require at least partial grouting of all exterior walls.

Integrated Design Implications

Well-insulated and sealed walls can reduce drafts and thermal loads in buildings, which can result in smaller HVAC equipment and reduced costs.

Insulation provides more than a barrier to heat flow: it can impede water vapor transmission or air infiltration, reduce noise transmission, and provide fire protection.

Cost Effectiveness

The cost of insulating the cavity of wood- and steel-framed walls is low. Fiberglass batt cavity insulation is typically much cheaper than rigid insulation. Approximate installed costs of batt insulation are \$0.48/ft² for R-11 batts to \$1.20/ft² for R-38 batts. For rigid continuous insulation, expanded polystyrene (EPS) foam is less expensive than polyurethane or polyisocyanurate, at approximately \$2.00/ft² for EPS vs. \$3.75/ft² for urethane.



Figure 107—Rigid Insulation

Source: CertainTeed

However, insulating mass walls is more difficult and expensive. Insulating the cavity of mass walls is not very effective because of thermal bridges across the concrete webs and seismic safety requires that most of the hollow cells be grouted and reinforced. The most effective way to insulate mass walls is to use an EIFS, which costs \$7/ft² for 1-in. insulation and \$8/ft² for 2-in. insulation. If budget permits, this is the preferred method, since the benefits of the thermal mass are maximized. As an alternative, steel or wood furring can be used on the interior of the wall, batt insulation can be placed in the cavities between the furring strips, and gypsum board can be used as the interior finish.

Costs	L		
	M	■	
	H	■	
	L	M	H
Benefits			

Benefits

Insulating walls has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Greater acoustic separation is provided from the outdoors.
- Masonry walls can be insulated on the interior, but the benefits of thermal mass are mostly lost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.

Design Tools

The Overview section of this chapter has a discussion of methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass walls, because of the time delays and dynamic effects inherent with this type of construction.

Design Details

For framed walls, provide a continuous vapor barrier on the inside surface of walls. If the vapor barrier that comes with batt insulation is used, then the paper or foil should be stapled to the face of the studs, not the inside. This will provide a more secure and continuous vapor barrier and will reduce compression of insulation.

For wood framing in the central valley, desert, and cold climates, use 2x6 framing. The studs should be spaced at 24-in. o.c., the headers over doors and windows should be insulated with rigid insulation, and minimum wood framing should be used at corners, wall intersections, and openings.

Concrete masonry unit (CMU) construction is high-strength, fire-resistant, durable, and economical. Improvements in manufacturing and quality control of colored concrete masonry ensure greater CMU uniformity and color consistency, reduced porosity, and reduced shrinkage. In addition, high-performance water repellents can be applied to walls or added to the concrete and mortar mixes so that it is unnecessary to paint or coat the units with block filler to avoid water penetration. EIFS systems used with mass walls should be installed according to manufacturers' instructions. Make sure that the exterior finish is durable and weather resistant.

Electrical and mechanical equipment should be minimized for exterior walls. Equipment such as electrical outlets and other recessed equipment can create thermal bridges and increase infiltration. Adding either an interior or exterior insulation layer will greatly reduce the heat transfer through the masonry wall. The Title 24 Joint Appendix IV Table IV.19 contains effective R values for insulation installed in furring spaces. For example, 2x4 framing with R-11 batt insulation has an effective R-value of 9.3. A 10-in. solid-grout medium weight concrete masonry unit has a U-factor of 0.59 (from Table IV.12 of Joint Appendix IV) or an R-value of 1.7. When the interior furring and insulation layer is added to the CMU, the combined assembly has an R value of 11.0, or a U-factor of 0.091. Thus, adding the interior furring and insulation reduces the rate of steady-state heat transfer by more than 80%. Refer to the Overview section for a review of fundamental concepts of heat transfer through building components.

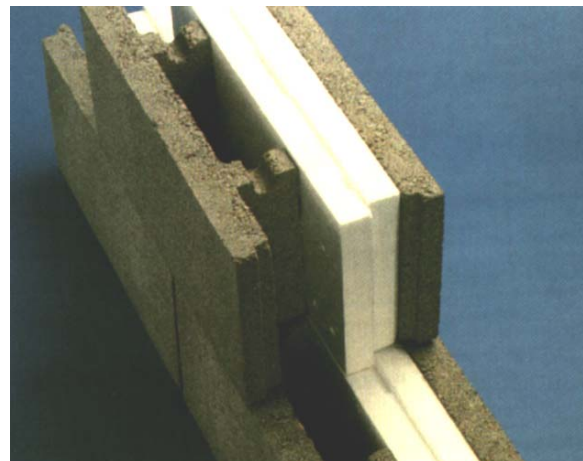
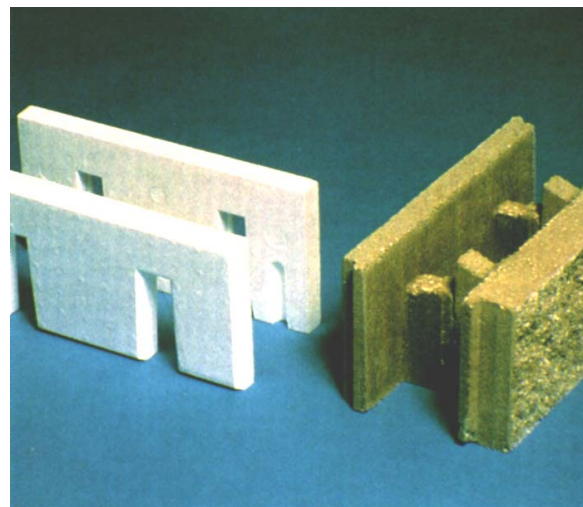
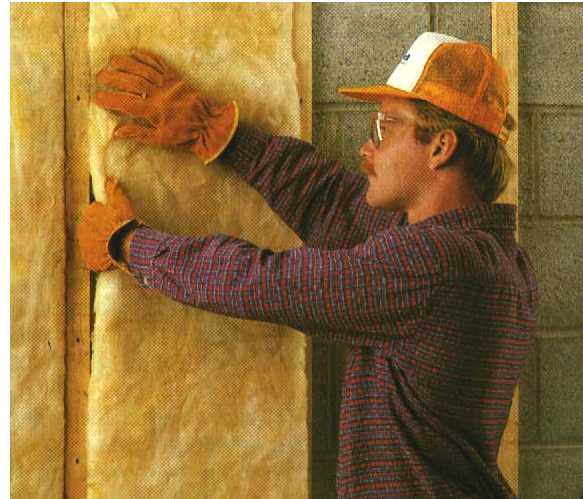


Figure 108—Integral Mass Wall Insulation Techniques
Source: Korfil CBIS

For wood framed walls, use wood products that are produced through sustainable forest practices. Require that framing members be certified by the Forrest Stewardship Council.

For metal-framed walls, specify that the steel used for manufacturing have 30% recycled content.

Insulation Choices

Installed cost, ease of installation, the use of recycled content, fire and safety issues, water permeability and performance degradation affect the choice of insulation.

Batts are installed between frame stud joists and beams of wood-framed and metal-framed walls. This type allows for easy installation, but gaps and compression may lower the effective R-value.

- Fiberglass batts are installed between frame stud joists and beams. They offer a low material and installed cost and good fire protection.
- Cotton batts have a good insulating value per inch and a high recycled content, and provide less exposure of harmful materials to installers. These are only offered as unfaced insulation and require a separate vapor retarder.
- Plastic fiber (PET) batts are environmentally friendly alternative, with less recycled content and reduced skin irritation for the installer. However, this product melts at a lower temperature than fiberglass and is more difficult to handle.
- Loose-fill ("blown-in") insulation can be used for retrofits of existing walls and hard-to-reach places.
- Cellulose has a high R-value per in, and forms a good air barrier due to its high density. It is also made from a very high recycled content. Its weight may cause settling, lowering its insulation effectiveness over time. Special fire retardants are required with this type of insulation.
- Fiberglass loose-fill insulation is also available. This also provides a good air barrier and has less settling than cellulose. Installed costs are slightly higher than cellulose insulation.
- Mineral wool (rock or slag wool) is a non-combustible product that provides good sound attenuation. With this insulation there is potential for emissions of respirable particles.

Spray-in-place foams can be used with steel framing. This insulation type provides a good air barrier and good coverage near obstructions, at a higher cost than batt insulation. The insulating material can be polyurethane, wet-spray cellulose, spray-in fiberglass, or icynene foam. Approximate installed costs are \$1-2/ft².

Rigid foam panels provide a continuous insulation barrier and air barrier. They are used with metal framed walls to provide a continuous insulation layer. Common materials are EPS, polyisocyanurate ("polyiso") and polyurethane. EPS foam boards are the most common; they are relatively low cost, have good moisture resistance, and maintain their rated R-value. Polyiso panels have a higher R-value per inch and good structural strength, but tend to lose their insulating properties over time, and are more

expensive. Extruded polystyrene foams are suitable for below-grade walls, and have excellent moisture resistance.

Structural panels, or structural insulated panels (SIPs) are prefabricated panels, typically consisting of a rigid foam insulation surrounded by an interior and exterior layer of oriented strand board for structural strength. These provide a continuous insulation barrier and allow for rapid construction. The insulating material may be EPS foam or polyisocyanurate. The R-value of the whole assembly varies from R-11 to R-38. More information can be found in Joint Appendix IV of the California 2005 Title 24 Nonresidential Standards.

Operation and Maintenance Issues

Exterior and interior wall finishes must be maintained. For interior finishes, maintenance is important for both aesthetic reasons and lighting reasons—light colors should be maintained to enhance the performance of the electric lighting and daylighting systems. Exterior surfaces should be maintained to be waterproof or water resistant, and secure. This is important to prevent water from entering construction cavities, which can cause the growth of mold, damage the structure, and deteriorate the performance of thermal insulation. Mold can be a major source of indoor air quality problems and needs to be avoided.

Thermographic measurement techniques can be used to assess the condition on insulation in walls. Cold spots in the wall indicate where insulation may be compressed or damaged from moisture penetration.

Commissioning

Verify that the specified levels of cavity and/or continuous insulation are installed. Check for gaps in insulation or compression near framing members or other penetrations.

The use of some insulation materials, such as cellulose or mineral fiber, phenolic or extruded polystyrene foams, polyurethane, and polyisocyanurate insulation must comply with the California Quality Standards for Insulating Materials (CCR, Title 24, Part 12). A list of compliant insulation products can be obtained from the Insulation Program of the Department of Consumer Affairs. Installations of insulation must also meet fire safety requirements.

References

Also see the Overview section of this chapter.

North American Insulation Manufacturer's Association (NAIMA). 2004. *Facts #35: An Insulation Comparison*.

www.naima.org/pages/resources/library/html/BI475.HTML, or
www.naima.org/pages/resources/library/pdf/BI475.PDF

Oak Ridge National Laboratory (for U.S. Department of Energy). 1997. *Insulation Fact Sheet*.

www.ornl.gov/sci/roofs+walls/insulation/ins_01.html

Sluis, Tom and Bodzin, Steven. 2004. *New Types of Insulation*. (Energy Efficiency and Renewable Energy Clearinghouse (EREC)

www.healthgoods.com/Education/Healthy_Home_Information/Insulation/new_insulation.htm

United States Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy. September 2003. *New and Alternative Insulation Materials and Products*

www.eere.energy.gov/consumerinfo/factsheets/eb9.html

Waier, Phillip R. 2005. *Building Construction Cost Data*. R.S. Means.

Additional Information

American Concrete Institute (ACI), PO Box 9094, Farmington Hills, MI 48333-9094. Tel: (248) 848-3800. Fax: (248) 848-3801. Web site: www.aci-int.org/.

National Concrete Masonry Association (NCMA). 2302 Horse Pen Road, Herndon, VA 20171-3499. Tel: (703) 713-1900. Fax: (703) 713-1910. Web site: www.ncma.org/. The Web site provides a list of certified masonry consultants.

Cellulose Insulation Manufacturers Association, www.cima.org.

GUIDELINE IN2: ROOF INSULATION

Recommendations

Insulate roofs at a level appropriate for each class of construction and climate. The recommended roof insulation depends on the class of construction and the climate. See also the guidelines for cool roofs and radiant barriers.

Roof Class	South Coast, North Coast	Central Valley, Desert, Mountain
Insulation above Deck Including Mass	Provide a continuous layer of R-13 rigid insulation over the structural deck and protect this with a durable weatherproof membrane.	Provide a continuous layer of R-19 rigid insulation over the structural deck and protect this with a durable weatherproof membrane.
Wood Framed, Attics and Other	Install R-30 blown in insulation in ventilated attics. Use R-30 batt insulation in other framed cavities.	Install R-38 blown-in insulation in ventilated attics. Use R-38 batt insulation in other framed cavities.



Figure 109—Blown-In Insulation

Source: CertainTeed

Description

The construction of roof assemblies affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood-framed, steel-framed, or mass) is usually determined by requirements for fire separation between spaces, durability, or other issues. The recommended insulation levels for these classes are based on life-cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates, with less in more temperate climates.

Concepts of thermal heat transfer are presented in the Overview to this chapter and should be reviewed, since they apply to roofs as well as other building enclosure components.

Applicability

This roof insulation guideline is applicable for all spaces in schools that are heated or cooled. The class of construction is usually determined in schematic design, but the insulation level can be set in design development or even contract documents.

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

Applicable Codes

The California Building Code requires R-11 in the south coast climates and R-19 insulation in the other climate zones. Criteria are provided as both a minimum R-value and a maximum U-factor. See the Overview to this chapter for a more comprehensive discussion of the codes applicable in California.

Fire protection codes (the California Building Code) require noncombustible construction for certain classes of schools, which may prohibit wood framing in roof assemblies.

Structural and seismic safety requirements often result in the roof being used as a structural diaphragm to resist twisting or buckling during earthquakes or extreme wind.

The North American Insulation Manufacturers Association (NAIMA) has published a standard for fiberglass insulation for metal buildings, NAIMA 202-96. Insulation for metal buildings must have higher tensile strength and better recovery after compression.

Integrated Design Implications

Well-insulated roofs and roof cavities can reduce drafts and thermal loads in buildings. HVAC ducts located in ceiling cavities can be leaky and can be a significant component of thermal loads. These losses are far less significant when ducts are located in sealed and insulated ceiling cavities. Reduced loads can result in smaller HVAC equipment and reduced costs.

Cost Effectiveness

Costs	L			
	M		■	
	H		■	
		L	M	H
		Benefits		

The cost of roof insulation varies with the class of construction. Insulating attics and the cavity of wood- and steel-framed roof assemblies is low since labor is minimal and the roof cavity is readily accessible during construction. Rigid insulation installed over structural decks is more expensive due to construction details and added insulation cost.

Benefits

Insulating roofs and ceilings has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.

Design Tools

This chapter's Overview has a discussion of methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass roofs, because of the time delays and dynamic effects inherent with this type of construction.

Design Details

The construction of the roofing membrane is important in controlling water and moisture and ensuring durability. The roof itself must be designed to support loads from foot traffic, wind, and thermal cycles. The selection of a roofing type depends on the roof structure, height, wind load, and installation requirements. For low-sloped roof construction that is common with classrooms, there are three common roof types. Built-up roofing (BUR) consists of several layers of fiberglass embedded with asphalt, bound together with hot tar. The tar binds with the asphalt to create a continuous membrane. Modified bitumen roofs contain a polymer additive to the asphalt, for good resistance to thermal shock, punctures and tears. The additive also allows for an installation without the use of hot tar. Single-ply roofs reduce the dependence on the contractor for a quality installation. More information on design issues and installation details can be obtained from the National Roof Contractors Association (NRCA).

Insulation installed in exposed applications or in return air plenums should be either encapsulated or otherwise sealed from contact with moving air.

Make sure that insulation is dry before walls or other cavities are enclosed. Moisture in building cavities can be a source of mold, which can cause building damage and indoor air contamination.

Do not install insulation over suspended ceilings, because the insulation's continuity is likely to be disturbed by maintenance workers. Also, a suspended ceiling is a poor barrier to infiltration. If the insulation is located at the ceiling, many building codes will consider the space above the ceiling to be an attic and require that it be ventilated to the exterior. If vented to the exterior, air in the attic could be quite cold (or hot) and the impact of the leaky suspended ceiling would be worsened.

Use type IC light fixtures in insulated gypsum board ceilings.

Consider recycled insulation materials for attics and other places where loose-fill insulation is used. If cellulose (recycled paper) is used, make sure that the chemicals used as a fire retardant contain no VOCs and are not a possible source of pollution.

Operation and Maintenance Issues

The roof membrane must be maintained to prevent moisture from entering the roof cavity. Moisture in ceiling/roof constructions is a common source of mildew, which can cause serious IAQ problems. Insulation materials themselves require no maintenance.

Emissions from hot tar used for built-up roofs and modified bituminous roofs can be a problem when application is done for year-round schools. One method to manage emissions is to stage the kettle in a

restricted area away from children and to use either a filter, an after-burner, low-fuming asphalt or some other odor control mechanism during application. Some fume recovery systems are able to pass gases through a thermal converter, where they are mixed with fresh air and superheated to avoid fumes and odors. The use of low-fuming asphalt also helps to eliminate some odor and fume at the point of application.

Commissioning

No commissioning is needed for roof insulation systems.

References

See the Overview section of this chapter.

National Roofing Contractors Association (NRCA). 2001. *Roofing and Waterproofing Manual*. 5th ed. Rosemont, Illinois: NRCA. Refer to the guideline on moisture control for information on how to design the roof to control moisture that has entered the roof assembly.

GUIDELINE IN3: COOL ROOFS

Recommendation

In air conditioned buildings, use a roof surface that is light in color (high reflectance), yet has a non-metallic finish (high emissivity). Asphalt roofs with a cap sheet and modified bitumen roofs should be coated with a material having an initial reflectance greater than 0.7 and an emittance³⁹ greater than 0.8. Single-ply roofing material should be selected with the same surface properties.

Description

Solar gain on roofs is a significant component of heat gain and using materials that have a high reflectance and a high emittance can significantly reduce the load. The high reflectance keeps much of the sun's energy from being absorbed. The high emittance allows radiation to the sky. Cool roofs are typically white and have a smooth texture. Commercial roofing products that qualify as cool roofs fall in two categories: single-ply and liquid-applied. Examples of single-ply products include:

- White PVC (polyvinyl chloride).
- White CPE (chlorinated polyethylene).
- White CPSE (chlorosulfonated polyethylene, e.g., Hypalon).
- White TPO (thermoplastic polyolefin).



Figure 110—White Single Ply Membrane with Heat-Welded Seams

Source: BondCote Roofing Systems

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

³⁹ Heat radiated from a roof surface is proportional to the 4th power of the absolute temperature and depends on emittance. Emittance is the ratio of radiant heat flux emitted by a specimen to that emitted by a black body at the same temperature and under the same conditions.

Liquid-applied products may be used to coat asphalt cap sheets, modified bitumen, and other substrates. Products include:

- White elastomeric coatings.
- White polyurethane coatings.
- White acrylic coatings.
- White paint (on metal or concrete).

Cool roofs are becoming available in different colors. Table 24 shows reflectance and emittance for some typical roofing products.

Table 24—Cool Roof Options

Roof Type		Reflectance	Emittance	Cost (\$/ft ²)
Built-up	With white gravel	0.30–0.50	0.80–0.90	1.2–2.15
	With gravel and cementitious coating	0.50–0.70	0.80–0.90	1.2–2.15
	Smooth surface with white roof coating	0.75–0.85	0.85–0.95	1.2–2.15
Single-Ply	White (EPDM, CPE, CSPE, PVC)	0.70–0.78	0.85–0.95	1.0–2.05
Modified Bitumen	white coating over a mineral surface	0.60–0.75	0.85–0.95	1.5–1.95
Metal Roof	white, painted	0.60–0.70	0.80–0.90	1.8–3.75
Asphalt Shingle	white	0.25–0.27	0.80–0.90	1.2–1.5
Liquid Applied Coating	Smooth white	0.70–0.85	0.85–0.95	0.60–0.80
	Smooth off-white	0.40–0.60	0.85–0.95	0.60–0.80
	Rough off-white	0.50–0.60	0.85–0.95	0.60–0.80
Concrete Tile	White	0.65–0.75	0.85–0.90	3–4
	Off-white coating	0.65–0.75	0.85–0.90	3–4
Cement Tile		0.70–0.75	0.85–0.90	3–4

Source: Akbari, H., et al., "Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements," Code Change Proposal, PG&E, 2002

A new single rating for the thermal performance of cool roofs is the Solar Reflectance Index (SRI). This incorporates the effects of both solar reflectance and emissivity on the thermal performance of a cool roof. (This rating is being considered for the upcoming LEED 2.2 criteria.) SRI indices for cool roofs can be calculated from the Cool Roof Rating Council's CRRC-1 test procedure results. Specify cool roofs with an SRI index of 79 or higher.

An alternative method of reducing roof heat gain is to plant natural vegetation on the roof, commonly known as green roofs. Green roofs provide multiple benefits: they reduce solar heat gain and prevent rain and moisture from penetrating the roof membrane. Their application in schools may be limited if mechanical equipment is located on the roof.

Applicability

Cool roofs are applicable to all spaces in schools and to all California climates. The benefits are less, however, in the cold regions. In order to take advantage of equipment downsizing, cool roofs should be considered in the schematic design phase.

Applicable Codes

The 2005 California Energy Efficiency Standards now require cool roofs on low-sloped roofs⁴⁰ of commercial buildings. The cool roof must be certified by the Cool Roof Rating Council with a minimum initial solar reflectance (α) of 0.70 and minimum initial thermal emittance (ϵ) of 0.75. This organization has a rating procedure, CRRC-1, for certifying cool roofs. The standard allows for a tradeoff for cool roof products such as metallic surfaces that have an emittance less than 0.75 if their solar reflectance exceeds 0.70. Cool roofs are also considered in ANSI/ASHRAE/IESNA Standard 90.1-2001 and state energy codes in Georgia, Florida, and Hawaii. Credit may be realized for cool roof products that exceed minimum requirements if the whole building performance method of compliance is used.

The Leadership in Energy and Environmental Design (LEED) program administered by the U.S. Green Building Council (U.S. GBC) requires low-sloped cool roofs to have an initial solar reflectance of 0.65, and aged solar reflectance of 0.50, and a minimum thermal emittance of 0.9.

Integrated Design Implications

Cool roofs can significantly reduce cooling loads, allowing for the use of smaller air conditioning equipment or in some cases, eliminating air conditioning entirely in favor of natural ventilation. Like all roofing systems, skylights and other roof penetrations, as well as the rooftop equipment mounts, should be considered in the design of the roof. Equipment access should be provided in a manner that does not create undue wear or damage to the roof membrane.

The cooling load reduction from a cool roof is inversely proportional to the level of roof insulation. For insulation levels that meet minimum code requirements, cool roofs result in lower life-cycle costs.

Cool roofs reduce the need for plenum and attic ventilation.

Cool roofs will increase winter heating energy consumption since the heat transmission through the roof is reduced. This could result in increased gas-furnace emissions where natural gas is used for heating.

Cost Effectiveness

The additional cost for coating an asphalt cap sheet or modified bitumen roof is about \$1/ft² to \$2/ft². The cost premium for white coatings, cementitious coatings, or white gravel is very low, between \$0.05 and 0.20/ft²⁴¹.

Costs	L	M	H
Benefits			
L M H			

⁴⁰ A low-sloped roof is defined as having a rise to run ratio of 2:12 or less.

⁴¹ Akbari, H., et al. 2002. "Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements," Code Change Proposal, 2005 Title 25 Building Energy Efficiency Standards Update, PG&E,

California has implemented a rebate program for cool roofs. Qualifying roofs must be Energy Star certified. In addition, the roof must have an initial solar reflectance of 0.65 and thermal emittance of 0.80, or a solar reflectance index of 75%, calculated using ASTM E-1980.

Benefits

Cool roofs can save demand charges and energy charges. They are highly cost effective, especially in the desert and central valley climates. However, there are other benefits as well. Since solar radiation (especially ultraviolet light) is a major cause of roof deterioration, cool roof coatings can significantly increase the life of the roof membrane. Smaller daily thermal cycles in surface temperature will reduce the wear on the roof membrane caused by material expansion and contraction. Cool roofs also can help make the whole community cooler by reducing the “heat island” effect.



Figure 112—Elastomeric Being Applied Roof

Source: Dow Corning

Design Tools

Cool roofs are effective for a number of complex reasons. They reflect heat from the sun, and assessing this benefit requires a model that accounts for the position and intensity of the sun. Sun that is absorbed by the roof (that which is not reflected) increases the surface temperature of the roof and induces heat gain in addition to that driven by temperature differences. At night and at other times, hot roof surfaces radiate heat to the night cool sky. This is a valuable benefit that requires knowledge of the roof surface temperature and the sky temperature. Because of the complexity of heat transfer related to cool roofs, energy simulation programs are necessary to accurately assess their benefits.



Figure 111—Standing Seam Metal Roof with White Coating

*Source: Snap-Clad Metal Roofing and Boarman Kroos
Phister Rudin & Associates*

Oak Ridge National Laboratory's Radiation Control Calculator can be used to estimate energy savings. See www.ornl.gov/roofs+walls.

Design Details

The performance of cool roofs is affected by the accumulation of dirt. Dirt accumulation can be reduced if roof surfaces slope at least 0.25 in./ft.

When liquid applied coatings are used, carefully select coatings that are compatible with the underlying substrate.

Liquid applied cool roof coatings should comply with ASTM Standard 6083-97 for durability and elongation and have a minimum thickness of 20 mils.

Operation and Maintenance Issues

To ensure continued performance of cool roofs, they need to be cleaned each year with a high-pressure water spray. (Verify that doing this does not void the product warranty.) Liquid-applied coatings may need to be refinished every 5 years or so.

Commissioning

No commissioning is needed.

References

- Akbari H., et al. 1997. Peak Power and Cool Energy Savings of High-Albedo Roofs. *Energy and Buildings* 25 (2):117–126.
www.ingentaconnect.com/content/els/03787788/1997/00000025/00000002
- Berdahl P.; Bretz S.E. 1997. Preliminary Survey of the Solar Reflectance of Cool Roofing Materials. *Energy and Buildings* 25 (2):149–158.
www.ingentaconnect.com/content/els/03787788/1997/00000025/00000002
Also, Lawrence Berkeley National Laboratory Report LBL-36020, Berkeley, CA.
<http://eetd.lbl.gov/HeatIsland/PUBS/PUBSLIST>
- Bretz S.E.; Akbari H. 1997. Long Term Performance Of High-Albedo Roof Coatings. *Energy and Buildings* 25 (2):159–167.
www.ingentaconnect.com/content/els/03787788/1997/00000025/00000002
- Environmental Protection Agency, U.S. 1998. Roof Products MOU—Version 1.0.
www.energystar.gov/index.cfm?c=product_specs.pt_product_specs_historical
- Gartland, L. January 1999. Cool Coatings Heat Up Savings. *Maintenance Solutions*
www.protek-ca.com/resources/articles/article1.htm
- Levinson, R., et al. December 2002. Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements. Lawrence Berkeley National Laboratory. Paper LBNL-50451.
<http://repositories.cdlib.org/lbnl/LBNL-50451>
- Parker D.S., et al. 1993, rev. 2000. Laboratory Testing of The Reflectance Properties of Roofing Materials. FSEC-CR670-00. Cocoa FL: Florida Solar Energy Center.
www.fsec.ucf.edu/bldg/pubs/cr670/

Parker D.S.; Barkaszi S.F. 1997. Roof Solar Reflectance and Cooling Energy Use: Field Results from Florida. *Energy and Buildings* 25 (2):105–115.

www.ingentaconnect.com/content/els/03787788/1997/00000025/00000002

Rosenfeld, A.H., et al. 1995. Mitigation of Urban Heat Islands: Materials, Utility Programs, Updates. *Energy and Buildings* 22 (3): 255–265.

www.ingentaconnect.com/content/els/03787788/1995/00000022/00000003

Also Lawrence Berkeley National Laboratory Report LBL-36587.

<http://eetd.lbl.gov/HeatIsland/PUBS/PUBSLIST>

Simpson J.R.; McPherson E.G. 1997. The Effects of Roof Albedo Modification on Cooling Loads of Scale Model Residences in Tucson, Arizona. *Energy and Buildings* 25 (2):127–137.

www.ingentaconnect.com/content/els/03787788/1997/00000025/00000002

Taha, H. 1997. Urban Climates and Heat Islands: Albedo, Evapo-Transpiration, and Anthropogenic Heat. *Energy and Buildings* 25 (2):99–103.

www.ingentaconnect.com/content/els/03787788/1997/00000025/00000002

Additional Information

Berdahl, 2000. Cool Roofing Materials Database. Lawrence Berkeley National Laboratory, Berkeley, CA.

<http://eetd.lbl.gov/coolroof/>

GUIDELINE IN4: RADIANT BARRIERS

Recommendation

Use a radiant barrier in conjunction with attic construction in schools in all climates.

Description

A radiant barrier is a surface with a low emittance that is installed at the ceiling of attics. The radiant barrier surface is usually aluminum foil or another shiny metallic finish that has a low emittance. A couple of installation methods exist. The least costly method is to use plywood or composition board with a film that is pre-applied to the board. An alternate, and more effective method, is to drape foil over the rafters before the sheathing is installed.

Radiant barriers are effective because they reduce one of the major components of heat gain, which is radiation from the hot attic ceiling to the cooler attic floor. The amount of heat that is radiated from the attic ceiling to the floor is directly proportional to the emissivity of the surfaces. Uncoated plywood and most other conventional building materials have an emittance of about 0.8, while the surface of a radiant barrier has an emittance of around 0.1. The radiation component of heat transfer can, therefore, be as much as eight times lower than without a radiant barrier.

Radiant barriers are effective in reducing cooling loads, but not heating loads. Radiant barriers can also improve the system efficiency of HVAC air distribution ducts that are located in attics. Duct losses during cooling mode are proportional to the temperature difference between air inside the duct and the temperature of the attic. Radiant barriers reduce the temperature of the attic during cooling conditions, and therefore, duct system efficiency is improved.

Applicability

Radiant barriers are highly recommended in the central valley and desert climates of California. They can also be effective in coastal climates. They are recommended for attics over any spaces that are



Figure 113—Installing Radiant Barrier

Source: Toolbase (Permission not requested)

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

cooled by air conditioners or natural ventilation. Radiant barriers should be considered no later than the design development phase so that the HVAC equipment may be appropriately downsized.

Applicable Codes

The California Building Code, which applies to schools, does not recognize radiant barriers. However, the California standards for low-rise residential buildings require radiant barriers in central valley and desert climates.

A radiant barrier must be rated Class A by the National Fire Protection Association or Class I by the Uniform Building Code (UBC). To meet the requirement, the material must have a Flame Spread Index of 25 or less and a Smoke Developed Index of 450 or less, as tested by ASTM E-84. Look for these ratings on material data sheets provided by the manufacturer.

Integrated Design Implications

Radiant barriers directly reduce cooling loads, which can result in smaller air conditioners. HVAC air duct efficiency is also improved when air distribution ducts are located in attics.

Cost Effectiveness

When applied to sheathing, the cost premium for radiant barriers is on the order of \$0.10/ft² to \$0.15/ft². Cost is a little higher for draped installation, mainly because additional labor is required.

Costs	L		
	M		
	H		
	L	M	H
Benefits			

Benefits

Radiant barriers reduce cooling loads and energy costs. They can also result in smaller air conditioners, which can more than compensate for the added cost of the radiant barrier. Attics where radiant barriers are installed have a lower temperature, which results in improved HVAC duct efficiency and other benefits.

In temperate California climates, the primary benefit is the reduction in load attributable to heat transmission through the roof. At peak cooling conditions, the radiant barrier blocks nearly 100% of roof heat gain. The primary benefit is the reduced peak demand, and lower cooling capacity for equipment. Because of the cool nights typical in most California climates, the net energy benefit is lower when averaged over the cooling season. The benefit will be much greater for schools with year-round operation.

As with cool roofs, the benefit of the radiant barrier is proportional to the heat gain through the roof. If the building already has a cool roof and good insulation levels, the energy savings specifically attributed to the radiant barrier will be much lower.

Design Tools

Estimating the benefits of radiant barriers can be approximated by making an adjustment to the U-factor of the ceiling/roof construction. The problem with this approach is that radiant barriers only have a benefit in reducing cooling loads. In fact, they can have a slightly negative effect on heating loads, since solar gains are reduced which might be useful when schools are in a heating mode. The most accurate way to evaluate radiant barriers in attics is to use an hourly simulation model where the attic itself is modeled as a separate, unconditioned thermal zone, and where radiation transfer can be explicitly modeled. The only models with these capabilities are for research purposes and are difficult for practitioners to use. However, the U.S. Department of Energy (DOE) released a tool called EnergyPlus, which has these capabilities. Version 1.2 was released in April 2004.

Design Details

Choose radiant barrier surfaces that have an emittance less than 0.1, when tested in accordance with ASTM E408. When comparing products, select a product with the lowest emittance. Some have an emittance as low as 0.05.

Install radiant barriers so that the shiny surface faces down to prevent dirt from accumulating on the surface. Dirt can depreciate performance.

When using radiant barriers that are pre-applied to sheathing, make sure that care is taken to not damage the surface during shipping and installation.

When using the draped method of installation, let the radiant barrier sag about an inch from the sheathing, creating an additional air gap. This accounts for the improved performance of the draped method of installation.

Use caution if installing radiant barriers on top of attic floor insulation. During colder weather, a radiant barrier could cause condensation to be trapped on the inside. If using radiant barriers over floor insulation, consider barriers that have high vapor permeability values, allowing moisture to escape.

Operation and Maintenance Issues

Radiant barriers rarely require any maintenance, unless they are damaged while other maintenance work is being performed in an attic.

Commissioning

No commissioning is necessary.

References

Oak Ridge National Laboratory. June 1991. *Radiant Barrier Fact Sheet*. U.S. Department of Energy.
www.ornl.gov/sci/roofs+walls/radiant/rb_01.html

Medina, M. May/June 2003. Radiant Barriers: Depends on Where You Live. *Home Energy* 20 (3): 14–16.

California Energy Commission. 2001. *Residential Alternative Calculation Method Approval Manual* The California ACM Approval Manual for low-rise residential buildings has detailed installation requirements in Section 4.24. This document is available at www.energy.ca.gov/.

Additional Information

Ross Middle School, Ross, CA. Architect: Esherick Homsey Dodge & Davis.

The California Bureau of Home Furnishings (as part of insulation certification) certifies radiant barriers with an initial product emissivity of 0.05 or less.

Reflective Insulation Manufacturers Association (RIMA)
661 East Monterey
Pomona, CA 91767
Telephone: 714-620-8011

GUIDELINE IN5: REDUCE INFILTRATION

Recommendation

Design and construct the building envelope to limit the uncontrolled entry of outside air into the building. This is achieved through building envelope sealing (caulking and weatherstripping), specifying windows and doors that have been tested to have low rates of infiltration, and by using air lock entries in cold climates. Specify windows that have a low air leakage rate, less than 0.30 cfm/ft², as tested by NFRC rating procedures.

Description

Controlling infiltration is very important to achieving energy-efficient buildings. Air leakage introduces sensible heat into conditioned and semi-heated spaces. In climates with moist outdoor conditions, it is also a major source of latent heat. Latent heat must be removed by the air conditioning system at considerable expense. The ANSI/ASHRAE/IESNA 90.1-2001 Standard has requirements for the sealing of building envelope elements, infiltration through doors and windows, and vestibules to limit infiltration at main entrance doors to buildings.



Figure 114—Performing a Blower Door Test for Testing Air Infiltration Rates

Source: Energy Conservatory (Permission not yet requested)

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

Applicability

Schools in all climates should be sealed to reduce infiltration, but it is especially important in the more harsh climates such as the cold, central valley and desert climates. The recommendations apply to all spaces in schools. Sealing and infiltration control should be first considered in the design development phase, but details should be specified in the contract documents. Tight construction is mainly a matter of care during construction and should be verified during construction and verified in the commissioning phase.

Applicable Codes

The California Building Code specifies minimum infiltration rates for fenestration products and requires that the building envelope be sealed to reduce unwanted infiltration.

The 2005 Title 24 standard requires fenestration products and single doors to have air leakage rates not exceeding 0.3 cfm/ft², and double doors to have air leakage rates not exceeding 1.0 cfm/ft², as tested by NFRC 400 or ASTM E 283.

Integrated Design Implications

Poorly sealed buildings can cause problems for maintaining comfort conditions when additional infiltration loads exceed the HVAC design assumptions.

Infiltration of warm, moist outside air can cause condensation on surfaces within the building assembly. Materials that are air barriers also inhibit moisture migration. See the guideline on Moisture Control for more information.

Cost Effectiveness

The cost of controlling infiltration is minimal. Mainly it is a standard of care that must be exercised during the construction phase.

	L		
Costs	M		
	H		
	L	M	H
	Benefits		

Benefits

Controlling infiltration makes it easier to balance and maintain HVAC systems. Energy costs are also reduced in a cost-effective manner. As warm, moist outside air moves through the building assembly, the air is cooled, which can result in condensation within the construction. Condensation can lead to mold growth, degradation of insulation performance, and structural damage, if not treated. Condensation will also accelerate corrosion of metal components in the building assembly.

Design Tools

All energy calculation methods are capable of accounting for infiltration in some manner. Some use an air-changes-per-hour method, while others are based on the concept of an effective leakage area. Many hourly simulation methods are capable of modeling infiltration using either calculation method. During construction, air leaks can be detected and repaired through pressurization tests, often called blower door tests. With this procedure, a building or space is pressurized with a large fan that is usually mounted in the door (thus, blower door). The space is pressurized to about 50 Pascals of pressure and leakage is measured. The location of leaks can be identified using smoke sticks.

Design Details

Exterior joints, cracks, and holes in the building envelope shall be caulked, gasketed, weather stripped, or otherwise sealed. The construction drawings and specifications should require the sealing, but special attention is needed in the construction administration phase to ensure proper workmanship. A tightly constructed building envelope is largely achieved through careful construction practices and attention to detail. Special attention should be paid to several areas of the building envelope including:

- Joints around fenestration and door frames.
- Junctions between walls and foundations, between walls at building corners, between walls and structural floors or roofs, and between walls and roof or wall panels.
- Openings at penetrations of utility services through roofs, walls, and floors.
- Site-built fenestration and doors.
- Building assemblies used as ducts or plenums.
- Joints, seams, and penetrations of vapor retarders.
- All other openings in the building envelope.

ANSI/ASHRAE/IESNA Standard 90.1 also has requirements for limiting infiltration through mechanical air intakes and exhausts. These requirements are addressed in the mechanical section (§ 6) of the standard, not in the building envelope section.

Fenestration and Doors

Fenestration products, including doors, can significantly contribute to infiltration. For glazed entrance doors that open with a swinging mechanism and for revolving doors, the infiltration should be limited to 1.0 cfm/ft². Infiltration rates should be verified with NFRC 400. A laboratory accredited by the NFRC or other nationally recognized accreditation organizations must perform the ratings.

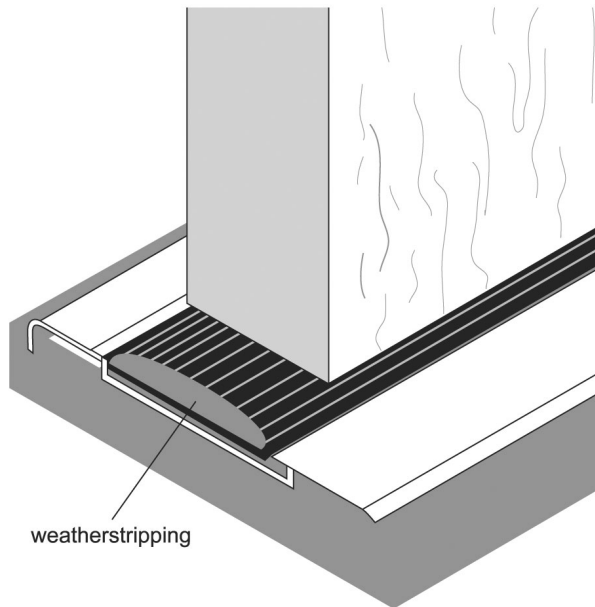


Figure 115—Door Weatherstripping

Vestibules

In cold California climates, vestibules should be created at the main entrance to schools. All the doors entering and leaving the vestibule must be equipped with self-closing devices and the distance between the doors should be at least 7 ft. This distance allows for exterior doors to close before the interior doors are opened, and complies with the Americans with Disabilities Act (ADA). The vestibule helps to control air pressure differences between indoors and outdoors. It reduces infiltration in the summer and exfiltration in the winter.

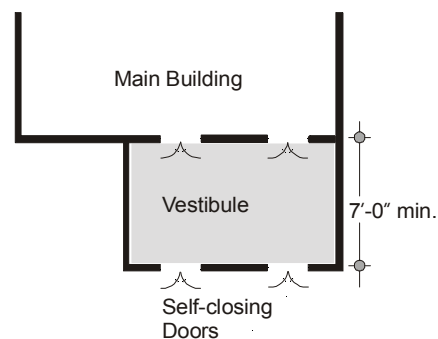


Figure 116—Vestibule Diagram

Air Barriers

Materials are considered air barriers if they have a permeability rating less than 0.004 cfm/ft² at a pressure of 0.3-in. w.g., according to standard ASTM E 2178.

Bituminous roof membranes, extruded polystyrene, plywood sheathing (1/2-in. thickness), foil-backed gypsum, foil-faced urethane and phenolic insulation, and closed-cell urethane foam are common air barrier materials. An air barrier system must be designed for continuity, durability, air impermeability, and structural support. The air barrier should be designed to last the life of the structure. The load imposed by wind and stack effects must be properly transferred to the building structure.

Air barriers can be classified as:

- Combined air and vapor barrier systems—can be asphalt membranes, fluid-applied membranes, torch-applied membranes or spray-applied urethane foams. They provide both an air barrier and a high resistance to vapor diffusion. These are installed on the winter-warm side of an exterior wall system.
- Vapor permeable air barrier systems—fluid-applied barriers that intentionally allow water vapor to pass through the material. These are located away from the condensing plane of the structure.
- Multi-component systems—consist of several air barrier materials joined by sealants, tape or foams. Quality of construction and coordination between trades is crucial in ensuring the air barrier effectiveness.

More information and sample installation details can be obtained from the Air Barriers Association of America (see www.airbarriers.org).

Operation and Maintenance Issues

Weatherstripping around doors and other openings must be maintained and replaced every 5 to 10 years. Caulking in exposed locations will need to be replaced or touched up each time the exterior of the school is painted.

Commissioning

The commissioning agent should verify that weather stripping and caulking is properly installed. Fenestration products should be labeled by NFRC to enable easy field verification of the infiltration requirements. Commissioning air barrier systems involves both visual and qualitative evaluations and tests, as well as quantitative testing. The Air Barrier Association of America provides product certifications and recommended test procedures. A “Level 2” contractor (with 3,000 hours experience) should be on the job site continuously when an air-vapor barrier is installed. Verifying the installation of an air barrier involves visual inspection, an adhesion test, and testing air infiltration rates through building pressurization.

Testing of air infiltration rates can be performed using either a building pressurization, a “blower door” test, or the use of a tracer gas. The ASTM E779-99 test procedure involves pressurizing a single-zone (such as a classroom with a packaged unit) with the supply fan. The Brookhaven National Laboratory developed a technique that measures the concentration of a PerFluorocarbon tracer gas (PFT) over time. The technique uses a small emitter of the gas and a receiver, which measures the average concentration of the gas in the room. While this method does not pinpoint the source of air leaks, it can reveal long-term problems with infiltration.

References/Additional Information

Nonresidential Manual for Compliance with the 2005 Energy Efficiency Standards, California Energy Commission, available from www.energy.ca.gov/.

Installing Caulking and Weatherstripping, www.weservehomes.com/diy/ha_diy.html.

Weatherstripping to Reduce Heating and Cooling Bills,
www.doityourself.com/energy/weatherstripping.htm.

Advanced Building Guideline, Reference Manual, New Building Institute, 2004.

Air Barrier Association of America 1600 Boston-Providence Highway Walpole, MA 02081 (866) 956-5888 Fax (866) 956-5819. The Air Barrier Association of America (ABAA) is a non-profit corporation organized to inform and educate the building construction industry of the values of including an air barrier system in building construction.

Commercial Air Barrier Systems—Professional Contractor Quality Assurance Manual, Air Barrier Association of America, 2001.

GUIDELINE IN6: SLAB ON GRADE INSULATION

Recommendation

Provide exterior insulation for slab-on-grade floors to prevent moisture condensation in cold, desert and mountain climates. Provide a vapor barrier to prevent moisture migration up through the slab.

Class of Wall	South Coast, North Coast Climates	Central Valley, Desert, Mountain
Slab-on-Grade	No requirement for unheated slabs. For heated slabs, use R-7 of continuous insulation for 12 in. and R-5 continuous insulation below the slab.	Use a minimum of R-10 continuous insulation for 24 in. around the perimeter for unheated slabs. For heated slabs, use continuous insulation below the slab.

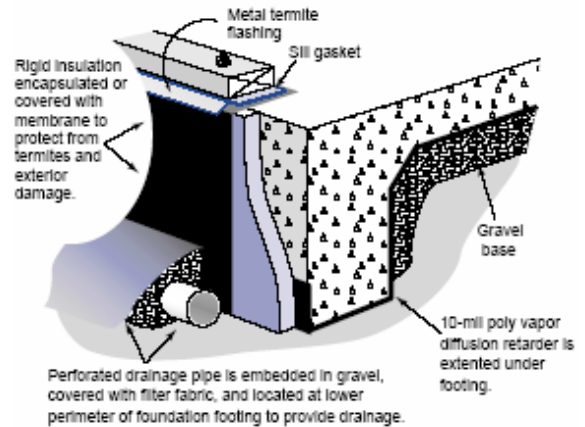


Figure 117—Slab Edge Insulation

Source: Technology Fact Sheet, Slab Insulation, Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department Of Energy

Description

Most school facilities in California use slab-on-grade construction. Slab-on-grade floors should be insulated around the perimeter to reduce heat loss to outdoors. Most of the winter heat loss occurs at the perimeter, through the foundation to the cold outside air. In some climates, continuous insulation should be placed beneath the slab. The requirement distinguishes two classes of slabs: heated and unheated. Heated slabs contain hot water piping or coils embedded within the slab or beneath the slab to provide for space heating. Since the heat losses are greater from the warmer heated slab, more insulation is required.

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

Applicability

These recommendations apply to all slab-on-grade floors in all spaces that are heated or cooled.

Applicable Codes

Insulation must meet Title 24 requirements and meet national fire protection codes.

Integrated Design Implications

A vapor barrier may be required underneath the slab to prevent moisture from migrating upwards through the slab. A thin layer of low-density polyethylene can be placed underneath the slab to prevent moisture migration. In cold climates, a layer of continuous insulation should be placed directly underneath the slab, to maintain the slab and floor above the dewpoint temperature. In cold climates, the frost line also acts as a vapor barrier.

Carpet will provide a small increase in the floor insulation level: typically carpet provides an R-2 to R-3 insulation level. The increase in surface temperature will improve thermal comfort.

The use of insulation at the slab perimeter will reduce heat loss and eliminate cold drafts. This may reduce or eliminate the need for perimeter heating.

Cost Effectiveness

Installation costs for slab insulation are generally low. For instance, for residential construction, installation cost is \$0.15-0.35 / ft².⁴² Costs can be higher in some instances because of issues related to coordinating insulation installation with other trades.

Benefits

The benefits of additional insulation are reduced heating and cooling requirements, due to reduced envelope loads. Insulation at the floor will also enhance comfort, by helping to maintain a floor temperature closer to room temperature.

Costs	L		
	M		
	H		
		L	M
		Benefits	

Design Tools

Building energy simulation tools such as DOE-2 may be used in determining the impact of insulation on building cooling and heating loads, but modeling ground heat transfer is tricky and needs to be pursued with caution. It is important to both capture the thermal mass effects as well as the heat loss. Simulation tools allow exterior components to be coupled to exterior air or to ground temperature, which can be entered as a schedule. Coupling to ground temperature is more accurate and the ground temperatures should approach the monthly average dry-bulb temperature.

For most projects, it is best to use published values that are based on tested data or advanced calculation procedures. Calculation of F-factors for slab perimeter heat losses requires two-dimensional heat transfer models. Computer programs are available for calculating the thermal conductance (U-factor) of complex assemblies (Therm-LBNL, EZFrame). Computer programs are also available for

⁴² Southface Energy Institute, "Insulating Foundation and Floors," 2003. Southface Energy Institute, 241 Pine St., Atlanta, GA 30308, 404-872-3549, www.southface.org.

calculating two or three-dimensional heat transfer using finite difference or finite element methods (ANSYS).

The 2005 California Title 24 Energy Efficiency Standards has tables with F-factors for slab-on-grade floors. Information can be found in Joint Appendix IV of the standard, and can be accessed on the California Energy Commission's Web site: www.energy.ca.gov/title24/2005standards/index.html.

Design Details

The figure below shows acceptable methods of using perimeter insulation for slab-on-grade.

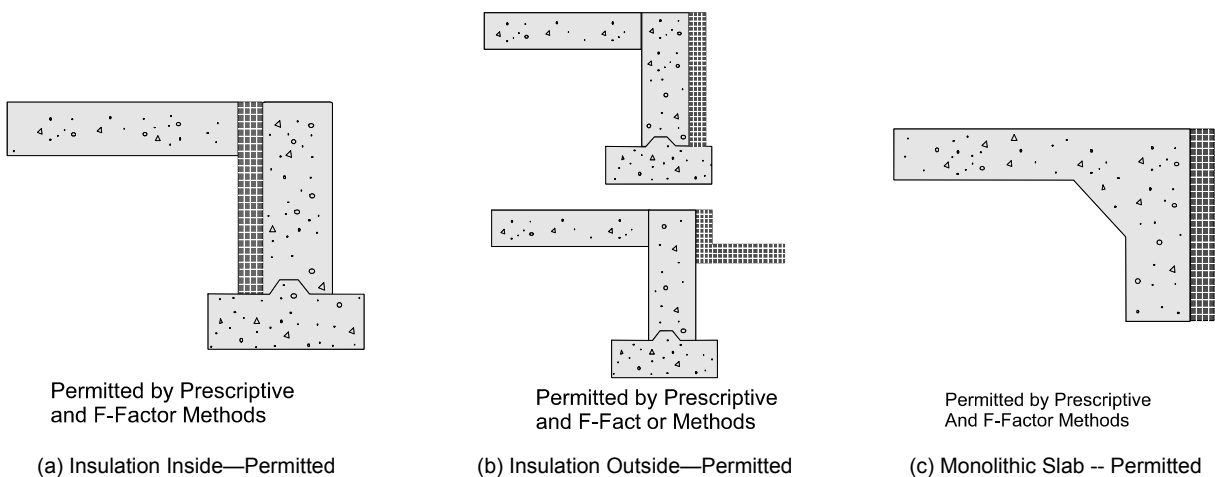


Figure 118—Slab-On-Grade Acceptable Perimeter Insulation Types

Source: ASHRAE 90.1-2001 User Manual

It is essential to use insulating materials that will not deteriorate when exposed to water. Extruded polystyrene is the preferred material because it has closed cells. Avoid using expanded polystyrene or polyisocyanurate, as the cells can fill with water and the insulation becomes ineffective.

Slab edge insulation is usually both above grade and below grade. The part that is above grade needs to be protected from ultraviolet (UV) exposure and from physical damage from landscaping and maintenance equipment.

In some areas, termite infestation can be a problem with slab insulation. The rigid insulation can provide a path for insects to enter the building. Refer to the CHPS Maintenance and Operations Manual (Volume IV) on integrated pest management recommendations.

Operation and Maintenance Issues

Foundations are susceptible to moisture infiltration and deterioration due to contact with earth. Keep all untreated wood materials away from the earth to avoid contact with the soil. In termite-prone areas, extra care should be taken to prevent termites from tunneling through insulation.

Provide an adequate drainage system to drain water away from the building. The earth should be sloped away from the building at a 5% grade to allow for adequate drainage.

Commissioning

No commissioning of slab-on-grade floors is needed other than normal construction administration.

References/Additional Information

Advanced Building Guidelines Reference Manual, New Buildings Institute, 2004.

Technology Fact Sheet, Slab Insulation, Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department Of Energy

ASHRAE 90.1 Users Manual

ASHRAE Handbook of Fundamentals

Southface Energy Institute, "Insulating Foundation and Floors," 2003. Southface Energy Institute, 241 Pine St., Atlanta, GA 30308, 404-872-3549, www.southface.org.

GUIDELINE IN7: FENESTRATION PERFORMANCE

Recommendation

Specify double-paned windows with low-emissivity coatings for energy performance. Such windows should be certified by the NFRC. If aluminum framing is used, specify a frame with a thermal break. Shade south-facing windows with exterior overhangs. When using skylights or windows for daylighting, specify products with a high visible light transmittance and low solar heat gain.



Figure 119—Skylight Used at Capistrano Unified with Dimming Controls

Source: Energy Design Resources

Description

Fenestration (windows and skylights) serves many purposes. It provides a connection to the outdoor environment, daylighting and in the case of operable windows, natural ventilation. This guideline focuses on the thermal performance of windows and skylights.

The thermal performance of fenestration can be measured by two properties: the U-factor and the SHGC, both described in the overview of this chapter. U-factor affects both heating and cooling requirements, while SHGC primarily affects cooling loads. For skylights, and windows intended for daylighting, a glazing should be selected that has a high VLT and a low solar heat gain.

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

Applicability

These recommendations apply to all spaces that are heated or cooled. Some window types are designed specifically for certain types of spaces—refer to the Lighting chapter for details.

Applicable Codes

The NFRC has procedures for determining the thermal performance of fenestration products. The NFRC has established a rating system to evaluate the whole window performance including the frame, spacer, and glazing. More information can be found at their Web site, www.nfrc.org. The whole-window U-factor, VLT, and SHGC are shown on a label attached to all rated windows. Site-built windows and skylights will not have these ratings available.

The American Architectural Manufacturers Association (AAMA) has a voluntary specification for skylights. This specification, AAMA 1600, provides rating procedures for measuring air infiltration and water penetration. Contact the AAMA for more information.

A maximum window to wall ratio (WWR) of 40% is allowed for commercial buildings, as specified in the 2005 Title 24 standards. Refer to the Overview for fenestration requirements for different climate regions.

Integrated Design Implications

Windows used for daylighting can reduce electric lighting requirements, which will reduce electricity use and lower peak cooling demand. High performance windows can prevent cold interior surface temperatures, reducing or eliminating the need for perimeter heating in many California climates.

The amount of glazing used has a large impact on the space heating and cooling loads. In California classrooms, window areas are typically well below the limits required by Title 24.

Interior shading devices are not required by code, but will reduce solar heat gain, lowering cooling loads. When used, Venetian blinds can reduce the radiant heat transmission through windows by 25%–30%. Tightly closed vertical blinds can reduce heat transmission by as much as 70%.

High performance windows will reduce heating and cooling loads and impact the sizing of HVAC equipment. Also, windows with low U-factors will improve thermal comfort, by keeping the window inner surface temperature closer to room temperature.

The benefits of high performance windows depend on the window area. Windows with low SHGC and U-factors are especially important for buildings with larger window areas.

Good daylighting design will reduce lighting requirements for portions of the building. Refer to the Chapter on Daylighting Design for more information.

For skylights, the skylight area should be between 3%–12% of the daylit floor area. Double-glazed skylights are recommended for cold, mountain and some inland valley climates, while single-glazed skylights are sufficient for temperate coastal climates.

Cost Effectiveness

High performance glazing costs a little more, but is extremely cost effective. Double-paned glass has a cost premium of \$3–\$4 per ft² and low-e coatings have a premium of \$1–\$2 per ft². Often cooling and heating capacity can be reduced and heating and cooling energy will also be reduced. These first cost and operating cost savings usually more than offset any cost premium associated with high performance windows and skylights.

Benefits

High performance windows have several important benefits for high performance schools:

- Cooling and heating energy use is reduced.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.
- Well-insulated windows will be more resistant to condensation.

Costs	L			
	M			
	H			
		L	M	H
		Benefits		

Design Tools

The Overview section of this chapter has a discussion of methods and procedures for calculating U-factors. Building energy simulation programs (DOE2, EnergyPlus, BLAST) are useful in determining the effect of window area and thermal performance on heating and cooling requirements.

SkyCalc is a free software tool that was developed for Southern California Edison as part of a California Public Interest Energy Research (PIER) research project. It enables the user to determine the best skylighting strategy to minimize lighting and electricity energy use. Refer to www.energydesignresources.com/resource/129/ for more information.

Design Details

The fenestration frame holds the glazing material in place and forms the structural link with the building envelope. The frame and the spacer between the glazing panes in multiple glazed units form a thermal short circuit in the insulating value of the fenestration. This degradation of the U-factor at the fenestration perimeter can be minimized with high performance frame and spacer technologies now available. This is important both for energy conservation and the potential for condensation on the frame.

Frames are available in metal, wood, vinyl, composite, and fiberglass. Metal frames conduct the most heat and must have a thermal break for good performance. Windows with insulated vinyl and fiberglass frames have the lowest U-factor. Vinyl and plastic frames are low maintenance and require no paint, but

the use of PVC can contribute to pollution, and thermal expansion can lead to premature failure of the seal. Fiberglass frames are durable with good energy performance, but emissions can affect IAQ, and the manufacturing process causes pollution. Specify durable, factory-applied finishes for metal frames.

Exterior overhangs should be deep enough to minimize direct sunlight on the window during the hottest times of the year. For south-facing windows, a good rule-of-thumb is to design the overhang with a shading cutoff angle about equal to 90° minus the site latitude. This provides full shading between March 21 and September 21. Providing good exterior shading can dramatically reduce peak cooling loads and cooling energy use. Overhangs for windows facing east and west should be carefully designed for the specific site, climate and space. Deciduous trees located south of a window can also provide summertime shading.

The NFRC also includes optional test procedures for rating air leakage and condensation resistance. The air leakage test determines a leakage rate in cfm/ft^2 of window area; typical ratings are 0.1–0.3.

Window Performance

High performance windows have a high VLT relative to the solar gain: they let the light in but not the heat. High performance fenestration features include double and triple glazing, low-emissivity coatings, and blue/green tints. These have become a very important means of energy conservation in modern construction to reduce both thermal losses and solar gains, while providing natural daylight. Fenestration has three principal energy performance characteristics, which have been identified by the NFRC to be tested and labeled on manufactured windows: VLT, SHGC, and U-factor. (These properties are defined in the Overview to this chapter.) Site-built windows and skylights may or may not have such tested information available.

In general, the U-factor and SHGC should be as low as possible. However, there are some tradeoffs between SHGC and U-factor. A high performance window with a low SHGC will lower summer cooling loads, but will reduce solar heat gain during the winter, resulting in higher heating loads. For buildings in colder climates that have high heating loads, the U-factor becomes more important. In California, most of the heat gain through windows is solar heat gain, so SHGC has a greater effect than the U-factor on cooling requirements.

There are different ways that manufacturers achieve high performance windows. First, tints will reduce the solar heat gain (lower SHGC), but will also reduce the VLT. Tints will not affect the U-factor. A second strategy is to use a coating on top of the glazing. Reflective coatings reduce heat gain and glare, but do not let light pass through. This has led to the development of “low e” coatings. “Low-e” coatings are spectrally selective: they reduce heat transmission while letting visible light pass through.

To reduce the U-factor, multiple layers of glazing are used, with air or inert gases used to fill the gaps between layers. Multiple glazings are applicable to cold climates with significant heating loads. The space between panes affects the performance: the thicker the air space, the better the insulation. However, if the space becomes too wide, convection occurs between glazing layers. Performance is not improved beyond an air gap of about 1 in. Combinations of these strategies are often used. With low-e

coatings, multiple glazings and the use of gas fills, windows can achieve SHGC values as low as 0.2 and U-factors as low as 0.25.

The table below provides standard practice (Title 24-compliant) fenestration products and best practice fenestration for different climate regions. Values are representative thermal performance characteristics of high performance windows. When specifying a fenestration product, NFRC rating data should be used. For coastal and mountain climates, the recommendation significantly reduces both the SHGC and U-factor. For valley and desert climates, high performance fenestration will provide a large reduction in SHGC and modest reduction in U-factor. Other fenestration options may provide even better thermal performance.

Table 25—Standard and High Performance Fenestration

Climate	Standard Practice				High Performance					
	Glazing	Frame	SHGC	U-factor	Glazing	Frame	SHGC	Diff.	U-factor	Diff.
Mountains	Tinted double low-e	Metal	0.39	0.57	High perf. tint double low-e	Metal with thermal break	0.31	21%	0.42	26%
North Coast	Tinted double low-e	Metal	0.39	0.57	High perf. tint double low-e	Metal with thermal break	0.31	21%	0.42	26%
South Coast	Tinted double low-e	Metal	0.39	0.57	High perf. tint double low-e	Metal with thermal break	0.31	21%	0.42	26%
Valley	High perf. tint double low-e	Metal with thermal break	0.36	0.49	Reflective high perf. tint double low-e	Metal with thermal break	0.19	47%	0.42	14%
Desert	High perf. tint double low-e	Metal with thermal break	0.36	0.49	Reflective high perf. tint double low-e	Metal with thermal break	0.19	47%	0.42	14%

Source: Small HVAC System Design Guide, California Energy Commission, 2003. Standard practice meets current Title 24 envelope requirements. Best practice glazing fenestration uses insulated spacers.

Skylight Performance Characteristics

Skylights are an effective method of providing natural daylight to school classrooms. High performance glazings are designed to transmit visible light while blocking solar radiation. As with windows used for daylighting, skylights should have a high VLT and low SHGC. A measure of the glazing effectiveness is the light to solar gain (LSG) ratio, the ratio of the visible light transmittance to solar heat gain (VLT/SHGC). For skylights this ratio should exceed 1.1.

Some skylights have automatic or manual louvers to block direct sunlight, useful when lower light levels are desired (such as during video presentations).

Skylight glazings can be glass, acrylic, polycarbonate or fiberglass. Some examples of high performance skylight glazings are shown in the table below.

Table 26—Representative Properties of Skylight Glazings

Type	Glazing	Color	VLT	SHGC	LSG
Acrylic/fiberglass	Single	Clear	0.92	0.77	1.19
		Med White	0.42	0.33	1.27
	Double	Clear	0.86	0.77	1.10
		Med White	0.39	0.30	1.28
Fiberglass	Insulated translucent	Crystal	0.30	0.30	1.01
Glass	Single	Clear	0.89	0.82	1.09
		Green	0.74	0.59	1.25
	Double	Clear	0.78	0.70	1.11
		Green	0.66	0.47	1.40
	Double, low-e	Clear	0.72	0.57	1.25
		Bronze	0.45	0.39	1.15
		Green	0.61	0.39	1.56
	Triple, low-e	Clear	0.70	0.53	1.32
		Bronze	0.42	0.37	1.14
		Green	0.61	0.38	1.61

Source: Energy Design Resources, www.energydesignresources.com/docs/sq-3-specs.pdf. For specific products, consult NFRC ratings.

In addition to the skylight itself, the effectiveness of the skylight at distributing light depends on the skylight well. A portion of the light that is transmitted through the skylight glazing will strike the skylight well. Some of this light will reflect off the well and be transmitted back out of the skylight. The skylight efficacy is a measure of the light that is transmitted through skylight glazing and skylight well to the space relative to the heat gain through the skylight. Using highly reflective surfaces for the skylight well will maximize the amount of light transmitted to the room. This is especially important for skylights with deep wells.

Diffusing properties of skylights should also be considered. A highly diffuse material will scatter the light and provide a more even light distribution. The ability of glazing to diffuse light is a distinct property from the VLT. A highly diffuse material that is not transparent can still have a high VLT. Unfortunately, specifications on diffusion properties are rarely available for fenestration products. A simple diffusion test is to place a sample of the product in the sun and see if it allows your hand to cast a shadow. A fully diffusing material will blur the shadow beyond recognition and will not concentrate the sunlight into local hot spots.

As with windows, heat transmission through the skylight is characterized by the U-factor. The U-factor primarily impacts winter heating loads. In the summer most of the heat gain through skylights is via solar radiation. Flush-mounted frames that are assembled on site will have less framing area exposed to the outdoors, and consequently, lower U-factors than integral frames.

Operation and Maintenance Issues

UV degradation and other aging effects may occur with some glazings. Durability characteristics, such as structural strength, scratch resistance, breaking and fire resistance, should be considered when selecting a glazing. Cleaning of windows will ensure proper VLT of daylight windows. Windows should be inspected and recaulked according to manufacturer's recommendations.

UV degradation and other aging effects may occur with some glazing materials. Durability characteristics, such as structural strength, scratch resistance, breaking, and fire resistance, should be considered when selecting a glazing. The VLT will change over time. Some skylight glazing materials, such as fiberglass, are particularly susceptible to UV degradation. Consult with manufacturer's specifications for long-term performance.

Commissioning

The commissioning process begins at the design phase. The design intent document should include a specification of energy performance goals and how those goals will be met.

Whole building commissioning involves inspection of the quality of the construction and checking details such as window flashing. The quality of construction ensures that performance meets design expectations and helps prevent problems with air infiltration and moisture.

References/Additional Information

The American Architectural Manufacturers Association has developed industry standards for doors, windows and skylights. For more information, see www.aamanet.org.

Advanced Building Guidelines, New Buildings Institute, 2004.

ASHRAE Handbook of Fundamentals, ASHRAE, 2001.

National Fenestration Rating Council, 8484 Georgia Avenue, Suite 320, Silver Spring, MD 20910. Voice: (301) 589-1776, Fax: (301) 589-3884, Email: info@nfrc.org

Efficient Windows Collaborative. University of Minnesota, Twin Cities. 1998-2003.

Jacobs, Pete, "Small HVAC System Design Guide," California Energy Commission, 2003.

Southern California Edison, "Design Brief: Glazing," E Source, Energy Design Resources, 2000.

Heschong, Lisa et al. *Skylighting Design Guidelines*. Southern California Edison, 1998. Available at www.energydesignresources.com/.

GUIDELINE IN8: MOISTURE CONTROL

Recommendation

Building envelope assemblies should be designed to prevent accumulation of moisture due to leakage, condensation of water vapor, or infiltration of warm humid air. Design building envelopes to maintain the relative humidity of surfaces below 80% to inhibit mold growth. Provide air and vapor retarder for all building envelope components.

Provide a means for low-slope roof assemblies to dry out if moisture accumulates during the winter rainy season.

Provide a grade for the first 10 ft around the building perimeter to direct rain and groundwater away from the foundation.



Figure 120—Smart Vapor Barrier

Source: New Buildings Institute

Description

Moisture accumulation in building envelopes affects the building's thermal performance and durability. If not properly addressed, moisture buildup can lead to mold growth and impact the health of the occupants. Building design to control both moisture and air infiltration is an integrated design practice that requires attention at the design phase and execution in the construction phase.

Moisture control is accomplished by preventing water entry, by designing the building envelope to prevent condensation of moist air, by minimizing air infiltration and by removing any accumulated moisture by draining, venting, or diffusion.

Applicability

These recommendations apply to all spaces in California climates. Buildings in warm, humid climates require vapor retarders to be installed on the exterior warm, humid side of the building structure.

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

Applicable Codes

Per Title 24, liquid-applied roof coatings must have a maximum permeance of 50 perms, tested by ASTM D1653.

Vapor retarders should be selected according to the procedure ASTM C755, "Standard Practice for Selection of Vapor Retarders for Thermal Insulation."

Integrated Design Implications

Vapor retarders are often used to control moisture migration. Materials that prevent moisture migration will tend to inhibit air infiltration and vice versa.

The major source of condensation in building assemblies is air leakage; an air barrier system to control air leakage is critical. Consider the airtightness requirements of the air barrier system and its location in the assembly so that building components affected by condensation have a chance to dry. The properties of air barrier materials should be selected carefully from a permeance standpoint, relative to their location in the assembly. The envelope designer needs to understand clearly the design conditions indoors and reconcile the owner's and program's needs with the HVAC designer.

Cost Effectiveness

Careful design to control air infiltration and moisture may increase costs at the design stage, but should not increase construction costs. The benefits of extended roof life and improved indoor air quality justify costs at the design stage.

Benefits

Moisture control will prevent the growth of mold and ensure proper IAQ. Insulation performance is maintained. Preventing moisture accumulation in roofing materials will extend the life of the roof.

Costs	L			
	M		■	
	H		■	
		L	M	H
		Benefits		

Design Tools

There are several software packages that model heat and moisture transfer across building envelope assemblies; a commonly used (free) software accessible to design professionals is WUFI-ORNL/IBP. This software, which originated at the Fraunhofer Institute of Building Physics in Holzkirchen, Germany, (Kuenzel 1996) was further developed at DOE's Oak Ridge National Laboratory (Karagiozes 2001) in a collaboration that resulted in a user-friendly package suitable for North America. It has hourly weather files for 50 U.S. cities and numerous Canadian ones as well.

The software calculates heat and moisture increase and loss in the materials of the building assembly due to rain wetting, solar radiation, wind, cloud cover, temperature, and relative humidity. It considers

the orientation effects on a wall relative to all of these. Inputs and outputs are either in inch-pound (IP) or metric (SI) units. The intent of a successful analysis is to maintain the relative humidity (equivalent moisture content) of all materials inboard of the drainage plane below 80% relative humidity. This ensures that the air in the construction assembly stays below the thresholds determined to be a trigger for rot, corrosion, chemical deterioration, and mold growth. Although this program provides a simplified model of heat transfer, it is one of the best tools available to model diffusion and include the effects of rain wetting, wind, orientation, solar radiant heating, and radiant cooling.

Design Details

Moisture Control Terminology

There are several terms describing materials and strategies for moisture control. It is important to differentiate vapor barriers from vapor retarders. A vapor barrier is virtually impermeable to water vapor. Examples of such materials are rubber membranes, glass, and plastic films. A vapor retarder is a material that inhibits transmission of water vapor but is not prevent its migration. Examples include plywood or oriented strand board (OSB) and some types of insulation. For mild California climates, vapor retarders are installed on the interior (“winter warm”) side of the building assembly. Building Science Inc. has identified three classes of vapor barriers and retarders based on the permeability of the material (see Table 27). Class I materials have a permeability of 0.1 or less. Class II materials have a permeability of 1.0 or less. Both are considered impermeable and are considered vapor barriers. Class III materials have a permeability of 10.0 or less and are considered vapor retarders, rather than vapor barriers.

Table 27—Types and Classifications of Vapor Barriers

Type	Description	Class	Perms	Examples
Vapor Barrier	Impermeable	I	0.1 or less	Rubber membranes, polyethylene film, glass, aluminum foil, sheet metal, oil-based paints, vinyl wall coverings, and foil-faced insulating sheathings
		II	1.0 or less	
Vapor Retarder	Semi-Permeable	III	10.0 or less	Plywood, oriented strand board, unfaced expanded polystyrene, fiberfaced isocyanurate, heavy asphalt impregnated building papers, the paper and bitumen facing on most fiberglass batt insulation and most latex based paints
Breathable	Permeable		more than 10.0	Unpainted gypsum board and plaster, unfaced fiberglass insulation, cellulose insulation, unpainted stucco, lightweight asphalt impregnated building papers, asphalt impregnated fiberboard, exterior gypsum sheathings, cement sheathings, and “housewraps.”

Source: Joseph Lstiburek. Understanding the Terms Barrier and Retarder for Vapor and Air, February 2002.

Controlling and Managing Liquid Water Entry

The building envelope (above and below grade) should be designed to resist water intrusion, and to effectively drain water that passes through the cladding. Manage water intrusion by providing a drainage plane behind the cladding. Manage liquid water intrusion by using waterproofing, damp proofing and dewatering techniques. Wall assemblies should be designed with flashings and drainage planes and should not depend on a single sealant layer as the primary means of water intrusion prevention. All windows should be flashed. Roofs should be pitched to drains.

Controlling Condensation

Controlling moisture accumulation by condensation is achieved by ensuring that the building surfaces remain above the indoor air dewpoint. To prevent the growth of mold, interior surfaces should be kept at a relative humidity of 80% or less. Reducing air infiltration will also minimize the potential for condensation in the envelope structure.

Control of Moisture Migration

Moisture migration is controlled through the use of vapor retarders, which inhibit moisture migration but do not completely block the diffusion of moisture through the building assembly. This limits the movement of moisture to colder areas of the building assembly, reducing the potential for condensation, which can cause deterioration and mold growth. The performance of these materials is classified by a permeance rating. A material is considered a vapor retarder if it has a permeance of between 1 and 10 perms (1 perm = 1 grain H₂O/h-ft²). Many materials can serve the dual purpose of limiting air infiltration and limiting vapor transmission. Such materials include asphalt-impregnated building papers, liquid-applied films, polymer-based wraps and insulation. Polymer-based films and wraps have a constant resistance to vapor diffusion that is independent of humidity level. Materials such as kraft paper that are wood-based behave very differently. These materials have low permeance at low relative humidity levels, which inhibits moisture migration outwards from the warm interior in the winter, while allowing for moisture migration when the reverse pattern occurs in the summer. Synthetic materials that are specifically designed to take advantage of the natural vapor diffusion processes that occur over the seasons are referred to as “smart vapor retarders.” The higher permeance during high relative humidity conditions promotes summer drying.

Roofs

Low-sloped roofs offer a special challenge in controlling moisture. The entry of water vapor through the roof membrane is inevitable. Installing an impermeable water vapor retarder below the insulation will prevent the construction assembly from drying out if moisture does enter. This problem is exacerbated as daily temperature swings cause moisture migration cycles through the assembly, degrading the roof structure. One strategy to control moisture in low-sloped roofs is to design a self-drying roof assembly. Any moisture that accumulates during the winter rainy season must be allowed to permeate through the structure. Desjarlais (1995) provides a straightforward design procedure for determining the desired vapor resistance of the vapor retarder. The moisture that accumulates in the roof structure in the winter is determined by the difference in vapor pressure between outdoors and indoors and the vapor resistance of the material, integrated over the winter season. This total moisture gain must be moved by summertime drying. One potential solution is to perforate insulation with very small diameter holes (1-3 mm) that allow moisture to pass through but block convective heat transfer.

Slabs on Grade

Concrete in slabs should be dried to an equivalent relative humidity content of 75%, as measured by ASTM Standard F-2170-02. Vapor retarders under slabs have to be placed in intimate contact with the

underside of the slab, never with a layer of sand or fill on top (that can store capillary moisture for months or years). Wet curing is better than applying a curing agent, because curing agents trap moisture.

Operation and Maintenance Issues

Roofs should be inspected twice a year, and after significant storms, to check for potential problem areas.

Thermographic testing can be used to detect spots where moisture has affected the building envelope. Moisture will degrade the performance of insulation, resulting in warm and cold spots in problem areas.

Commissioning

Success of the building enclosure in preventing moisture depends on the quality of construction. A whole building commissioning process that begins at the design phase provides a systematic means of designing for moisture control.

References/Additional Information

ASHRAE Handbook of Fundamentals. ASHRAE, 2001.

Advanced Buildings Reference Guide. 2004. New Buildings Institute.

Desjarlais, Andre and David Kyle. 1995. "Assessment of Technologies for Constructing Self-Drying Low-Sloped Roofs." Oak Ridge National Laboratory for DOE.

National Roofing Contractors Association, 10255 W. Higgins Road, Suite 600, Rosemont, IL 60018, www.nrca.net. NRCA is a trade association that provides information for designers and building owners on products and best practice.

GUIDELINE IN9: ACOUSTIC DESIGN

Recommendation

Design the building envelope to provide acoustical performance that meets the 2002 voluntary American National Standards Institute (ANSI) Standard S12.60. This specifies a background noise level of 35 decibels on the A scale (dBA) or lower. To achieve this, design walls separating classrooms with a minimum sound transmission class (STC) of 50, bathroom walls with an STC rating of 53, and walls isolating noise from music spaces, cafeterias and mechanical equipment rooms with STC ratings of 60.

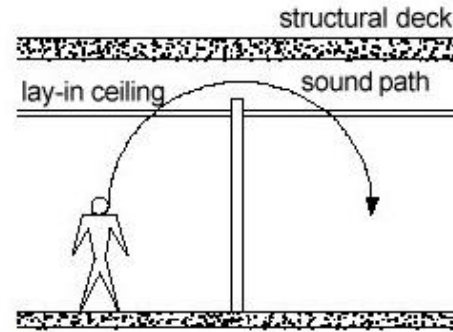


Figure 121—Example of Poor Acoustic Design

Interior partitions should extend up to the structural deck to limit sound transmission between classrooms. Source: Acoustical Society of America

Description

Good acoustic performance is a result of integrated design of both building envelope components and HVAC equipment selection and location. For the building envelope, acoustics is affected by reverberation, sound transmission between classrooms, and exterior noise sources. ANSI Standard S12.60 specifies a maximum background noise level of 35 dBA. A low STC rating for wall assemblies will ensure that sounds are not transmitted between classrooms. Classroom sound levels are especially critical in elementary schools, as children do not develop contextual listening skills at such a young age.

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

Applicability

These recommendations apply to all occupied spaces. Larger spaces such as auditoriums and gymnasiums have special considerations that are described below.

Applicable Codes

State energy codes do not provide requirements for indoor acoustic levels.

Structural and seismic safety requirements often dictate the thickness and spacing of framing members. For masonry walls, they usually require at least partial grouting of all exterior walls.

Integrated Design Implications

Classroom acoustics is also affected by sound reverberation from interior surfaces, and noise generated from HVAC equipment and exterior sources. HVAC equipment selection and location and duct design play a large role in classroom acoustics. Refer to chapters on Interior Surfaces and HVAC for more information. Design the site layout to eliminate or mitigate exterior noise sources. Acoustics is a criterion for selection of insulation materials. Heavyweight batts such as recycled cotton fibers provide good sound attenuation. Spray-in foams also provide good sound attenuation.

Cost Effectiveness

Designing the building envelope for good acoustic performance may require: higher NRC acoustic ceiling tiles, good quality drop seals and gaskets on doors, and an extra drywall layer to reduce sound transmission. HVAC design may require longer duct runs, larger duct cross-sectional area and a higher number of diffuser grilles. Costs average around \$4.50/ft² for new classrooms but can be as low as \$1.50/ft². Designing new construction for good acoustic performance is much less costly than retrofitting a bad design.

Benefits

Proper classroom acoustics will ensure an environment conducive to learning. It will prevent the teacher from having to strain his or her voice to be heard. Studies have shown that in many classrooms only 75% of spoken words can intelligibly be heard.⁴³

Costs	L	M	H
	L	M	H
Benefits			

Design Tools

There are a variety of acoustic software packages that can be used to analyze acoustics in buildings (more information is available at www.acoustics.org). Estimated STC ratings for common constructions can be found at www.stcratings.com. For music halls, special design considerations may be required that require assistance from an acoustics professional.

⁴³ Seep, Benjamin, et al. 2000. "Classroom Acoustics I—a resource for creating learning environments with desirable listening conditions." rev. 2002. Acoustical Society of America.

Design Details

Sound Transmission Class

Design interior walls to minimize sound transmission between rooms. The ability of a wall assembly to limit sound transmission between spaces is known as the STC. This is a measure of the noise reduction in decibels, weighted over frequencies common in human speech (125 Hz–4000 Hz). A change in STC of 3 dB is noticeable; an increase in STC of 10 dB provides twice the sound reduction. STC ratings do not address noise that occurs at other frequencies, such as that generated from HVAC equipment, musical instruments and some exterior noise sources. Modern construction that uses lightweight materials for interior walls provides only limited sound reduction. Providing a layer of gypsum board on both sides of a stud wall, with staggered joints, will reduce sound transmission. Other options for reducing sound transmission are to use metal studs, to include an air space in the cavity, or to increase the wall mass.

STC Requirements

The ANSI requirement for STC depends on the space. Interior walls separating classrooms, and exterior walls, should have an STC rating of 50 or higher. Walls separating music spaces or isolating noise from a mechanical equipment room should have a minimum STC of 60, while bathroom walls should have a minimum of 53. Metals studs provide better sound isolation than wood studs. Adding mass to a wall or increasing the air space will also improve performance. Staggering studs or using dual studs can provide a significant increase in acoustic performance. Typical STC ratings for wall constructions are shown below. Ratings are usually based on laboratory tests of a construction assembly. Actual performance will depend on the quality of construction, as air leakage paths will reduce the effective STC rating.


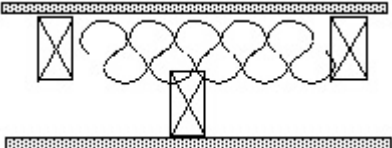
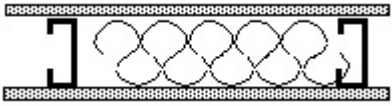

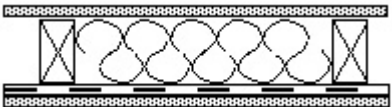

Concrete walls have relatively high STC ratings due to their thermal mass. Representative values are shown in Table 28.

Table 28—Estimated STC Ratings for CMU Walls

Wall Thickness, in.	Hollow Units		Grout Filled		Sand Filled	
	Weight	STC	Weight	STC	Weight	STC
4	20	44	38	47	32	46
6	32	46	63	51	50	49
8	42	48	86	55	68	52
10	53	50	109	60	86	55

Source: STCRatings.com. Values have a margin of error of +/- 4dB.

Table 29—Typical STC Ratings of Wall Constructions

Description	Estimated STC Rating	Wall Assembly
2x4 stud, 5/8-in. gyp (2 layers total), Batt insulation	34–39	
Staggered studs, 5/8-in. gyp (2 layers total), Batt insulation	46–47	
5/8" metal studs, 5/8-in. gyp (2 layers total), Batt insulation	43–44	
2x4 stud, 5/8-in. gyp (4 layers total), Batt insulation	43–45	
2x4 stud, 5/8-in. gyp (2 layers total), Resilient Channel, Batt insulation	45–52	
2x4 studs, 5/8-in. gyp (2 layers total), Batt insulation	56–59	

Source: STCratings.com

For exterior windows, double paned windows will have a higher STC rating (typically around 30) than single paned windows, with an STC rating near 27. Soundproofed windows that use laminated glass and spring-loaded seals can have STC ratings of 41–51. Larger windows will vibrate more than small windows of the same construction type when exposed to exterior noise, lowering their STC rating.

Impact Insulation Class

For multi-story facilities, another important design criterion is Impact Insulation Class (IIC). This rating is a measure of the ability of a floor-ceiling assembly to block transmission of structure-borne noise to the space below. IIC is measured using a tapping machine and a sound level meter. A minimum of IIC 50 is recommended for floors above learning spaces (measured without carpet). Carpet will significantly increase the ability of the assembly to block sound transmission. To increase the sound isolation from wood joist or concrete floors, special sound mats can be installed, as well as a layer of gypcrete that is spray-applied or mopped in place.

Make sure that partition walls extend up to the structural deck and do not terminate at suspended ceilings.

Consider location of classroom equipment. Classroom computers are often left running throughout the day. The CPU fans generate noise, which can be amplified when reflected off of hard surfaces. Television monitors are often located in classroom corners. This highlights the importance of reducing sound transmission between classrooms.

Manage exterior noise with good site planning and high performance windows. Locate classrooms away from playgrounds, busy roads, mechanical equipment, and other noise sources. Use double-paned glass to minimize sound transmission. For exterior walls, continuous insulation and designs that control air infiltration will also provide good sound attenuation. Exterior doors of adjacent classrooms should not be located side-by-side. Increasing the distance between exterior doors will help to reduce sound transmission.

Retrofit options to the building envelope include window replacement with double-paned insulating windows, installing drop seals and gaskets on doors, and adding carpet to classrooms (particularly to reduce noise sources from elementary grades).

The design of music education classrooms is complex and is best done with guidance from acoustic professionals.

Seal drywall at the top and bottom of the walls to ensure a continuous air barrier.

Operation and Maintenance Issues

No special maintenance is required for building envelope components with good acoustic properties.

Commissioning

Testing the sound levels of an empty classroom requires the use of a Type II sound meter. Typical meters only measure down to 40 dBA, so you should not get a reading in an empty classroom. This type of meter calculates a 1-hour average sound level that is required by the ANSI standard. For a low cost alternative, sound meters are available for as low as \$79 that can provide an instantaneous reading to detect problem areas.

Measuring reverberation levels requires an acoustics consultant, but it can be estimated from the surface area and sound absorptance properties of the classroom interior surfaces.

No commissioning of exterior walls is needed other than normal construction administration.

References/Additional Information

The content of this guideline is largely based on recommendations from the Acoustical Society of America.

Seep, Benjamin, et al. 2000. "Classroom Acoustics I—a resource for creating learning environments with desirable listening conditions." rev. 2002. Acoustical Society of America.

The United States Access Board. 2003. "Listening for Learning: Counting the Costs of Noisy vs. Quiet Classrooms." www.quietclassrooms.org.

Nixon, Mike. 2003. "A Crash Course in Classroom Acoustics." Acoustical Surfaces, Inc., Chaska, MN.

Lubman, D. and L.C.Sutherland. 2001. "Good Classroom Acoustics is a Good Investment." Presented at the 17th Meeting of the International Commission for Acoustics, Rome, Italy, Sep. 2001.
www.nonoise.org/quietnet/qc/ica22001.htm

Masonry Advisory Council. (library of typical STC ratings for masonry wall assemblies)
www.maconline.org

The CHPS prerequisite is to design the classrooms and other core learning spaces to have background noise level less than 45 dBA. Credit is given for reducing the background noise level to 40 dBA or 35 dBA, the level recommended by the ANSI standard.