The Efficient Windows Collaborative Tools for Schools

www.efficientwindows.org January 2011

I. Window Design Tools for Schools

As energy prices increase and school budgets tighten, school districts are looking for cost-effective ways to improve building energy efficiency and operation. With almost one quarter of Americans spending their day in the classroom, efficient window design is an important opportunity to not only save energy and money but also to enhance the learning environment. Windows affect heating and cooling needs, the potential for natural ventilation, and the availability and quality of daylight. Integrated design that takes these factors into account can improve a school's energy performance as well as students' visual and thermal comfort.

As shown in Figure 1, several factors need to be considered to achieve these improvements.

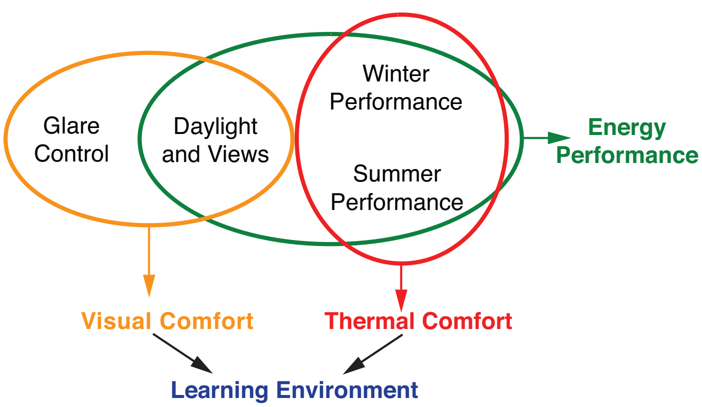

Figure 1: Window System Performance Factors

Visit www.efficientwindows.org for more information on the benefits of efficient windows, how windows work, how to select an efficient window, and what manufacturers provide efficient windows.

Tools for Schools Contents

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Energy Performance

Windows can affect energy use in classrooms in several important ways. Heat loss and heat gain through windows impact heating and cooling demand. Operable windows can provide natural ventilation, and daylight penetrating into classrooms may diminish or eliminate the need for electrical lighting.

Learning Environment

Windows can provide vital elements for a healthy learning environment: natural light, views, and fresh air. Although light and air can also be provided by electric and mechanical means, there is growing recognition that views, natural light and ventilation contribute to the satisfaction, health, and productivity of students and teachers.

Windows can have both positive and negative impacts on student comfort and performance. Access to natural light and pleasant views are positive factors, but student performance can be negatively impacted by factors such as glare, uncomfortable temperature extremes, stuffy air and noise pollution. Proper window design and operation can help mitigate these issues, creating more comfortable and productive learning environments.

~(Heschong Mahone Group, 2003)

II. Window Design Parameters

Window design involves climate and solar conditions based on location and building type. Within these conditions, several design variables can strongly influence the impact of windows on energy performance and the learning environment. Computer simulations and professional design analysis can help determining this impact. As a starting point, however, the following pages summarize several of the key parameters involved in an integrated window design. Figure 2 on the next page shows a recommended sequence of design decisions to account for these parameters.

Orientation

The orientation of classroom windows determines the potential for solar heat gain, daylight, and glare. East and west are usually the least favorable orientations since they permit little control over solar radiation. A south orientation is most likely to permit daylighting throughout the school day, although the indirect and ambient light through north-facing glazing can also be substantial.

Orientation affects:

- Winter performance – South-facing windows provide the best potential for passive solar heating.
- Summer performance – Solar heat gain through east- and west-facing windows is most difficult to control.
- Daylighting & views – Year-round potential for daylighting can best be achieved with south-facing windows.
- Glare control – Glare is most difficult to control with east- and west-facing windows.

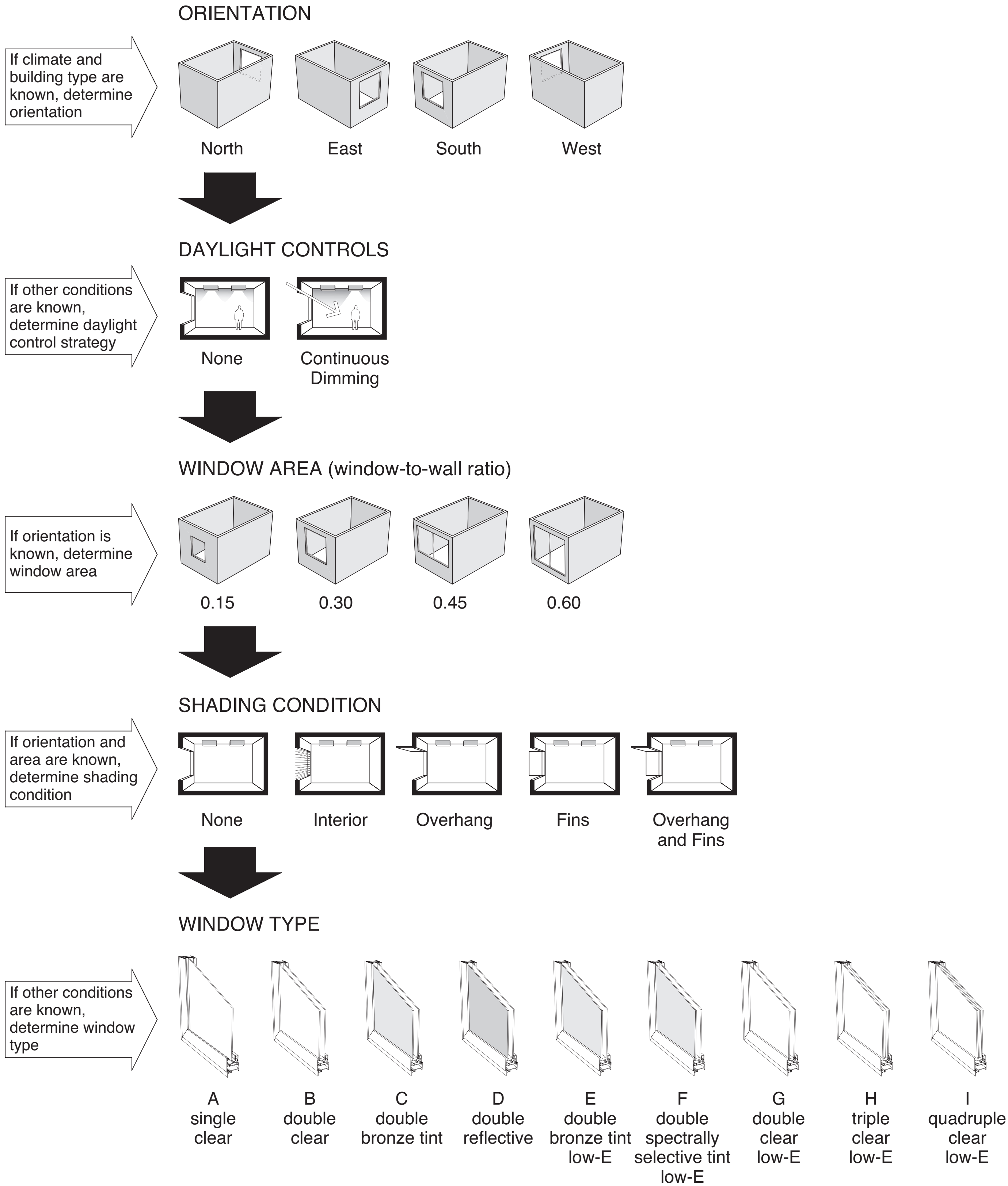


Figure 2: Window Design Parameters (source: Carmody et al.)

Daylight Controls

If the building location and window orientation allow for sufficient daylighting, an integrated daylight control system should be considered early in the design process. Daylight control systems dim and/or switch off lights when sufficient daylight is available. The graphs below show how simulations of a Chicago classroom predict significant savings in lighting and cooling—through avoided waste heat—resulting from the use of daylighting controls (Figure 3). The effect of daylighting controls provides useful information for subsequent window design decisions.

Window Area

Windows should be sized to allow for access to daylight and views while avoiding excessive glare, solar heat gain, and winter heat loss. The desirable size of windows depends on their placement and orientation. If windows face east or west, glare and solar heat gain are more difficult to control. *The Advanced Energy Design Guide for K-12 School Buildings*, developed with support from the Department of Energy, recommends avoiding large window areas on the east and west façades and limiting overall vertical window area to no more than 35 percent of the gross exterior wall area. Nevertheless, north- and south-facing windows should be sufficiently large to provide daylight and views while skylights and other means of toplighting, such as tubular daylighting devices and clerestory monitors, can provide additional high-quality daylighting.

Daylight controls affect:

- Summer performance – Daylight controls limit peak cooling demand by limiting excess heat from electric lighting.
- Daylighting & views – Daylight controls greatly reduce lighting energy use.

Window area affects:

- Winter performance – Larger window areas increase the importance of insulating value.
- Summer performance – Larger window areas potentially increase solar heat gain.
- Daylighting & views – Sufficient glazing area is required for daylighting and views.
- Glare control – Glare potential increases with larger glazing areas.

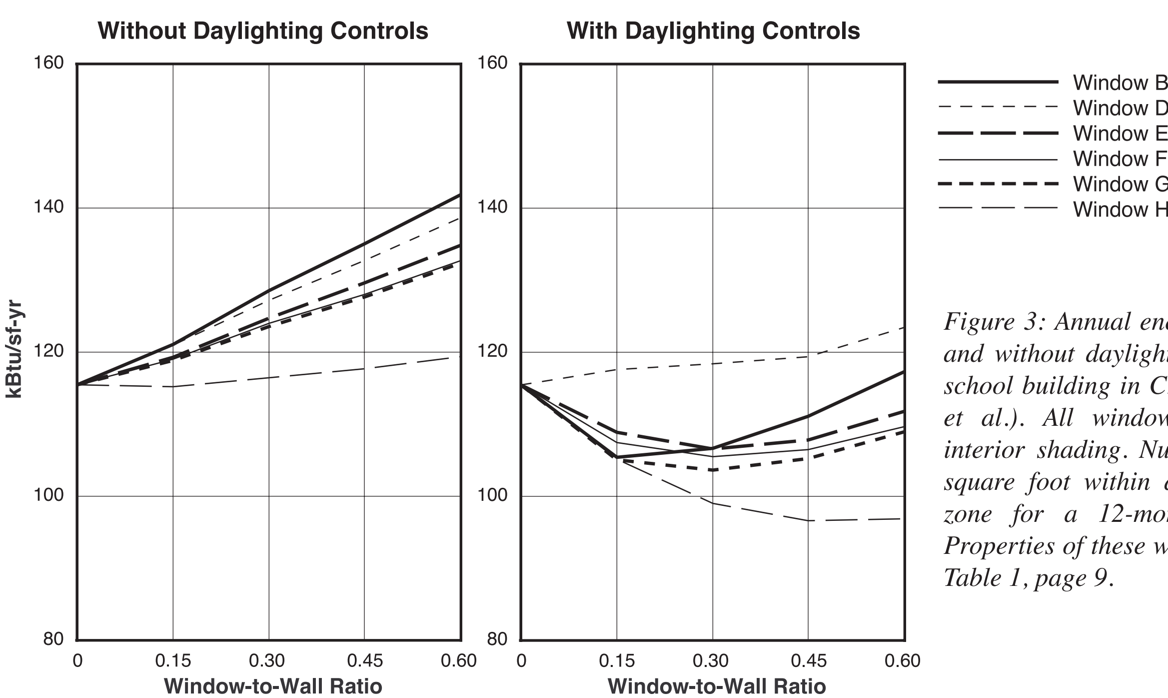


Figure 3: Annual energy use comparison with and without daylighting controls in a typical school building in Chicago (source: Carmody et al.). All windows are west-facing with interior shading. Numbers are expressed per square foot within a 30-foot-deep perimeter zone for a 12-month operating schedule. Properties of these window types are shown in Table 1, page 9.

Shading Conditions

Some shading conditions, such as trees or nearby buildings, may precede the design process. Other shading elements are up to the designer to optimize. Shading can be designed so that it controls solar heat gain but permits daylight access. For instance, light shelves can shade large window areas while redirecting visible light through high clerestory windows to the room's ceiling. To darken the room for projections, some form of operable shading is also required in most classrooms.

Window Type

Once orientation, daylighting, window area, and shading conditions are known, the window type must be chosen. Considerations include the glazing and frame type, which affect the energy-related window properties. Operator type and the potential for natural ventilation also need to be considered. Apart from vertical windows, skylights, clerestory windows, and other toplighting fenestration may be considered to enhance daylighting.

When the window type is chosen, the effect of the window design on HVAC demand should be taken into account. Energy-efficient window design often allows for smaller and less costly HVAC systems, thus freeing funds that can be allocated to the efficient window technologies.

Shading conditions affect:

- Summer performance – Interior and exterior shading reduce solar heat gain.
- Daylighting & views –Shading systems such as light shelves and overhangs can allow daylight and views
- Glare control – Shading can be crucial for glare control.

Window types affect:

- Winter performance – Good insulating value is required to limit heat loss.
- Summer performance – High-performance glazing options can limit solar heat gain.
- Daylighting & views – The visible transmittance of windows impacts daylight access. Daylighting design typically distinguishes between daylighting glazing and view glazing.
- Glare control – Some windows reduce glare by providing for indirect daylighting and blocking or filtering direct sunbeams.

Figures 4 and 5: The use of various glazing and design elements in schools can enhance daylighting, views, and student performance. Photo: ©Jim Schafer www.jimschaferphotography.com.

III. Window Performance Factors

Winter Performance

The winter performance of windows depends on their ability to control heat loss and to prevent discomfort from cold window surfaces. The principle measure of heat loss is the window U-factor.

It is important to consider the impact of window performance on the heating system requirements. Conventional windows are usually places of temperature variation and winter discomfort, requiring perimeter heating to counter the effect of cold window surfaces. High-performance windows with a very low U-factor, on the other hand, retain higher glass temperatures, which in some cases allows for the elimination of perimeter heating and a significant reduction in heating system size—in turn offsetting much of the cost premium for the high-performance windows. *The Advanced Energy Design Guide for K-12 School Buildings* (see References) recommends U-factors of 0.42 or less in a mixed climate and of 0.33 or less in a heating-dominated climate.

Summer Performance

The summer performance of windows depends on orientation, shading, and their ability to control solar heat gain through a low solar heat gain coefficient (SHGC), their potential to reduce electric lighting via daylighting, and on the natural ventilation they offer. Solar heat gain is a significant contributor to cooling demand and the heat generated by electric lighting is an additional factor. Control of solar heat gain combined with daylighting to offset electric lighting effectively reduces the peak demand on the cooling system. Reduced peak demand may in turn allow for smaller cooling equipment or, in moderate climates, may eliminate the need for mechanical cooling. Figure 6 illustrates how window options and the use of daylighting controls impact peak cooling demand.

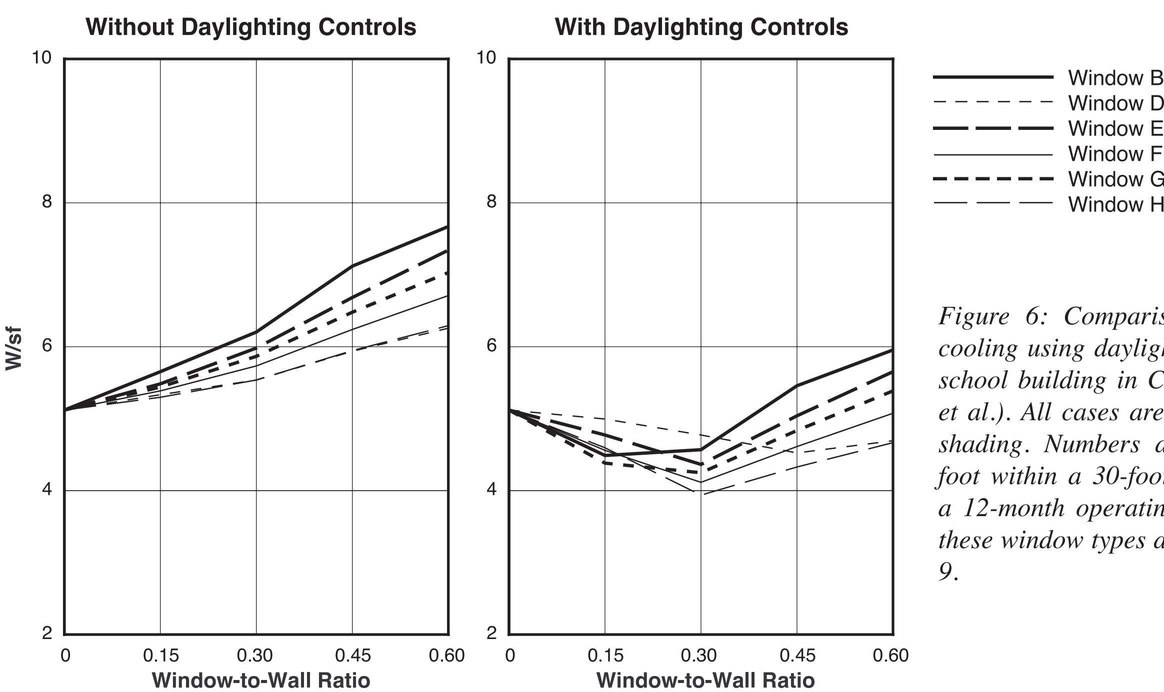


Figure 6: Comparison of peak demand for cooling using daylighting controls in a typical school building in Chicago (source: Carmody et al.). All cases are west-facing with interior shading. Numbers are expressed per square foot within a 30-foot-deep perimeter zone for a 12-month operating schedule. Properties of these window types are shown in Table 1, page 9.

Daylighting and Views

Daylight has qualities that cannot be replicated by electrical light. The changing intensity, direction, and color of natural light connect building occupants to the weather, season, and time of day. Views through windows, especially those including elements from nature, stimulate the well-being and productivity of students. With careful design and daylighting controls, daylighting can also substantially reduce lighting energy use.

The potential for daylighting and view is largely a function of orientation, window placement and window area, as well as the windows' visible transmittance. However, modern daylight design is far more sophisticated than simply providing windows with high visible transmittance. To balance daylight admission with glare and solar heat gain control and provide uniform light distribution, modern daylight design suggests that glazing is separated into glazing for daylighting and glazing for views.

Daylight glazing is typically placed high in the wall, or ceiling in the case of toplighting. Daylight glazing can be designed to keep light beams from directly entering the room—which could cause glare—but instead reflect the light deep into the room via light shelves, reflective blinds, or other reflective surfaces.

Resources for Daylight Design and Control Systems

Lawrence Berkeley National Laboratory's Windows and Daylighting Group (windows.lbl.gov) has developed a detailed daylight design guide: Tips for Daylighting with Windows (http://btech.lbl.gov/pub/designguide/dlg.pdf).

Illuminating Engineering Society of North America (IESNA): a resource for literature, standards, codes, guidelines and a monthly journal covering lighting, daylighting, and visual comfort. Local chapters may also offer classes or other resources. For publications, call (212) 248-5000, ext. 112 or view www.iesna.org.

Electric Power Research Institute (EPRI): has an extensive collection of fact sheets, brochures, guidelines and software. Call EPRI Lighting Information Office (800) 525-8555 or view www.epri.com.

View glazing is located lower in the wall, offering a view to the outdoors for occupants seated in a room. If sufficient daylight is provided through separate daylight glazing, shading can be increased for view glazing to control glare and solar heat gain without a daylighting penalty.

Reaping the full benefits of daylight design requires daylight control systems as described above. The first requirement for an integrated daylight control system is that electric lights are controlled such that energy savings will occur. For example, lights near windows must be switched off separately from the rest. In addition, individual fluorescent tubes within light fixtures may be switched separately allowing for a range of light levels instead of only 100 percent on or off. Dimmable light fixtures also permit electric light levels to be reduced.

To take advantage of the natural light from a window, either people or automatic controls must switch off the electric lights. Occupant switching can be effective but requires active participation and usually will not be done optimally to reduce energy use. If the daylighting is plentiful and uniformly distributed, there is a greater chance that people will switch off the lights. Portions of the electric lighting can also be switched off or dimmed automatically in response to a photo sensor. This type of system is designed to operate optimally without depending on occupant participation. However, these systems are more expensive than simple switching and represent emerging technology where their installation and operation must be carefully monitored to ensure the projected savings.

Glare Control

Too much daylight can produce excessive glare, resulting in eye strain that negatively affects the learning environment. The likelihood of glare varies depending on orientation, window area, shading conditions, and window type. South-facing windows, can be shielded from direct glare with overhangs and fins whereas glare control is more difficult with east- and west-facing windows. Smaller window areas and glazing with lower visible transmittance can reduce glare, but may lower the potential for beneficial daylighting. Solutions to this are glazing designs that separate daylight glazing from shaded view glazing and redirect daylight by means of light shelves or other elements. Toplighting fenestration such as clerestory monitors or tubular daylighting devices can help with controlled daylight access.

IV. Efficient Window Technology Options

This section provides an introduction to window components and to the energy related properties of windows. It starts with a summary of the quantitative measures that help to determine winter and summer performance, daylight access, and glare: U-factor, solar heat gain coefficient, visible transmittance, and air leakage. Window materials and technologies are presented next. Finally, the potential for natural ventilation is discussed.

Energy-related Window Properties

The four metrics listed below define window energy performance. These performance metrics should be measured and rated over the entire window assembly, not just the center of glass. Labels denoting that the window rating is certified by the National Fenestration Rating Council (NFRC) assure that the whole window assembly has been rated in a consistent manner.

- **Insulation value (U-factor).** When there is a temperature difference between inside and outside, heat is lost or gained through the window frame and glazing by the combined effects of conduction, convection, and radiation. The U-factor of a window assembly represents its insulating value.

  The U-factor is a measure of the rate of non-solar heat loss or gain through a window assembly. It is expressed in units of Btu/hr-sq ft-°F. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value. Typical U-factors range between 1.25 for single glazing in aluminum frames to U-factors as low as 0.15 for low-E coated triple glazing in insulated frames.

- **Solar Heat Gain Coefficient (SHGC).** Regardless of outside temperature, heat can be gained through windows by direct or indirect solar radiation. The ability to control this heat gain through windows is measured in terms of the solar heat gain coefficient of the window.

  The SHGC is the fraction of solar radiation admitted through a window or skylight, both directly transmitted, and absorbed and subsequently released inward. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater its shading ability.

- **Visible Transmittance (VT).** Visible transmittance is an optical property that indicates the portion of incoming visible light transmitted through the window (also referred to as visible light transmittance – VLT). It affects energy by providing daylight that creates the opportunity to reduce electric lighting loads and thus, indirectly, reduce cooling loads through reduced lighting use.

- **Air Leakage (AL).** Heat loss and gain also occur by air leakage through cracks in the window assembly. This effect is measured in terms of the amount of air that passes through a unit area of window under given pressure conditions. In reality, infiltration varies slightly with wind-driven and temperature-driven pressure changes. Air leakage may also contribute to summer cooling loads by raising the interior humidity level.

  The air leakage rating is a measure of the rate of air-leakage around a window or skylight in the presence of a specific pressure difference. It is expressed in units of cubic feet per minute per square foot of frame area (cfm/sq ft). The lower a window's air-leakage rating, the better is its airtightness.

Window properties differ from product to product. Typical window properties for a few common window types are shown in Table 1. Note that air leakage is not shown in this table since it largely depends on factors such as workmanship and the window operator type.

Table 1: Typical Window Properties for Selected Common Window Types

Window type		U-factor	SHGC	VT
A	Single glazing, clear, aluminum frame	1.25	0.72	0.71
B	Double glazing, clear, aluminum frame	0.60	0.60	0.63
C	Double glazing, bronze tint, aluminum frame	0.60	0.42	0.38
D	Double glazing, reflective coating, aluminum frame	0.54	0.17	0.10
E	Double glazing, low-E, bronze tint, aluminum frame	0.49	0.39	0.36
F	Double glazing, selective low-E, bronze tint, aluminum frame	0.46	0.27	0.43
G	Double glazing, spectrally selective low-E, aluminum frame	0.46	0.34	0.57
H	Triple glazing, low-E, insulated frame	0.20	0.22	0.37
I	Quadruple glazing, low-E, insulated frame	0.14	0.20	0.34

Window Technologies and Designs

Designers can choose from a wide range of possible window materials and assemblies. Different glazing and frame materials and special assemblies can provide insulation value, sun control, and daylight redirection as appropriate for a given room or building. The following is a quick overview of different glazing options, frame options, and emerging window technologies.

Glazing

Low-E coatings

Low-E (low-emittance) coatings reduce radiant heat transfer through window glazing, thus improving its insulating properties. In addition, the solar reflectance of low-E coatings can be manipulated so that desirable wavelengths of the solar spectrum are transmitted and others specifically reflected. Of particular value for school buildings are coatings that reflect heat from solar infrared radiation (resulting in a low SHGC) while allowing the visible light spectrum to enter (high VT). These coatings are called spectrally selective.

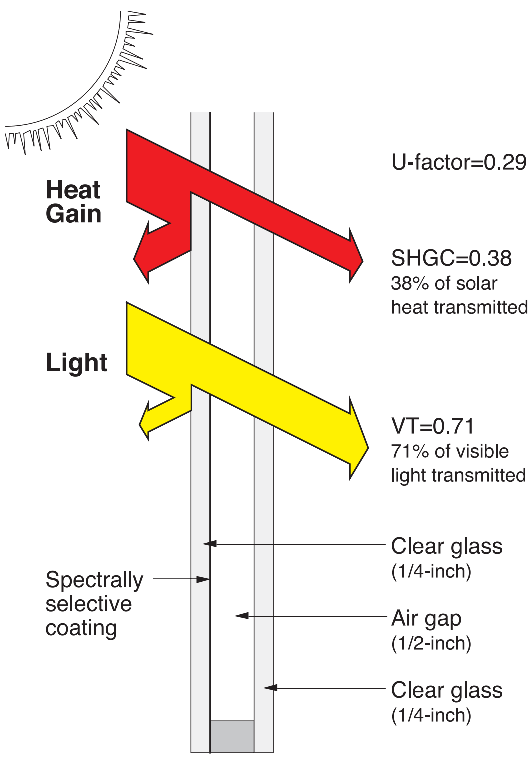


Figure 7: Double glazing with low-E coating on spectrally selective tinted glass. All values are for the glazing alone (center-of-glass). Values for the total window will vary with frame type.

Tinted glass

The primary uses for tinted glass are reducing glare from the bright outdoors and reducing the amount of solar heat transmitted through the glass. Tinted glass retains its transparency from the inside, although the brightness of the outward view is reduced and the color is changed.

Traditional bronze and gray tinted glass diminishes the amount of daylight entering the room. For windows where daylighting is desirable, it may be more satisfactory to use clear low-E coatings (see Figure 7) or high-performance tints that preferentially transmit the daylight portion of the solar spectrum but absorb the near-infrared part of sunlight. High-performance tints are light blue or light green with a relatively high visible transmittance. They can also be combined with low-E coatings to enhance their performance further.

Reflective coatings

If larger reductions or glare and solar heat gain are desired, a reflective coating can be used. By increasing the surface reflectivity of the glass, these coatings can reduce solar heat gain substantially, but visible transmittance usually declines even more, which is problematic if daylighting is desired. Reflective glazings are usually used for glare control or for large windows in hot climates.

Highly-insulating glazing

In addition to the insulating capabilities of double-glazing and low-E coatings, gas fills and additional glazing layers can further improve the insulating value of glazing. Triple- and quadruple-glazed windows are available with the middle layers consisting either of glass or of suspended plastic films. These middle layers decrease the U-factor of the unit by dividing the inner air space into multiple chambers, which can be filled with insulating gas. In addition to reducing heat loss, these additional layers also reduce visible light transmission and solar heat gain.

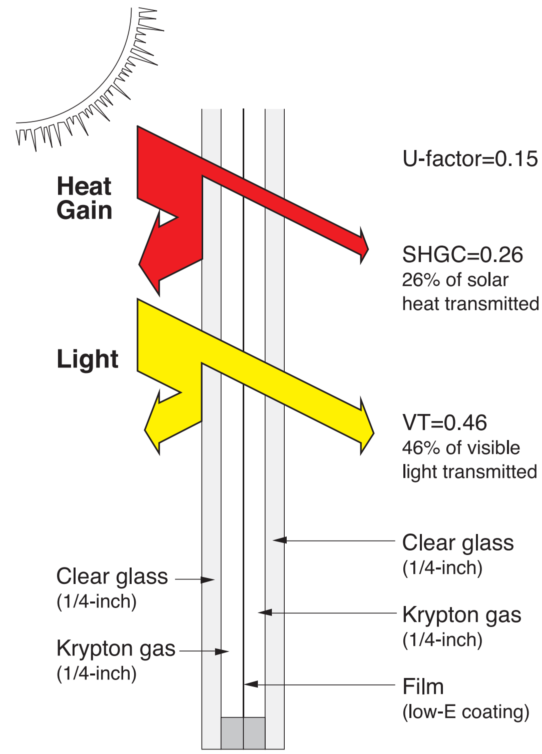


Figure 8: Triple glazing with clear glass and a low-E coating on plastic film. All values are for the glazing alone (center-of-glass). Values for the total window will vary with frame type.

Laminated glass

Laminated glass consists of a tough plastic interlayer made of polyvinyl butyral (PVB) bonded between two panes of glass under heat and pressure. Once sealed, the glass sandwich behaves as a single unit and looks like normal glass. Laminated glass offers increased protection from the effects of disasters such as hurricanes, earthquakes, and bomb blasts. Another benefit is that laminated glass reduces noise transmission due to the PVB layer's sound-dampening characteristics.

Smart glazing

An emerging concept for state-of-the-art windows is "smart glazing" that can be changed from a clear to a tinted state in response to solar heat gain and glare. By actively managing lighting and cooling, smart glazing could reduce peak electric loads by 20–30 percent in many buildings, increase daylighting benefits, and improve comfort and learning environments in schools.

The most promising smart glazing technology today is electrochromic glazing. When a small voltage is applied to an electrochromic coating, it switches between a clear and tinted state, similar in appearance to photochromic sunglasses. Electrochromic glazing has been commercially available for some years, and is undergoing steady improvements.

Frame Materials

Aluminum

Aluminum frames can provide great structural strength. However, aluminum as a material is of high thermal conductance, which raises the overall U-factor of a window unit and increases the potential for heat loss and condensation. The most common solution to this are thermal breaks, which split the frame components into interior and exterior parts, joined by a less conductive material. Current thermal breaks can cut heat transfer through aluminum frames in half.

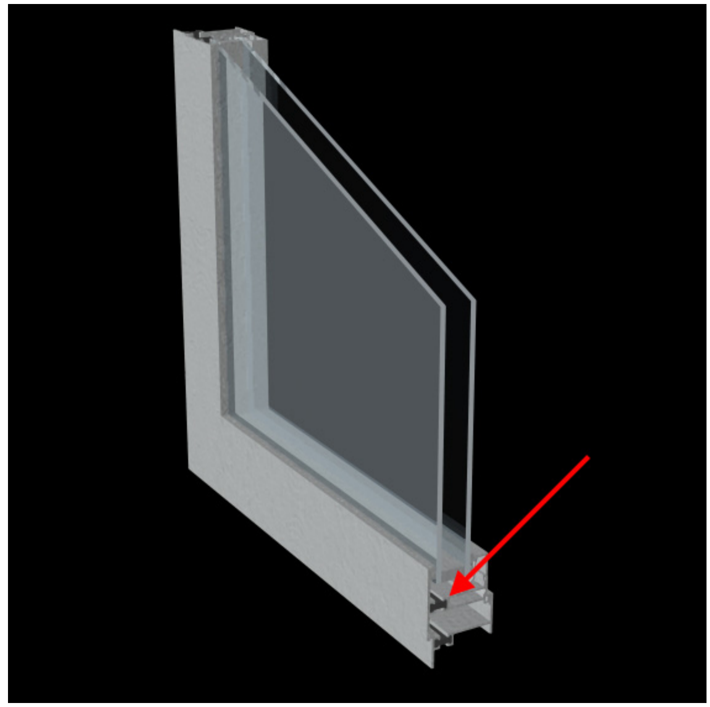


Figure 9: Thermal breaks split the aluminum frame components into interior and exterior parts, joined by a less conductive material—cutting heat transfer through the frame.

Wood

Wood has good thermal performance, so that thicker wood frames provide more insulation. Wood is susceptible to rot and can have high maintenance requirements, but well-built and well-maintained wood windows can have a very long life. Cladding the exterior face of a wood frame with either vinyl or aluminum creates a permanent weather-resistant surface and thus lowers maintenance requirements.

Wood/Polymer Composites

A new generation of wood/polymer composites can be extruded into a series of lineal shapes for window frame and sash members. These composites are very stable, and are comparable to or exceed the structural and thermal properties of conventional wood, with better moisture resistance and more decay resistance.

Vinyl

In terms of thermal performance, most vinyl frames are comparable to wood, and can be filled with insulation for superior thermal performance. Vinyl window frames require very little maintenance, do not require painting, and have good moisture resistance. For structural integrity, larger vinyl units will often need to incorporate metal or wood stiffeners. Vinyl has a higher coefficient of expansion than wood, aluminum, or fiberglass, meaning that it expands or contracts when temperatures change.

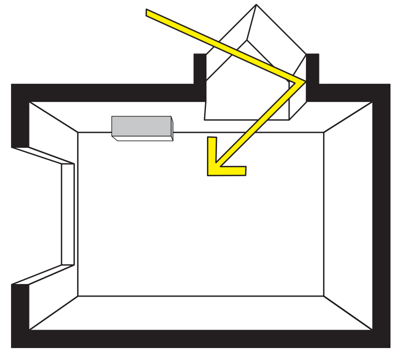
Fiberglass

Frames made from fiberglass are dimensionally stable and achieve good thermal performance by incorporating air cavities which can be filled with insulation. The strength of fiberglass allows the use of sleek frames like in aluminum windows while achieving significantly lower U-factors. The low coefficient of thermal expansion maintains seal integrity and minimizes warping or leakage in case of high inside/outside temperature differentials.

Toplighting Fenestration

Daylight from vertical windows cannot always adequately light the deep ends of a room. Toplighting with skylights, clerestory windows, or tubular daylighting devices helps bringing daylight deeper into rooms. Since many schools buildings are low-rise with the classrooms directly under the roof, toplighting is a very feasible as a supplement to sidelighting.

Skylights

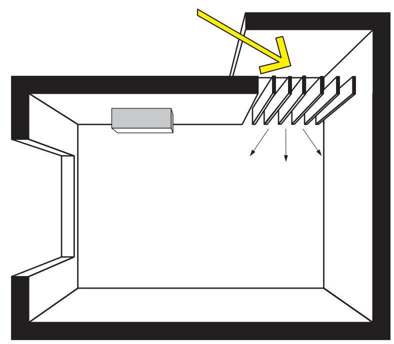


Appropriately placed skylights can illuminate rooms where daylight from vertical fenestration does not reach. Horizontal skylights provide light from above, but also solar heat during the summer. However strategically placed skylights with solar-heat-reducing low-E coatings may save more electricity through daylighting than they increase energy use for cooling. Low sun angles in northern latitudes limit the effectiveness of horizontal skylights in the winter. This drawback can be addressed by tilting the skylights, or with clerestories.

Tubular daylighting devices

Tubular daylighting devices (TDDs) capture daylight through a glazed dome protruding from the roof and reflect it down to the interior space through highly reflective shafts. Since no framing is necessary, TDDs are simpler to install than traditional skylights and are a good option for retrofits.

Clerestory Monitors



With their vertical glazing, clerestory monitors capture low sun angles more easily than skylights. North-facing clerestories can capture indirect daylight, avoiding direct solar heat gain. Clerestories facing the sun can be shaded with overhangs or louvers in the same way as vertical windows. Baffles beneath clerestories can provide diffuse glare-free daylight to the back of a room. Reflective roof surfaces help enhance the amount of daylight captured by clerestories.

Light Shelves

Light shelves are flat or curved elements in the window façade that reflect incoming light to the ceiling— bouncing the light deep into the room. Light shelves typically divide the window aperture into a view window below the shelf— to which the shelf can provide shading and daylight glazing above. Light shelves improve the quantity and quality of light in a space and should be designed specifically for each window orientation, room configuration, building latitude, and climate. They are most appropriate for south-facing glazing.

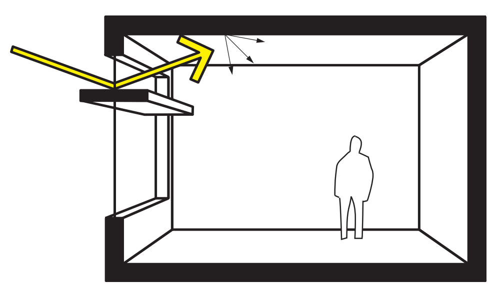


Figure 10: Toplighting with skylights, clerestory windows, or tubular daylighting devices helps to bring daylight deeper into rooms. Toplighting is feasible as a supplement to sidelighting. Photo: Velux America.

Natural Ventilation

Operable windows allow for natural ventilation, which may improve occupant comfort and the learning environment. Especially during moderate temperatures in spring or fall, fresh outdoor air can provide an inspiring connection to the environment and reduce HVAC use.

Open windows can also increase HVAC use if temperatures outdoors are significantly lower or higher than indoors. Nevertheless, as is reflected in the 2004 version of ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy, occupants in naturally vented spaces are likely to be comfortable with a wider range of temperatures than occupants in mechanically cooled spaces. Therefore, natural ventilation is an acceptable practice for a range of moderate outdoor temperatures. To avoid that the HVAC system operates while natural ventilation is provided, HVAC systems should shut off when and where windows are open for a longer time. Automatic controls such as interlocks are available for this purpose.

V. Retrofit Options for Existing Windows

Given the relevance of windows for energy performance and the quality of the learning environment, upgrading windows is a retrofit priority for many existing schools. Financing such measures is a hurdle but as described on the next page, there are programs and approaches that facilitate investments for energy cost savings in schools. Not all of the options described earlier in this guide can easily be applied to existing schools. For instance, the options for daylighting improvements may be limited depending on window orientation, on whether toplighting can be integrated into existing roofs, and on the existing lighting system. Nevertheless, substantial opportunities exist. Pre-WWII schools, for instance, constitute over a quarter of the existing school stock and often have large windows that maximize daylighting. Measures that improve the thermal performance of these windows can help transform old schools into energy-efficient buildings. The vast majority of the more than 130,000 public and private K-12 schools pre-date 1970, before building energy codes started to improve window performance. This leaves a vast need for energy efficiency and comfort upgrades through window repair, replacement and retrofits.

Window Replacement

Window replacement can bring multiple benefits including heat loss reduction, solar gain control, better protection from outside noise, and potential removal of lead-painted windows. Window replacement is among the higher-cost options for school renovation, so financing options are crucial. When windows are replaced, an analysis of heating and cooling loads should be performed in order to identify opportunities for downsizing HVAC equipment, which reduces equipment cost and improves the efficiency of the heating and cooling system.

Window Repairs, Caulking and Weatherstripping

Many schools have old windows that are not going to be replaced due to financial constraints or for historic preservation. Repairs may be needed to ensure the operability of old windows, and air leakage often calls for caulking and weatherstripping. While comprehensive repairs can be costly, caulking and weatherstripping are lower-cost measures that may reduce the waste of heating and cooling energy enough for a one-year payback. However, the reduction of air leakage alone may not be sufficient to boost winter comfort and does not address solar gains.

Secondary Glazing

To boost winter comfort and reduce heat loss through existing windows, secondary glazing can be added, such as exterior storm windows or interior glass panels. Exterior storm windows come as operable units with insect screens, while interior panels can be removed for ventilation or cleaning. Secondary glazing can also reduce air leakage and is an effective means of improving acoustic insulation. For further heat loss reduction, the panes of exterior and interior secondary glazing can consist of low-E glass. However, the exposure to moisture reduces the options for secondary glazing to low-E types that do not typically have a significant effect on solar heat gain.

Solar heat Gain and Glare Control

Exterior shading and solar control window film can help reduce solar heat gain and glare. Exterior shading is the most effective way of controlling solar radiation and can often be applied to existing schools. Trees do not only provide shade but may boost the attractiveness of school yards. Awnings can block glare and the high summer sun while allowing a view to the outside. Solar screens impact views to some extent, but may be applied when needed most. A permanent interior solution is window film, which is available as clear low-E film that reduces solar heat gain while retaining high visible transmittance and as tinted film for glare control. The properties of most available window film options are rated and certified through the National Fenestration Rating Council (NFRC).

VI. Financing and Incentive Options

Upgrades to institutional buildings such as schools are among some of the best-funded opportunities for energy retrofits. This is due to the public interest in better-performing school buildings and due to successful experiences from across the country demonstrating how school energy efficiency projects can free up long-term resources for education. Nevertheless, energy efficiency upgrades are often delayed because of financial concerns, thus forgoing achievable energy cost savings. The financing options listed below are a good starting point for addressing financial hurdles.

Information on financing vehicles for energy-efficient retrofits

- The U.S. Department of Energy (DOE) has created a public/private partnership called **EnergySmart Schools** to support energy efficiency improvements in K-12 schools. The financing options include revolving investment funds, debt financing, and energy-saving performance contracts. DOE also offers access to software programs that can calculate the life-cycle analysis of an energy-efficient retrofit project. http://www1.eere.energy.gov/buildings/energysmartschools/finance.html

- The Environmental Protection Agency's **ENERGY STAR** initiative offers information on financing for energy-related improvements to public facilities, focusing on the advantages of tax-exempt lease-purchase agreements. www.energystar.gov/ia/business/COO-CFO_Paper_final.pdf

- The **Database of State Incentives for Renewables & Efficiency** is a comprehensive source of information on state, local and utility incentives and policies that promote energy efficiency. www.dsireusa.org

- The **National Association of Energy Service Companies** (NAESCO) provides a large database of energy service providers (ESPs) available for projects with public schools. www.naesco.org/providers/default.aspx

- The **National Clearinghouse for Educational Facilities** is a database of information resources on financing school construction and renovation through partnerships between schools and the private sector, community organizations, public agencies and school districts. www.edfacilities.org/rl/funding_partnerships.cfm

- For information on green performance contracting that utilizes the LEED for Existing Buildings rating system, the U.S. Green Building Council offers a "**Guide to Green Existing Buildings**," which includes descriptions of a variety of financing methods. www.usgbc.org/DisplayPage.aspx?CMSPageID=2204

VII. Glossary

Air leakage (AL). Air leakage ratings indicate the amount of air leaking in and out of a building through closed windows, doors, or skylights in the presence of a specific pressure difference. These ratings are expressed in units of cubic feet per minute per square foot of frame area (cfm/sq ft). The lower a window's air-leakage rating, the better its airtightness.

ASHRAE. American Society of Heating, Refrigerating and Air Conditioning Engineers.

Clerestory. A window in the upper part of a lofty room that admits light to the center of the room.

Conduction. Heat transfer through a solid material by contact of one molecule to the next. Heat flows from a higher-temperature area to a lower-temperature one.

Convection. A heat transfer process involving motion in a fluid (such as air) caused by the difference in density of the fluid and the action of gravity. Convection affects heat transfer from the glass surface to room air, and between two panes of glass.

Double glazing. In general, two sheets of glass separated by an air space within an opening to improve insulation against heat transfer and/or sound transmission. In factory-made double glazing units, the air between the glass sheets is thoroughly dried and the space is sealed airtight, eliminating possible condensation and improving insulating properties.

Electrochromics. Glazing with optical properties that can be varied continuously from clear to dark with a low-voltage signal. Ions are reversibly injected or removed from an electrochromic material, causing the optical density to change.

Fenestration. The placement of window openings in a building wall, one of the important elements in controlling the exterior appearance of a building. Also, a window, door, or skylight and its associated interior or exterior elements, such as shades or blinds.

Fiberglass. A composite material made by embedding glass fibers in a polymer matrix. May be used as a diffusing material in sheet form, or as a standard sash and frame element.

Gas fill. A gas other than air, usually argon or krypton, placed between window or skylight glazing panes to reduce the U-factor by suppressing conduction and convection.

Glazing. The glass or plastic panes in a window, door, or skylight.

Insulating glass. Two or more pieces of glass spaced apart and hermetically sealed to form a single glazed unit with one or more air spaces in between. Also called double glazing.

Low emittance (low-E) coating. Microscopically thin, virtually invisible, metal or metallic oxide layers deposited on a window or skylight glazing surface primarily to reduce the U-factor by suppressing radiative heat flow. Low-E coatings are typically highly transparent to visible light but can reflect heat from infrared radiation.

NFRC. National Fenestration Rating Council. A nonprofit, public/private organization created by the window, door, and skylight industry. It is composed of manufacturers, suppliers, builders, architects and designers, specifiers, code officials, utilities, and government agencies. The NFRC has developed a window energy rating system based on whole product performance.

Operable window. Window that can be opened for ventilation.

Radiation. The transfer of heat in the form of electromagnetic waves from one separate surface to another. Energy from the sun reaches the earth by radiation, and a person's body can lose heat to a cold window or skylight surface in a similar way.

Reflective coatings. Coatings on window glass that reflect radiation striking the surface of the glass.

Solar heat gain coefficient (SHGC). The fraction of solar radiation admitted through a window or skylight, both directly transmitted, and absorbed and subsequently released inward. The solar heat gain coefficient has replaced the shading coefficient as the standard indicator of a window's shading ability. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater its shading ability. SHGC can be expressed in terms of the glass alone or can refer to the entire window assembly.

Solar radiation. The total radiant energy from the sun, including ultraviolet and infrared wave lengths as well as visible light.

Spectrally selective coating. A coated or tinted glazing with optical properties that are transparent to some wavelengths of energy and reflective to others. Typical spectrally selective coatings are transparent to visible light and reflect short-wave and long-wave infrared radiation.

Thermal break. An element of low conductance placed between elements of higher conductance to reduce the flow of heat. Often used in aluminum windows.

Tinted glass. Glass colored by incorporation of a mineral admixture. Any tinting reduces both visual and radiant transmittance.

Triple glazing. Three panes of glass and/or plastic with two air spaces between.

U-factor (U-value). A measure of the rate of non-solar heat loss or gain through a material or assembly. It is expressed in units of Btu/hr-sq ft-°F (W/sq m-°C). Values are normally given for NFRC/ASHRAE winter conditions of 0° F (18° C) outdoor temperature, 70° F (21° C) indoor temperature, 15 mph wind, and no solar load. The U-factor may be expressed for the glass alone or the entire window, which includes the effect of the frame and the spacer materials. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value.

Visible transmittance (VT). The percentage or fraction of the visible spectrum (380 to 720 nanometers) weighted by the sensitivity of the eye, that is transmitted through the glazing.

VIII. References and Resources

Reference Books

Carmody J., S. Selkowitz, E. S. Lee, D. Arasteh, T. Willmert. Window Systems for High Performance Buildings. New York, NY: Norton, 2004.

Guidelines

Advanced Energy Design Guide for K-12 School Buildings. ASHRAE, AIA, IESNA, USGBC, DOE, 2008.

Guide to Financing EnergySmart Schools. Department of Energy, http://www1.eere.energy.gov/buildings/energysmartschools/financing_guide.html.

Studies and Reports

Heschong Mahone Group. Daylighting in Schools, An Investigation into the Relationship Between Daylight and Human Performance. A Report to Pacific Gas and Electric, 1999.

Heschong Mahone Group. Windows and Classrooms: A Study of Student Performance and the Indoor Environment. California Energy Commission, 2003.

Web Sites

Collaborative for High-Performance Schools (CHPS), www.chps.net.

Council of Educational Facility Planners (CEFPI), www.cefpi.org.

U.S. Department of Energy, Energy Smart Schools, http://www1.eere.energy.gov/buildings/energysmartschools.

Windows for High Performance Commercial Buildings, www.commercialwindows.org.