

The following sections cover some of the specification issues and technical concepts that designers should understand in the selection of skylight products.

### Glazing Materials 3.1.

Glazing is one of the most important factors in good skylight design. There are many alternatives and choices to consider, and careful selection is important to a successful design. The optical properties of glazing materials influence both daylighting quality and potential energy savings, and the thermal properties affect heating and cooling loads. (See Section 3.3.2. for a more complete discussion of thermal properties.)

First we introduce two important concepts—glazing efficacy and skylight efficacy—which should guide selection of other properties of skylights.

**Glazing Efficacy** is the measure of how much light penetrates all the layers of glazing in relation to how much solar heat gets through. It is more specifically referred to as the “light-to-solar gain ratio” or LSG. It is a ratio of the visible transmittance ( $T_{vis}$ ) to the solar heat gain coefficient (SHGC) of the glazing. It is important to understand that it is not just one property or the other that is important, but the relationship between the two that determines how efficiently the glazing material will perform. LSG values for various products are shown in Figure 3-1: Solar-Optical Properties of Skylight Glazings.

**Skylight Efficacy** combines LSG with the effects of the light well. The well factor (WF) describes how much of the light that enters the well is actually transmitted down to the room, after reflectances and absorption. (WF is explained in greater detail in Section 3.3.1.) Thus, skylight efficacy is a measurement of how efficiently the overall skylight assembly can deliver light to the room below without causing an undue burden of additional heat.

### **3.1.1. Visible Transmittance**

The visible transmittance of a glazing material is the essential measurement for judging how much light will get through. It is reported as a ratio, and labeled either  $T_{\text{vis}}$  or VT for visible transmittance.

It is best if the manufacturer can provide test results for the skylight unit which account for multiple layers and obstruction by any intermediate framing members. The NFRC 300-1994 test procedure was developed to measure or calculate overall visible transmittance of windows. Unfortunately, unit test results are currently only available for a few products. Because overall unit performance varies with the size of the unit, manufacturers have found it very expensive to provide test results for their full product line.

If these results are not available, the manufacturer should at least be able to provide the visible transmittances of the individual sheets of glazing material. It should be noted whether these are values for the flat material before it has been formed, or tested values after the material has been formed. For example, an acrylic bubble skylight made from sheet material which is nominally one-eighth inch thick will stretch in the center and have higher visible transmission in its thinner areas. An appropriate test method is ASTM Standard E972-88. When the overall transmittance for a multiple layer glazing is not available, multiplying the visible transmittances of the various glazing layers will provide a reasonable approximation.

Very often the only available  $T_{\text{vis}}$  values are generic values for the product material, such as those published in the ASHRAE or IESNA Handbooks. When this is the case, specifiers should include a test procedure to verify that the product delivered has the specified light transmittance. At the very least, using a light meter to take readings of light levels immediately above and below a product will give a rough indication of the visible transmittance. Be sure that the light meter is taking an average reading for the product, and that there is no light leakage from other sources. Placing the skylight unit over an opaque box and using a light meter that will take a remote reading will increase accuracy.

Another issue with visible transmittance is performance over time. Some products may degrade over time, and have lower transmittance as they age. Fiberglass is especially suspect in this area, as the thermo-setting resins used in manufacture can change their properties under extended exposure to heat or ultraviolet light. And, of course, there can be a great deal of heat and ultraviolet light on the top surface of a building roof. If this is a concern, specifiers should check with manufacturers on the long-term performance of their products.

### **3.1.2. Solar Heat Gain Coefficient or Shading Coefficient**

While visible transmittance measures the amount of the visible spectrum that will pass through a material, the solar heat gain coefficient (SHGC) measures the amount of the solar spectrum that will pass through the material. Solar radiation contains a wide spectrum of

wavelengths including ultraviolet, visible light, and infrared radiation. All of this energy eventually degrades to heat within the building.

The SHGC and shading coefficient (SC) are often used interchangeably, and are just as often confused. They both describe a ratio of how much of the overall solar radiation will penetrate the glazing materials and eventually be transformed into heat. However, there is an important distinction between the two. The earlier, less accurate SC assumes that all wavelengths of light are reflected or absorbed at the same rate. The SC provides sufficient accuracy as long as you are only evaluating the solar heat gain through *single-glazed tinted glass*.

The SHGC is the preferred measurement because it accurately accounts for variations in reflectance and absorption for different wavelengths and can handle a wider range of materials. The SHGC more accurately measures solar heat gain through multiple layers of glazing, materials with low-e coatings, or plastic materials that interact differently with various wavelengths of the solar spectrum.

Currently, most skylight manufacturers describe their products in terms of SC. If the SC is the only solar gain information available for a given glazing material, divide by 0.87 to approximate the SHGC<sup>1</sup>.

Reflective coatings that reflect the visible spectrum are sometimes used on window glass to obtain a lower SHGC. These optically reflective coatings are not available on plastics formed for skylights. Although they could technically be used for glass skylights, they are not recommended. When used on a roof they can create blinding reflections for occupants of nearby buildings or hillsides, and also can be disorienting for aircraft and birds.

There are other reflective coatings which primarily reflect the infrared portion of the spectrum rather than visible light. These are called “low-emissivity” or “low-e” coatings, or are also known by the trade name of “Heat Mirror.” These coatings can be formulated to reflect specific portions of the solar spectrum, and so are also called “spectrally-selective surfaces.” We will use “low-e” as a generic name to refer to all varieties. Since a low-e coating reduces the flow of heat, it can affect both the SHGC and the U-value for a glazing material.

Low-e coatings can be applied to the surface of glass or polyester film. They are not currently applied to other plastic materials which are subsequently heated for forming. A low-e coating requires a very high-tech, highly controlled plant for uniform application. Low-e surfaces are also susceptible to scratching and atmospheric damage, and so are usually protected on an inner layer of multiple layer glazing<sup>2</sup>.

Low-e coatings are available in some residential glass skylights, where heat loss and occupant comfort at night are important concerns. They are not widely available for commercial applications, although some manufacturers offer a low-e coated polyester film glazing layer for special triple- (or quadruple-) glazed products.

### 3.1.3. Glazing Efficacy

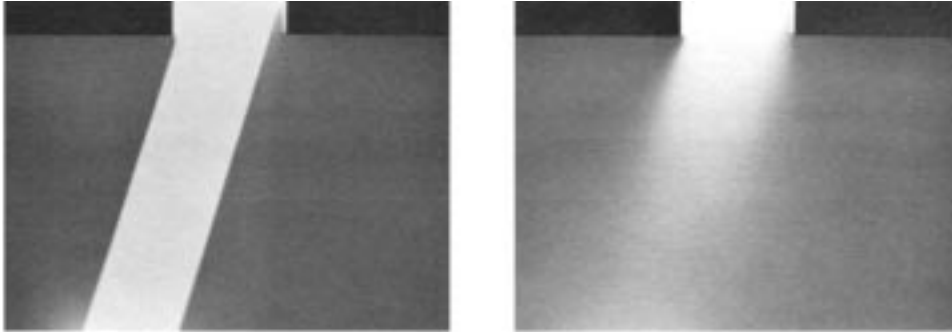
Figure 3-1 illustrates how the  $T_{vis}$ , the SHGC, and the resulting<sup>3</sup> LSG vary depending on the glazing material and color, number, and type of layers. These are some of the generic values used in *SkyCalc*. Product-specific values should be obtained whenever possible. Note that the LSG varies from a low of 0.59 for single-glazed bronze acrylic to a high of 1.61 for low-e, triple-glazed green glass.

**FIGURE 3-1:**  
SOLAR-OPTICAL  
PROPERTIES OF SKYLIGHT  
GLAZINGS

### 3.1.4. Diffusion

Merely specifying the visible transmittance and solar heat gain coefficient is not a sufficient description of a glazing product for skylights. Any specification should also include a description of diffusing properties. *SkyCalc* assumes that the skylights used in the calculations are perfectly diffusing, which is an ideal case. The more diffusing the material, the more uniform the distribution of light. However, there is a wide range of diffusion among the various skylight materials commonly used.

Unfortunately, there is no standard language or widely available measurement that accurately describes diffusion properties. There are test standards such as ASTM E167-96 which measure diffusion; however these results are rarely available. As a result, the specifier should describe a visual inspection procedure to evaluate samples of the glazing material or the skylight assembly for diffusion.



**FIGURE 3-4:**  
**EFFECT OF SKYLIGHT**  
**GLAZING ON LIGHT**  
**TRANSMISSION**  
TRANSPARENT GLAZING  
MATERIALS (LEFT) ADMIT  
BEAM SUNLIGHT TO THE  
BUILDING, WHICH CAN  
RESULT IN EITHER HARSH  
SHADOWS OR PLEASANT  
BRIGHT SPOTS, DEPENDING  
UPON THE DESIGN INTENT.  
DIFFUSING GLAZING  
(RIGHT) PROVIDES A  
MORE UNIFORM LIGHT  
DISTRIBUTION AND  
AVOIDS THE CREATION OF  
“HOT SPOTS” THAT CAN  
RAISE THE PERCEIVED  
TEMPERATURE IN A  
PARTICULAR AREA.

A quick first judgment can be made by looking through a translucent material. If any image can be seen through the material, some portion of light must be passing directly through, and thus the material will not be highly diffusing. However, even a product that passes this test could have poor diffusion, since such a visual test does not evaluate how widely scattered the diffused component is. A better test is to measure the variation in light levels produced underneath a skylight. For example, if, on a sunny day, any image of the skylight can be seen on the floor below, then some amount of direct beam sun remains unscattered. More accurate comparisons between skylights can be made by taking a series of light meter readings in a grid pattern underneath. The skylight with the most uniform readings under identical sunny day conditions will be the most diffusing.

Currently, most acrylic and polycarbonate glazings use pigments in their “white” products to diffuse light. Since these pigments also absorb visible light, generally the higher the visible transmission, the less diffusing it is. Thus, “high white” acrylic, with a high  $T_{vis}$  is less diffusing than a “medium white” with lower transmission. Bronze and gray acrylics do not follow this pattern, and usually have poor diffusion even at lower transmission values.

There are clear plastic products formed with a “prismatic” surface that are both highly diffusing and have very high  $T_{vis}$ . These are similar to the prismatic lenses used on light fixtures. Extruded double-walled plastics can also create a diffusing pattern.

Fiberglass materials also have a different relationship of  $T_{vis}$  to diffusion. In fiberglass, the glass fibers act as a diffusing element. Fiberglass is a highly variable material, however, since it depends upon the mix of resins and glass fibers used in the manufacture. Also, most fiberglass skylights are not made from a uniform pre-manufactured sheet material, but rather are made by applying the resin and glass mixture to a form. Thus, exact thickness and composition of the material can vary among manufacturers, and even among individual units.

Glass skylights can improve their diffusion performance with the use of frosted glass, fritted glass, or miniature lines etched into the surface. While many advanced glass products are available for use in windows<sup>4</sup>, they are not common in commercially available skylights.

It should be noted that the diffusion from skylights can also be enhanced with other design

options, such as the light well design, or other diffusing elements. See Section 2.4. Daylight Distribution for more discussion on designing for light diffusion.

### 3.1.5. Glazing U-Value

The U-value of a skylight measures its heat transfer capabilities when placed between two spaces of different temperatures. The U-value is simply the inverse of the R-value, which measures the material's resistance to heat transfer. The overall U-value of a skylight is a function of its glazing materials and its frame. This is often referred to as the "unit U-value" and is discussed further in Section 3.4.5. below. Here we will only address the U-value of the glazing assembly.

Most skylight manufacturers offer units with double, and some even triple, glazing. Increasing the number of glazing layers produces higher insulating qualities (lower U-values), but will also lower the SHGC and  $T_{vis}$  of the skylight. Thus, for diffusing skylights, generally one layer is of a diffusing material and other layers are of a clear, highly transparent material. Inner layers of glazing can be constructed of less resilient material, since they do not need to resist the weather or physical impacts. Some manufacturers use a very thin polyester film layer to provide additional insulating value with little loss in  $T_{vis}$ .

Another alternative to increasing the insulating value of skylights is to add fiberglass insulation between layers of glazing. This is typically done in units with two flat layers of fiberglass stretched across a rigid frame. A wide range of U-value options is available, with some featuring extremely low U-values. For these products, generally the better the U-value, the worse the visible transmission.

Skylights are also made with extruded glazing materials that have hollow chambers cast between two outer layers of plastic. These integral air spaces lower the U-value, and the multiple surfaces of the extruded material serve to diffuse some of the light.

The incorporation of low-e glazing materials into a skylight assembly can also lower the U-value and SHGC while preserving a high  $T_{vis}$ . Glass skylights can include a low-e surface on an inside surface. Plastic skylights can include a layer of low-e coated polyester film. Because the polyester film is fragile and easily punctured or torn, it is generally protected between an upper and lower glazing layer, to create a triple-glazed assembly.

See Figure 3-6: Skylight Unit U-values for sample U-values for various glazing materials combined with frame types.

### 3.1.6. Other Properties

Other physical properties of glazing materials that should be considered include:

- Impact resistance: The ability to resist breakage from impacts such as hail, rocks,

or ballast from adjacent roofs.

- Breaking characteristics: Whether the material shatters into dangerous shards, or fails in a less dangerous fashion.
- Strength: The ability to withstand applied forces, such as wind, snow, and gravity.
- Thermal expansion: The length of expansion per degree of temperature difference. This determines the amount of movement that must be accommodated by the glazing framing.
- Weatherability: The ability of the material to resist surface erosion due to dust and other airborne abrasives, and ultraviolet or thermal degradation resulting in yellowing or hazing, which would reduce light transmission and desired performance.
- Flammability: The amount of heat, smoke, and/or toxic fumes generated by the material in a fire.

Plastic materials vary considerably in these characteristics. The glazing material or skylight manufacturer should be consulted for information about the particular properties of their materials. Some of these properties are discussed more thoroughly in the sections below.

## Shading Devices 3.2.

A number of exterior shading devices for skylights have been tested over the years, including static overhead shades that block the direct sun at certain sun angles and operable “hatches” that can be moved to alternately shade a skylight, focus additional sun into the skylight, and/or insulate it at night. While these devices can be designed to improve the long-term energy performance of a skylight, they can add considerably to the expense. They are also subject to the torments of weather, dirt, and debris, which combined with the usual rarity of roof-top maintenance, tend to result in eventual failure.

Interior shading devices include horizontal louvers, roller shades, screens, and shutters. They are usually manufactured products, but they can also be custom-assembled from fabrics, panels, screens, or other architectural components. Interior shades are typically located within or at the bottom of skylight wells. Because they are inside the building, they are not subjected to the rigors of wind and weather that beset exterior shading devices.

Shading devices should be included in any calculations of skylight efficacy and SHGC. *SkyCalc* can account for static shading devices in the Optional Inputs tab. However, manual or automatic operable devices cannot be modeled easily. Since correct operation would lead to lower solar heat gains when there is ample daylight, and perhaps also lower heat losses when there is no daylight, the user should assume that the *SkyCalc* run is a worst-case scenario. The reader is referred to the ASHRAE Handbook of Fundamentals for more detailed guidance on determining the lighting and heating effects of various shading devices.

### **3.2.1. Horizontal Blinds**

Some of the most flexible interior shading devices are adjustable horizontal blinds. These are available for mounting in a horizontal or tilted plane. By orienting the blinds on an east-west axis, they can best respond to changes in the sun's elevation both during the day and seasonally. By changing the tilt of the blinds, the amount of light (and heat) entering the space can be reduced and partially reflected back to the sky.

The materials used should be highly reflective, so that they bounce much of the unwanted direct solar radiation back to the exterior. The reflective materials could become glare sources themselves if they are not kept out of the viewing angle.

Horizontal blinds must have enough strength to span the width of the skylight without sagging or losing their ability to adjust angles. Thus, they are typically made just for this purpose; and given the limited market, there are currently only a few national manufacturers of such blinds.

The adjustment of the blinds can be done manually or automatically, and can change hourly or seasonally. Horizontal blinds can be operated manually, often with a removable turnwand located in the skylight well, or automatically, either with a wall switch or with a photocontrol. An automatic system requires the addition of a small motor to open or close the blinds plus wiring to a wall switch or dial, and so adds considerably to the expense. Photo control of the automatic motor adds yet another expense. However, if the photosensor can control multiple blinds, and thus provide reliable control of a large space, it may be an appropriate choice.

### **3.2.2. Screens, Roller Shades, and Shutters**

Horizontally mounted shades, screens, or shutters can also be pulled across a skylight well. Typically these are mounted on a track to keep them from sagging across the opening. They can be operated with a pull cord, a crank, or an automatic switch.

They can vary from opaque to translucent, or an open mesh allowing five to 20 percent of the light through. The color of the shade should be carefully considered so that it does not become a glare source if it is within the viewing angle. The amount of daylight can be adjusted by the extent to which the shade is pulled closed, although uniform light distribution may also be somewhat affected.

A horizontal blind or shade, if it is sufficiently sealed at the edges, can provide a small additional layer of insulation at night and/or help to keep hot air stratified in the upper light well on hot days.

Shutters are often rigid opaque devices that can be swung open or closed from a horizontal hinge. If the shutter fits neatly into the light well, it can be fairly unobtrusive when open. While a shutter offers fewer light control options, it does offer the ability to add considerable



insulation during cold or very hot weather. One inch of foam can provide an addition of R-3 to R-5 to a light well. One school in Colorado uses a system of insulated shutters that automatically close every night and automatically open every morning. The teachers have the option of using an override switch to close the shutters during the day to darken the room for video presentations or prevent unwanted heat gain during hot months.

**3.2.3. Maintenance**

The operating mechanisms of any shading device should be accessible to maintenance personnel, and replacement parts easily obtained. Anything that moves will eventually break if it cannot be cleaned, oiled, and/or repaired on occasion.

The Elk Grove School District in California uses horizontal louvers in skylights so teachers can darken the classroom. The accumulation of dust and grime has made the louvers difficult to operate. The maintenance staff has tried to replace the louvers, but decided that the expense and delay of waiting for parts was unacceptable. Now, each time a louver fails, they give the teacher the option of leaving the louvers permanently open or closed. So far, all of the teachers have chosen to leave them permanently open.

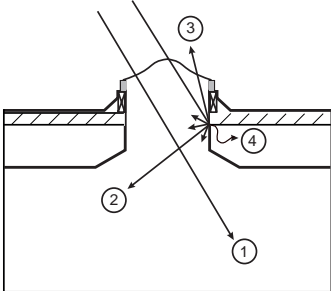
**Light Wells 3.3.**

The light well is as important to the efficiency of the skylight as is the glazing material. A specifier should realize that there is not much point in trying to specify the most efficient glazing material if the light well is inefficient. Paying attention to the details of light well configuration and surface materials, such as the selection of paint color, can be a less expensive first step to efficiency than specifying high-tech glazing materials.

Understanding how light well shape and reflectance affects the efficiency of the skylight leads to some simple guidelines on how to maximize the efficiency of skylight wells. Figure 3-3 illustrates how daylight passing through the light well can 1) pass directly through unhindered, 2) be reflected and exit the light well into the building, 3) be reflected and exit backwards through the skylight or 4) be absorbed by the sides of the light well.

A few basic observations can be made about light wells:

- The shallower a light well is relative to its width, the less light is transmitted.
- Splaying the light well, so the bottom of the light well is wider than the top, as illustrated in Figure 3-3, transmits more light than a light well with vertical sides.
- For a given geometry, a light well which is painted white will have the highest efficiency.



**FIGURE 3-3:**  
LIGHT TRANSFER THROUGH  
A LIGHT WELL

**FIGURE 3-4: TYPICAL SURFACE REFLECTANCES**  
PROVIDES SOME GUIDANCE ON TYPICAL REFLECTANCES OF VARIOUS MATERIALS. SOME PAINT MANUFACTURERS CAN PROVIDE TESTED REFLECTANCE VALUES FOR ALL THEIR PAINT COLORS. IN THE ABSENCE OF TEST RESULTS, A ROUGH APPROXIMATION OF THE REFLECTANCE OF A MATERIAL CAN BE MADE BY USING A LIGHT METER TO COMPARE THE AMOUNT OF LIGHT INCIDENT ON A SURFACE TO THE AMOUNT OF LIGHT ONE FOOT AWAY THAT IS REFLECTED BY THAT SURFACE.

### 3.3.1. The Well Factor

The well factor (WF) describes the fraction of the light entering the light well that penetrates into the room below. This factor is determined by the geometry of the light well and the reflectance of the surfaces of the light well. To calculate a WF, first you need to determine the well cavity ratio (WCR) and the reflectances of the well surfaces.

The WCR is a single value that describes the proportions of the light well. It is the ratio of wall area to opening area, similar to the room cavity ratio used in electric lighting calculations. The well widths and lengths used here are those at the bottom of the light well.

$$\text{WCR} = \frac{5 \times \text{Well Height} \times (\text{Well Width} + \text{Well Length})}{\text{Well Width} \times \text{Well Length}}$$

A cube shape has a WCR of 10. An extremely narrow, tall well might have a WCR of 20, and a very shallow well might have a WCR of two or three.

A graph plotting the WF is shown in Figure 3-5 for three wall reflectances over a range of well cavity ratios. Notice that the less reflective the surfaces of the well, the lower the WF. Indeed, lowering the reflectance of the surfaces can lower the overall WF by the same amount or more. Clearly, the deeper the well, the more important surface reflectance is to the overall light transmittance of the skylight.

**FIGURE 3-5:**  
WELL FACTOR GRAPH

### 3.3.2. Skylight Efficacy

The efficiency of a skylight design is described as the skylight efficacy (SE), which is a ratio of the light transmitted, to the solar heat gain of the entire skylight assembly. It is defined as a function of the light-to-solar gain ratio of the glazing material times the WF. Skylight efficacy<sup>5</sup>, SE, can be expressed by the following equations:

$$SE = LSG \times WF \frac{T_{vis} \times WF}{SHGC}$$

It can be seen from this simple equation that doubling the WF will directly double the SE. For a cube-shaped light well, cutting the reflectance of the surfaces in half (by changing the paint color from white to goldenrod, for example), will also reduce the SE by half. Thus, a skylight specifier should take a considerable interest in the choices made by the interior design department.

## Frames and Unit U-Value 3.4.

The most basic function of any skylight frame is to provide a rigid frame for the glazing material and a secure method of attachment to the roof. However, there are many possible secondary functions that can add complexity to the design of a frame, such as:

- raising the skylight above any ponding water on the roof
- venting the building
- dispersing internal condensation
- securing multiple layers of glazing
- resisting heat flow
- resisting vandalism
- supporting internal shading devices
- supporting internal screens or safety grills
- venting smoke automatically

Unit skylights are typically fabricated with glazing material and frame bonded together with a gasketing material and all sealants at the factory, and shipped as a ready-to-install unit. The attachment of glazing material to frame must accommodate potential expansion and contraction of the materials, natural building flex and vibrations, and aging due to exposure to weather and ultraviolet light. The method of attachment of glazing material to frame may largely determine its long-term weather resistance and resistance to vandalism.

Skylight frames can be made out of a variety of materials. Most common are metal (typically aluminum), wood, or vinyl. There are also variations, such as metal-clad wood, metal-reinforced vinyl, and insulated metal frames.

Thus, the design of the skylight frame is a very important criteria in the selection of a skylight product. Given our concern with the energy performance of skylights, we will concentrate on the thermal performance of frames. The U-value of a unit skylight is a function of both its glazing material and the thermal resistance of its frames.

#### **3.4.1. Frame Thermal Performance**

Metal is highly conductive of heat, thus a metal skylight frame can contribute a lot of heat to the light well on hot days, and allow even more heat to conduct to the outside at night and during cold weather. The larger the surface area of metal exposed to the weather, the larger the magnitude of this heat flow will be. A very cold frame will also cause moisture from the interior of the building to condense on its surface. This condensed moisture is likely to drip down the light well and potentially cause water stains on the ceiling, giving the appearance of a leaking skylight. There are a number of solutions to these problems.

The most energy-efficient solution is the use of a “thermalized” frame that may include either or both a “thermal break” and an insulating layer. A thermal break is a rubber or plastic insert into a metal frame that prevents any continuous thermal path of metal from inside to outside. Metal frames with thermal breaks have become a standard in the window industry in order to improve the thermal performance of windows. They are less common in the skylight industry, where heat loss has been less of a concern.

A frame can also be insulated to reduce heat flow. This can be either a factory-applied foam insulation or a site-installed insulating material on the inside of the frame. Wood frames are naturally much more insulating than metal. Hollow vinyl performs similarly to wood. A vinyl frame with injected insulating foam will be the most insulating of all. A frame can be rated with its own R-value or U-value. An even better indication is an overall unit U-value that integrates the performance of both glazing material and frame.

#### **3.4.2. Condensation**

In addition to thermal breaks or insulation, condensation problems can be reduced in two other ways. Many unit skylights will have condensation gutters that capture the condensed water that drains off of the glazing. This water is vented to the outside via weep holes. In a non-critical application, this is usually sufficient. However, weep holes do allow a potential path for both infiltration and wind-driven rain to enter the building. An alternative is to size the condensation gutters with enough capacity so that the condensed water will be stored until it can evaporate. Typically this is a daily cycle, with condensation forming at night and evaporating during the day.

#### **3.4.3. Mounting Types**

There are three major mounting types for skylight frames:

- Curb mounted frames: The frame attaches to the top of a separate curb. The curb is the structural connection to the roof, most commonly site-built of wood 2x10s or 2x12s. The curb also creates the transition from roofing material to skylight flashing to ensure a water-tight seal around the skylight opening.
- Integral curb: The curb is pre-manufactured as part of the skylight frame, typically of the same materials as the frame.
- Flush mount: The skylight is flush with the surface of the roof. This can be appropriate for a tilted roof surface.

An integral frame skylight, if it is not insulated, will lose more heat than a similar curb-mounted skylight, because there is a larger surface area of frame exposed to the outdoors. Flush-mounted skylights, on the other hand, will usually have less heat loss than a comparable curb-mounted or integral skylight, because they do not project from the surface of the roof and have less area to lose heat.

#### **3.4.4. Operable and Venting Frames**

Operable skylights are designed to open to provide natural ventilation and occasionally even egress. This type is fairly common in residential applications but is rarely seen on larger commercial buildings.

More common are venting skylights which feature louvers in the frames designed to allow air to escape from the building while preventing rain from entering. Venting frames are used on unconditioned buildings, such as warehouses, agricultural, and industrial buildings, to increase the flow of air through the space, and especially to allow heat build-up at the roof to escape. They are more common in hot climates, where cooling is more of an issue than heating. Venting skylights do, however, have the potential to allow wind-driven rain to penetrate into the building. One manufacturer found that by turning on exhaust fans in his building during rain storms he could create enough of a pressure differential to keep the rain out.

Smoke vent skylights are designed to pop open automatically in case of fire, releasing fumes and hot air at the ceiling plane, and thus reducing the spread of the fire in the building. They usually have a fusible link which breaks at high temperatures, and a spring action hinge that is freed to pop open. An alternate design allows the glazing material to drop out when overheated. Smoke vent skylights are a fire-code requirement for some building types (See Section 3.7.2.). Often these buildings will have a mixture of smoke vent frames for the code-required area and standard frame skylights for additional daylighting.

#### **3.4.5. Unit U-value**

The heat losses or gains due to temperature differences between the outside and inside air result from the product of the U-value (thermal transmittance) skylight area and the

temperature difference. An accepted way of describing U-value is in terms of Btu per hour of heat loss per square foot of skylight opening, per degree Fahrenheit of temperature difference between the outside and inside air temperatures. The heat loss through the glazing, frame, and curb all contribute to the overall unit U-value.

When specifying a product unit U-value, you should make sure that you are comparing similarly defined values. U-values can be made to look “better” (lower) by considering the loss only through the glazing or by defining the area as the total surface area of the skylight, including sides, instead of the skylight opening. There is room for confusion here since for a window, the rough opening is larger than the nominal size of the window, whereas with skylights, the rough opening is smaller than the nominal size. Ultimately, heat loss calculations are concerned with the heat loss through the opening in the insulated wall or roof.

Current standards for skylight U-value testing include AAMA 1503.1-1988 and NFRC 100-1997. The current NFRC standard will slightly underestimate (approximately 15 percent) the U-value of skylights because it tests skylights in a vertical orientation as if they were windows. With new procedures that allow computer modeling to extrapolate test results to other conditions, it is hoped that more manufacturers will be able to publish U-values with consistent criteria.

Representative U-values are shown in Figure 3-6 for low-profile skylights (either flat skylights or low-rise dome skylights). Barrel-vaulted or pyramidal skylights have larger surface areas to lose heat. The resulting increased “effective U-value” per horizontal area covered by skylights can be found by multiplying by the relative area increase relative to a flat skylight.

**FIGURE 3-6:**

**SKYLIGHT UNIT U-VALUES**

NOTE: THESE VALUES ARE  
CALCULATED ASSUMING A  
FLAT GLAZING MATERIAL.  
THEY ARE REASONABLY  
REPRESENTATIVE FOR  
LOW PROFILE SKYLIGHTS.  
USE TESTED VALUES  
WHENEVER POSSIBLE.

When discussing U-value, we are mainly concerned with the heat losses in winter, because for most parts of the country, the difference between outside winter temperatures and normal inside temperatures are so much greater than those in the summer. Considering U-value only to estimate summer thermal transmittance will overestimate this component of

heat gain because in the summer, the stratified air rises and is trapped in the light well. This stratified air acts like a blanket, insulating somewhat against heat transfer.

The U-value of skylights is primarily a function of the number of glazing layers, the emissivity of the glazing itself or an applied coating, any special thermally insulating gasses injected between the layers of glazing, the material used in the spacers which hold the glazings apart, and the materials used in the frame holding the glazing.

## Structural and Safety Issues 3.5.

There are three basic structural and safety issues that must be addressed in skylight design:

- Maintenance of roof structure integrity
- Resistance of the skylight itself to weather loads and abuse
- Prevention of accidental breakage or entry

### Roof Structure

The roof of a building is often a structural “diaphragm” or plane that is designed to stiffen the building and resist forces that tend to twist the structural frame. This diaphragm can have a certain number and size of holes in it and still continue to function. But at some point, additional holes will weaken its strength. Thus, the structural engineer for a building may calculate that there are limits on the number, size, and location of holes in the roof that can be made for skylights or any other penetrations, such as mechanical ducts, vents, or access hatches.

There are ways to strengthen the diaphragm to allow additional penetrations. If more skylights than the initial structural limit are desired, redesigning the roof structure may be an option. In wood construction, thicker plywood and additional nailing can strengthen the diaphragm. In steel construction, added framing members around openings can strengthen the roof. In concrete construction, additional reinforcing or formed concrete curbs can be used. Thus, while structural considerations can be a limiting factor on skylight design, there are usually alternatives that can be considered.

### Structural Loads

Skylight units (frames and glazing) must also be able to resist a variety of potential loads. These include:

- Snow loads
- Wind (uplift) loads
- The weight of the skylight assembly
- Loads transferred from the building to the skylight (flexing and vibrations)
- Weight of people
- Forcible entry and vandalism
- Flying objects (wind-driven gravel, debris, and errant birds)

We would like to emphasize that structural and safety concerns do not begin and end with the glazing only—the attachment of the glazing to the frame, the frame itself, and the attachment of the frame to the roof are also concerns.

The magnitude of potential snow loads are usually addressed in local building codes that specify a maximum loading that can be expected for a given area. This is normally specified in terms of withstanding a particular “live,” or changeable, load of a particular number of pounds per square foot. Testing for this requirement is typically done by evenly placing enough sandbags on the skylight so that the loading exceeds the requirement. The requirement should exceed the worst-case predicted snow load by a healthy safety margin.

Wind blowing over a roof can create uplift pressures on the roof and skylights. Most local building codes will also specify a wind loading that must be resisted. This loading, however, is more commonly calculated for vertical surfaces resisting a horizontal wind, than for horizontal surfaces resisting suction uplift. Very strong storms, such as hurricanes, can also cause sudden pressure differentials that can blow a skylight off from the inside, especially if there is an opening elsewhere in the building. The manufacturer should be able to detail suitable attachment methods in shop drawings and warrantee the skylight and attachment method for a given set of wind conditions.

Small unit skylights do not usually have a problem supporting their own weight. But large site-assembled skylight assemblies have to be carefully designed to prevent failure. Skylights are not designed to support any structural loads transferred from the roof. The structural engineer should ensure that all structural forces are diverted around the skylight openings. For further guidance on the design, selection, and installation of skylights, refer to the AAMA guidelines for skylight structural criteria listed in the bibliography.

### **Safety Grates**

Only a few skylights can withstand the impact of people, whether inadvertently falling on them, intentionally jumping on them, or trying to break them with a heavy object. These should be labeled as not resistant to standing or falling people. There are, however, some skylight products that can resist these abuses. Underwriters Lab (UL) Standard 972 covers the strength of the glazing in resisting the efforts of burglars, while American Society of Testing Methods (ASTM) Standard F588 tests how well the frame will hold up to “forced entry.” To meet these standards, one may be limited to specialty glazing materials and a heavy-duty frame. These types of skylights are particularly popular with school districts.

Another way of addressing security and safety issues is to install a safety grate above or below the skylight. A metal grate will effectively resist the weight of a person and stop a fall. The most common safety grate is a grid of steel bars spaced every six inches mounted inside to either the frame or the curb. This both protects people from accidental falls and prevents thieves from breaking in. Some manufacturers provide a safety grate as a factory-built option for their units. Other building owners include it as a standard site-built specification item.



A safety grate will, of course, also reduce the amount of light transmitted through the skylight, and should be accounted for in any calculations (*SkyCalc* has a safety grate option.). A white-painted grate will reflect more light, but sometimes is more visible from below, especially at night. Depending on visual conditions, a black grate can sometimes be less apparent.

## Roofing and Insulation Decisions 3.6.

The integration of the skylight with the roofing system is another important consideration. A roof membrane is usually selected independent of the choice of skylights. Skylights can be successfully flashed and waterproofed with any roofing system. The flashing design is no different from that of mechanical curbs, roof parapets, or other interruptions of the roof surface. (See the AAMA Skylight Installation Manual, to be published in late 1999.)

The vast majority of commercial skylights are probably installed with a hot-mop, multi-ply asphalt roofing system. Properly installed, the skylight junction will last as long as the rest of the roof. Single-ply roofing systems are also amenable to skylights. Probably the biggest concern is the cost of additional penetrations, which can raise the installed cost significantly.

Probably the most important roofing choices are in your specification language. Many specifiers require skylight installers to have a minimum number of years of experience. Others mandate a roofing team meeting of the roofing contractor, structural engineer, skylight installer and distributor, and general contractor to resolve all timing and detailing issues. It is an excellent idea to require a warranty of roof performance from the contractor (10 years and 15 years are standard) that specifically includes the skylight penetrations, and a guarantee that any leaks which are identified will be addressed immediately (within a fixed time period of hours or days). A water pressure test on the roof after installation and before occupancy is also an advisable element for your specifications. With these provisions, you will have good reason to expect your skylights, and the rest of the roof, to remain leak-free for the expected life span of the roof.

### **Roof Insulation**

The choice of a roofing system also includes the choice of roof insulation. In an “upside-down” roof, the insulation is installed above the roof deck and membrane, in the form of a foam insulation held down with stone ballasts. Any gravel on the roof is a potential source of abrasion—or even puncture—of the skylights, and thus these systems are rarely used with skylights. Locating foam insulation under the roof membrane but above the deck typically does not involve the same ballasting problem. It does, however, raise the height of the skylight curb that must reach from the structure to above the insulation. There may be more flex at the membrane-to-curb joint, creating a potential source of failure.

By far the most common insulation approach is to locate fiberglass batt or board insulation below the roof deck. For buildings without a finished ceiling, this offers the potential of using a reflective-surfaced insulation material which will reflect more light down into the space. Alternatively, the surface of the insulation material can be painted white, which will probably reflect even more light, and result in fewer glare problems.

Finally, thought should be given to insulating the light well and skylight curb. As discussed above, this will not only reduce heat losses, but will also greatly reduce the potential of damage from condensation forming on a cold skylight frame surface.

## 3.7. Building Codes and Standards

Skylights are regulated by a variety of building codes to assure that their application does not compromise the energy efficiency, structural integrity, or safety of a building. Building codes as they apply to skylights may vary from municipality to municipality. Therefore, the codes for the municipality where the skylights are to be used should be reviewed prior to initial design.

In spite of the variations, however, some general comments can be made about the more widely used codes. These apply primarily to energy efficiency, the load-bearing capabilities of the skylight, and the area and spacing for combustible skylight materials (principally plastic glazing)

### 3.7.1. Energy Codes

Many of the key energy codes enforced in the United States recognize that appropriately sized skylights, when used with daylighting controls, save energy. The California Standards and the national ASHRAE/IESNA 90.1 Code are reviewed below.

#### California

The prescriptive path of the California Nonresidential Building Energy Efficiency Standards (Title 24) allows up to five percent of the roof area to be covered with skylights. This area is exempted from the calculation of the roof overall U-value. There is also an exception for atriums that allows up to 10 percent of the roof area to be in skylights if the atrium is more than 55 feet tall.

Along with limitations on skylight area, the standards have a maximum climate specific U-value for the skylight units and SC requirements. The skylight unit U-values vary from U-0.85 to U-1.31. The shading coefficient requirement is lower for transparent glazing than for translucent materials<sup>6</sup>. Daylighting controls are not required, but if daylighting controls are used, control credits are allotted which gives the designer the flexibility to add more electric lighting.

There is a second approach, the “prescriptive overall envelope approach,” which allows the designer to calculate an overall heat loss for the entire building. This approach does not limit skylight area. However, skylights are treated as windows, and so contribute to a maximum allowable solar heat gain and heat loss. In this approach the effects of wall and roof insulation are combined with the insulating qualities of the windows and skylights for one value.

California has a third, highly flexible compliance approach called the “performance approach” which uses whole building energy budgets. The designer can use whatever skylights (and other building features) are desired, as long as an approved building simulation program demonstrates that their design uses less energy than a similar building that meets the prescriptive energy standards.

### **National**

The ASHRAE/IESNA 90.1 Energy Code for Commercial and High Rise Residential Buildings is becoming the basis for many of the other states’ nonresidential energy codes and the federal building standards. It is adopted by reference in the 1995 Model Energy Code. The ASHRAE/IESNA 90.1 prescriptive requirements for skylights are markedly different than California’s. The code has an overall U-value requirement for roofs, including the skylights. But it exempts some skylight area contingent on the installation of daylighting controls in the daylit zone. The maximum exempt area is dependent on climate zone, lighting power density of the area under skylights (higher LPD results in more allowable area), and visible transmittance of skylights (lower  $T_{vis}$  results in more allowable area).

There is also a requirement in ASHRAE/IESNA 90.1 that the “exempt” skylights have a minimum curb U-value of 0.21 Btu/hr/sf.

States and local jurisdictions are free to modify parts or all of the ASHRAE/IESNA 90.1 Code or develop their own. Therefore, it is essential to check local requirements.

Many of the national codes also have a performance-based compliance path that allows the designer to use skylights if an approved building simulation program demonstrates that their design uses less energy than a similar building that meets the prescriptive energy standards. Like California’s Title 24, ASHRAE/IESNA 90.1 has a performance-based compliance path.

### **Lighting**

Both California’s Title 24 and the ASHRAE/IESNA 90.1 Code define the “daylit zone” as an area within 45 degrees of the bottom of the skylight well. Thus the daylit zone becomes a rectangular area with dimensions that are two times the ceiling height, plus the length or width of the well. These formulas do not account for the shape of the well.

California allows lighting credits based on the control type, visible light transmittance, and the skylight-to-roof area ratio<sup>7</sup>. There is also a threshold “effective skylight aperture” below

which daylight credits are not allowed.

Both codes also limit the connected lighting load in commercial buildings, variously termed the “lighting power density” (LPD) or “unit power density” (UPD), both of which are measured in Watts per square foot (W/sf). Lighting power density is a measure of the amount of electric lighting *installed* in a building, not necessary the amount used. It is not directly related to skylights, but it is directly related to the amount of electrical energy they can save and to their load management potential. In general, buildings with high LPDs present opportunities for greater energy savings with daylighting, both through lighting savings and through reductions in cooling loads from internal heat gain.

**FIGURE 3-7:**  
**COMPARISON OF CODE**  
**LIGHTING POWER**  
**DENSITIES**  
 THESE VALUES, WHICH  
 PROVIDE SOME GUIDANCE  
 ON LIGHTING POWER  
 DENSITIES TO BE EXPECTED  
 IN THE BUILDING TYPES  
 AVAILABLE IN *SkyCalc*,  
 ARE ONLY ILLUSTRATIVE,  
 AND MAY BE REVISED IN  
 NEW ADDITIONS. BE SURE  
 TO CHECK CURRENT LOCAL  
 REQUIREMENTS.

LIGHTING POWER DENSITIES in Watts/sf	CA Title 24 1998	ASHRAE /IESNA 90.1 (to 50,000SF)
Classroom, K-12	1.40	1.65-1.83
Class, University	1.40	2.01
Grocery	1.50	2.50
Hotel Lobby (area)	2.20	1.90
Office	1.20	1.65
Restaurant	1.20	2.50
Retail	1.70	2.50
Warehouse	1.00-1.20	0.48

Figure 3-7 compares some of the currently allowed LPDs in W/sf for several of the building types included in *SkyCalc*.

Energy codes are the fastest-changing area of building regulation that affects skylights, and applicable requirements should be reviewed carefully during the design process.

### 3.7.2. Fire Codes

Plastic glazing materials are combustible and their use is allowed with area limitations and spacing requirements. The use of automated fire suppression equipment (sprinklers) affects these parameters, as does the type of plastic used. Approved plastics are separated into two types, based on a small-scale flammability test: CC-1 (or C-1) and CC-2 (or C-2). The Uniform Building Code places the following limitations on plastic skylights:

- The plastic glazing must be mounted at least four inches above the plane of the roof
- Skylights with CC-1 glazing may be no larger than 200 sf per skylight
- Skylights with CC-2 glazing may be no larger than 100 sf per skylight
- The total area of skylights containing CC-1 materials is limited to maximum of one third of the roof area (SFR = 33%)
- The total area of skylights containing CC-2 materials is limited to maximum of one quarter of the roof area (SFR = 25%)

The use of sprinklers may relax some of these limitations.

The Uniform Building Code (UBC) requires smoke vents for one percent of the roof area in Business, Factory, Mercantile, and Storage occupancy single-story buildings with over 50,000 square feet of undivided space. Office and retail spaces are exempt from this smoke vent

requirement if storage height does not exceed 12 feet. The UBC also requires that Hazardous occupancy buildings with more than 15,000 square feet per floor have two percent of the roof area in smoke vents.

These smoke vents typically have a metal or plastic cover and many manufacturers have developed clear covers so that the smoke vent doubles as a skylight. Though the skylight-to-floor ratio (SFR) of one or two percent required for smoke vents is less than what is usually needed for an effective skylighting system, the smoke vents can be interspersed with non-opening skylights and help reduce the incremental cost of the skylighting system. Smoke vents are usually Factory Mutual rated. The fusible links on mechanical smoke vents are also typically UL or FM listed.

### **3.7.3. ANSI and other standards**

The following is a list of organizations and their publications that may be referred to when specifying skylights.

#### **AAMA - American Architectural Manufacturers Association**

- AAMA 501.2: Field Check of Metal Curtain Walls for Water Leakage
- AAMA 1503.1-1988: Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors, and Glazed Wall Sections. U-value class is in terms of hundredths of a Btu/hr·ft<sup>2</sup>·°F (i.e., class U20 has a maximum tested U-value of 0.20 Btu/hr·ft<sup>2</sup>·°F)
- AAMA 1600-90: Voluntary Specification for Skylights. Specifications include material and finish requirements as well as performance requirements for air infiltration, water resistance, and structural loading
- AAMA 1605.1-1987: Voluntary Uniform Standard Test Procedure for Plastic-Glazed Skylights by Uniform Static Air Pressure Difference
- AAMA 1601-1993: Voluntary Load-Bearing Specification for Plastic Skylight Domes. Presents recommended strength values for exterior one-piece thermoformed plastic skylight domes. No safety factors have been applied to these domes
- AAMA Installation Guidelines for Unit Skylights: To be released in 1999

#### **ANSI - American National Standards Institute**

- ANSI-Z97.1-84: Standard For Safety Glazing Materials Used In Buildings—Safety Performance Specifications and Methods of Test

#### **ASTM - American Society for the Testing of Materials**

- D1929-96: Standard Test Method for Determining Ignition Temperature of Plastics
- ASTM D1003-95: Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics. Materials with haze greater than 30 percent are considered diffusing and should be tested in accordance with ASTM E167-96
- ASTM D1925: Yellowness Index (discontinued in 1995)

- ASTM D4364-94: Standard Practice for Performing Outdoor Accelerated Weathering Tests of Plastics Using Concentrated Sunlight. Equivalent to ISO877.2-1991 Method C.
- ASTM E167-96: Standard Practice for Goniophotometry of Objects and Materials
- ASTM E283: Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors
- ASTM E330-97e1: Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference
- ASTM E331: Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls and Doors by Uniform Static Air Pressure Difference
- ASTM Standard E972-88: Standard Test Method for Solar Photometric Transmittance of Sheet Materials Using Sunlight
- ASTM E1423-91: Standard Practice for Determining the Steady-State Thermal Transmittance of Fenestration Systems
- ASTM F588-1997: Standard Test Methods for Measuring the Forced Entry Resistance of Window Assemblies, Excluding Glazing Impact
- ASTM F1233-1995: Standard Test Method for Security Glazing and Systems
- ASTM G90-94: Standard Practice for Performing Outdoor Accelerated Weathering Tests of Nonmetallic Materials Using Concentrated Sunlight

**CPSC - U.S. Consumer Product Safety Commission**

- 16 CFR 1201: Consumer Product Safety Commission Standard for Glass

**CSA - Canadian Standards Association**

- CSA Standard A440-90: Windows Temperature Index I is equivalent to CRF as defined in AAMA 1503.1-1988

**ICBO - International Conference of Building Officials**

- ICBO Evaluation Service: Acceptance Criteria for Plastic Skylights 1989: Durability, safety, water leakage, flame spread are combined under one acceptance criteria. Does not address energy issues of U-value, solar heat gain coefficient or visible transmittance.
- Uniform Building Code 1994: Section 2409 - Sloped Glazing and Skylights: Mainly safety considerations for glass skylights and frames. Section 2603 - Light Transmitting Plastics: This covers acceptable construction, size limitations, etc. of plastic skylights (2603.7), and requirements for light diffusers (2603.8).
- Uniform Building Code Standard 15-7: Automatic Smoke and Heat Vents

**ISO - International Standards Organization**

- ISO 877:1994: Methods of Exposure to Direct Weathering, to Weathering Using Glass Filtered Daylight, and to Intensified Weathering by Daylight Using Fresnel Mirrors

### **NFRC - National Fenestration Rating Council**

- NFRC 100-1997 Procedure for Testing Determining Fenestration Product U-Factors. Currently NFRC procedures for determining U-Values are based on a vertical tilt and thus underestimate heat loss
- NFRC 300-1994 Procedure for Determining Solar Optical Properties for Simple Fenestration Products
- NFRC 400-1995 Procedure for Determining Fenestration Product Air Leakage

### **OSHA - Occupational Safety and Health Administration**

- 29CFR Part 1926 Subpart M - Fall Protection. This has a generic description of methods of fall protection, but is not an explicit test standard

### **UL - Underwriters Laboratories**

- UL 972-1995 Burglary-Resisting Glazing Material

### **Footnotes, Chapter 3**

<sup>1</sup> The Lawrence Berkeley National Laboratory has published a public domain software program, *Window 5.0*, which calculates the solar heat gain coefficient for a wide variety of glass types, coatings, and number of layers. This program does not include plastic glazings as part of its data libraries.

<sup>2</sup> See *Residential Windows: A Guide to New Technologies and Energy Performance*, listed in the bibliography, for a more thorough discussion of low-e coatings.

<sup>3</sup> Light-to-solar gain ratio (LSG) is the ratio of visible transmittance to solar heat gain factor, and is used later to calculate overall skylight efficacy. There is no industry-wide consensus on the terminology for a measure of glazing performance. Most other terms in use, such as coolness index (CI) or performance index (PI) are based on the use of shading coefficient rather than solar heat gain coefficient.

<sup>4</sup> See *Residential Windows: A Guide to New Technologies and Energy Performance*, listed in the bibliography, for a more thorough discussion of advanced glazing products.

<sup>5</sup> The concept of Skylight Efficacy (SE) was introduced in the original *Skylighting Handbook* as a function of the shading coefficient, not the solar heat gain coefficient. In order to use the more accurate SHGC, we have redefined the term for the text. The values shown in the original *Handbook* were based on the following equations:

$$SE = \frac{T_{vis} \times WF}{SC} \quad \text{or} \quad SE = \frac{T_{vis} \times WF \times 0.87}{SHGC}$$

<sup>6</sup> See Table 1-I: Prescriptive Envelope Criteria in the California Nonresidential Building Energy Efficiency Standards for both required skylight unit U-values and shading coefficients.

<sup>7</sup> See Table 1-L: Lighting Power Adjustment Factors in the California Nonresidential Building Energy Efficiency Standards.