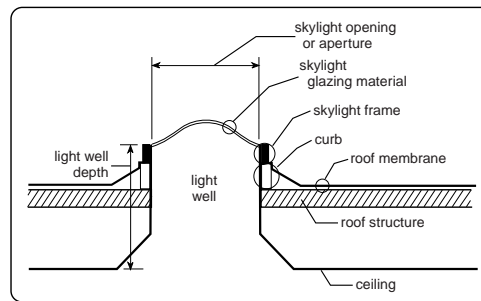


This chapter covers the more conceptual and qualitative aspects of skylights and daylighting controls that need to be understood by the architect and engineer as a building's design is being formulated. Later chapters provide numerical values useful in calculations, and more detailed information and advice useful to the specifier and building manager.



**FIGURE 2-1:**  
COMPONENTS OF A  
TYPICAL SKYLIGHT

We start with how the sources of daylight outside interact with the building, then move through the skylight itself into the space below, to interior design and building operation issues. The basic parts of a skylight are shown above in Figure 2-1.

### Characteristics of Daylight 2.1.

The amount of light skylights can provide depends directly on how much daylight is available outside, which varies with climatic conditions, the time of day, and the season of the year. On bright, sunny days, the maximum amount of daylight is available. On very dark, rainy days there is less light available. In the winter, days are short, and the number of daylight hours may be eight hours or less. In the summer, days are long and daylight may last for 16 hours or more per day.

Since our light sources in skylighting are the sun and the sky, it is important to understand the different quantities and qualities of daylight available from each source, and how they vary with climate and time of day. The specifics of your local climate will affect the optimum design of skylights for your area.


### 2.1.1. Sunlight versus Skylight

People often assume that “sunlight” and “skylight” can be used synonymously. In reality, they have very different physical properties and different effects on skylighting design. The most important differences are their intensity, their color, and the extent to which their light is scattered, or diffused.

The sun is considered a point source of light, often referred to as “beam” sunlight, because it is highly directional. Light from the sky, on the other hand, arrives from a large area and is more or less diffuse, meaning scattered and arriving from all directions. Beam light will cast a shadow; diffuse light will not cast a distinct shadow. On a bright, cloudy day, sometimes you can see a partial shadow, indicating that some beam sunlight is penetrating the clouds. Skylights perform differently, depending on the proportion of beam to diffuse light delivered by local weather conditions.

Sunlight is also a very intense source of light, generally providing 5,000 to 10,000 footcandles of illumination. The intensity of sunlight varies with time of year and location on the planet. It is most intense at noon in the tropics when the sun is high overhead and at high altitudes in thin air, and least intense in the winter in the arctic, when the sun’s light takes the longest path through the atmosphere.

Sunlight also provides a relatively warm color of light (which we characterize by its correlated color temperature—CCT—expressed in degrees Kelvin), varying from a warm candlelight color at sunrise and sunset, about 2000°K, to a more neutral color at noon of about 5500°K.



**FIGURE 2-2:**  
DAYLIGHT  
CHARACTERISTICS

The term “skylight” includes the light from both clear blue and cloudy skies. People are often surprised to learn that cloudy skies can be much brighter than clear blue skies. The brightness of cloudy skies depends largely on how thick the clouds are. A light ocean mist can be extremely bright, at 8,000 footcandles, while clouds on a stormy day can almost blacken the sky. The daylight on a day with complete cloud cover tends to create a very uniform lighting condition.

Skylight from clear blue skies, on the other hand, is surprisingly non-uniform. It is darkest at 90° opposite the sun’s location, and brightest around the sun. It also has a “blue” cast to

it, and is characterized as a “cool” color temperature of up to 10,000°K. Skylight from cloudy skies is warmer in color, a blend somewhere between sunlight and clear blue skies, at about 7,500°K.

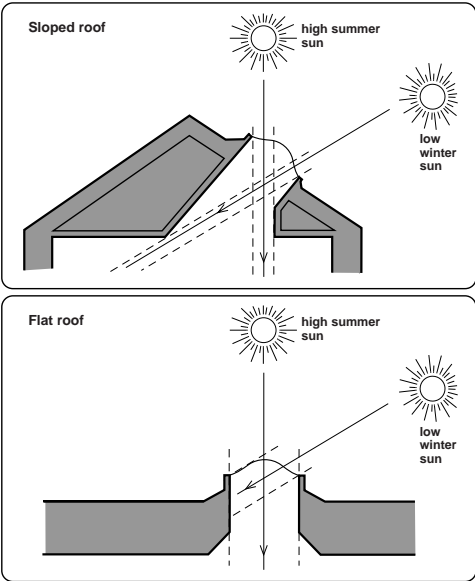
The proportion of cloudy days to clear blue days, and of direct beam sunlight to scattered skylight, in your local climate will determine how much illumination is available for skylighting. The mix of climate conditions should also influence your choice of glazing materials, light well design, and daylighting control strategies. For example, a transparent skylight material may be acceptable in a mild cloudy climate, whereas a diffusing skylight is essential in areas with a significant number of sunny days. Similarly, dimming controls may be more appropriate for areas with low daylight availability, while on-off controls may be acceptable in areas with predictably sunny weather.

### 2.1.2. Solar Geometry

The majority of commercial and industrial skylights are installed on flat roofs, where the skylight can “see” almost the full hemisphere of the sky. Typically, there are also few obstructions to block sunlight from reaching the skylight.

A skylight on a sloped roof cannot see the full sky hemisphere, but only a partial view determined by the slope of the roof. Furthermore, depending upon the angle and orientation of the sloped roof, the sun may not reach the skylight during certain times of the day or year. For example, a skylight on an east-facing roof with a 45° slope will only receive direct sun during the morning and midday hours. In the afternoon it will receive skylight, but only from three-fourths of the sky. As a result, in the afternoon it will deliver substantially less light to the space below than an identical skylight located on a flat roof.

The shape of a skylight also affects how much daylight it can provide at different times of the day, although these effects tend to be much more subtle than building geometry. For example, a flat-glazed skylight on a flat roof will intercept very little sunlight when the sun is very low in the early morning and at the end of the day. However, a skylight with angled sides, whether a bubble, pyramid, or other raised shape, can intercept substantially more sunlight at these critical low angles, increasing the illumination delivered below by five to 10 percent at the start and end of the day.



**FIGURE 2-3: SUN PENETRATION ON FLAT VERSUS SLOPED ROOFS**  
THE SLOPE AND ORIENTATION OF THE ROOF AND THE LIGHT WELL HAVE A MAJOR IMPACT ON HOW MUCH SUNLIGHT PENETRATES INTO THE INTERIOR OF THE BUILDING.

**FIGURE 2-4:**  
**TRANSMISSION OF LIGHT**  
**IN DOMED SKYLIGHTS<sup>1</sup>**  
 A DOMED OR PYRAMID  
 SKYLIGHT SHAPE ON A  
 FLAT ROOF WILL TRANSMIT  
 SLIGHTLY MORE SUNLIGHT  
 THAN A FLAT SKYLIGHT AT  
 LOW SUN ANGLES AND  
 LESS SUNLIGHT AT HIGH  
 SUN ANGLES.

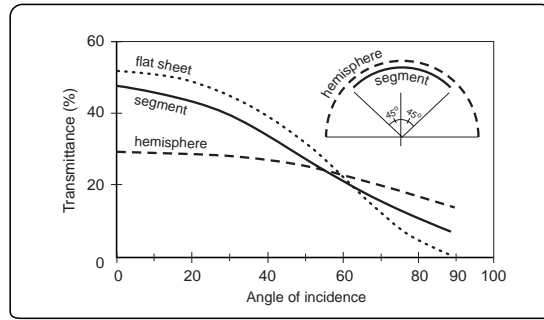


Figure 2-4 illustrates the difference in transmission of solar energy (light and heat) for a 50 percent translucent glazing material as a function of the angle of incidence for three different shapes: a flat skylight, a hemispherical skylight, and a segment of a sphere (which most closely models the typical

bubble skylight). It shows for very low sun angles (60° - 90° angle of incidence) that the rounded shapes will collect noticeably more light. It is also interesting that they allow in less light at midday<sup>2</sup>.

## 2.2. Skylight Types and Placement

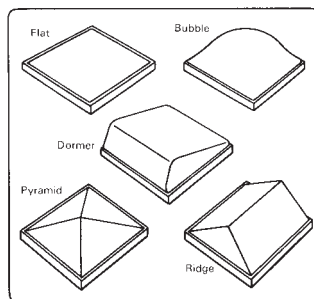
The selections of size, shape, number, and placement of skylights on the roof of your building are some of the most basic decisions to be made about a skylighting system.

### 2.2.1. Sizes and Shapes

Skylights are available in a wide variety of sizes and shapes to match nearly any building need. They range from simple rectangles to complex polygons. They can be small, to fit between rafters, or large enough to run the length of a building. To cover big spaces, the skylights can be in the form of long barrel vaults or smaller units combined on a space frame.

The glazing comes in several configurations as well. Flat glazing can be used in a single plane or in a faceted framing system that assumes various pyramid shapes. Plastic glazing is also available in molded dome or pyramid shapes for greater stiffness. Figure 2-5 shows a variety of standard skylight shapes.

**FIGURE 2-5: BASIC**  
**SKYLIGHT SHAPES**  
 SKYLIGHTS ARE AVAILABLE  
 IN A WIDE RANGE OF  
 STANDARD SHAPES AND  
 SIZES. IN ADDITION,  
 CUSTOM SKYLIGHTS CAN  
 BE FABRICATED TO  
 MEET NEARLY ANY  
 REQUIREMENT.



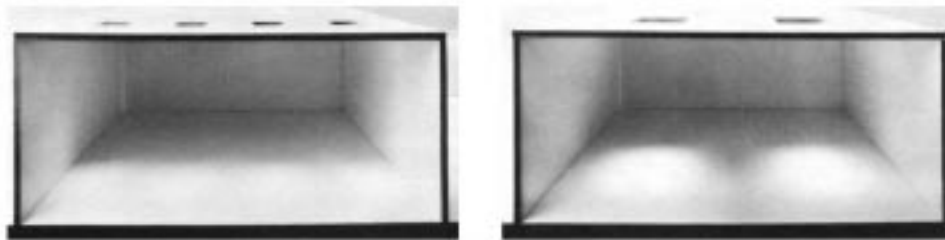
From a designer's point of view, the challenge is to integrate the form and light-admitting properties of the skylight with the design concept for the building. This is usually done by selecting skylights that complement the ceiling grid and room proportions. Examples of this are shown in the case studies. More examples can be found in manufacturers' literature and by visiting buildings with skylights.

For complete information on the skylight size and shape options available, consult specific manufacturers' data.

### 2.2.2. Layout and Spacing

The layout and spacing of skylights in a roof are important determinants for the light distribution characteristics of the skylighting system. Given a fixed percentage of the roof area devoted to skylights, a designer could select anything from a single large skylight to many small skylights distributed uniformly across the roof. For special applications, such as entry lobbies or small rooms, the skylight layout will probably be dictated primarily by the design concept for the space. However, when skylights are provided in order to create uniform lighting in large open spaces, careful attention to spacing is important.

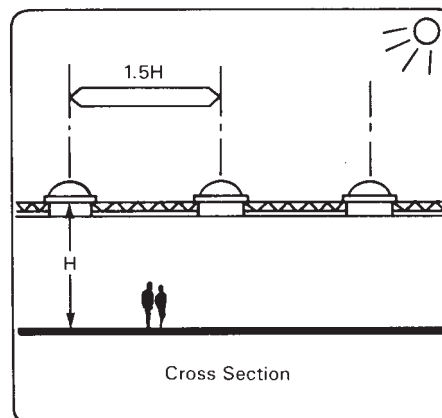
For the same total skylight area, the tradeoff is typically between large skylights far apart versus smaller skylights arranged closely together. Large, widely spaced skylights are usually the most economical to install, but may produce bright conditions under the skylights and relatively dark conditions in between. This results in uneven light distribution, reduced energy savings, and possible glare problems. Small, closely spaced skylights, on the other hand, will provide more uniform lighting conditions and greater energy savings, but will be more costly to install.



**FIGURE 2-6: EFFECT OF SKYLIGHT SPACING**  
SKYLIGHTING SPACING AFFECTS THE UNIFORMITY OF LIGHT DISTRIBUTION.

The differences in illuminance level between locations directly under the skylight, compared to locations between skylights, will be greater as skylight spacing becomes wider. The left photo shows close skylight spacing, with relatively even illuminance at the work plane; the right photo shows a wider range of light and dark areas. The total skylight area is the same for both.

The general rule of thumb is to space skylights at 1.0 to 1.5 times ceiling height (center-to-center in both directions). This assumes a highly diffusing glazing and a modest depth for light wells. Actual designs can vary considerably from this rule of thumb. For example, if the light well is widely splayed (see Section 2.4.1. Light Wells), the vertical dimension to the bottom of the skylight can be used instead of the ceiling height. Skylight placement must also be coordinated with the structural, mechanical,



**FIGURE 2-7: SPACING RULE OF THUMB**  
TRY TO SPACE SKYLIGHTS AT A DISTANCE BETWEEN 1.0 AND 1.5 TIMES THE CEILING HEIGHT. THIS GENERALLY PRODUCES ACCEPTABLE UNIFORMITY IN ILLUMINANCE LEVELS.

and lighting systems. Other variables also come into consideration, such as glazing type, light well design, controls, and the other factors discussed below. *SkyCalc* includes a simple “Spacing Calculator” to help designers choose an optimum spacing.

## 2.3. Skylight Glazing

Common glazing materials for skylights include a variety of plastics and glass. The common plastic materials include acrylics, polycarbonates, and fiberglass. These materials come in a number of colors—from clear and translucent white, to bronze and gray colors. They also come in a variety of thicknesses and number of layers. All these variables affect the performance of the skylight.

The choice of the glazing material for a skylight can have an enormous effect on the quality of the light provided and the energy efficiency of the design. Factors to consider include:

- How much light is transmitted through the glazing—measured by the visible transmittance ( $T_{vis}$ )
- How much of the direct beam sunlight is diffused—measured by the transparency of the material<sup>3</sup>
- How much of the sun’s radiant heat is transmitted through the glazing—measured by the solar heat gain coefficient (SHGC) or the less precise shading coefficient (SC)
- How much heat from the air will pass through the glazing—measured by the R-value of the material or the U-value of the skylight unit assembly

Other properties of glazing are also important in selection, such as the strength of the material, the resistance to breaking or cracking, and how the material will age over time—perhaps losing some of the properties described above. These and other technical issues related to glazing, are discussed in greater detail in Chapter 3: Specification Choices.

### 2.3.1. Transmission of Light

In terms of the lighting performance of a skylight, the two most important properties are how much light it allows to pass through (transmittance) and how much it diffuses the sunlight that strikes it (transparency). Most people assume that the more transparent a piece of glazing is, whether glass or plastic, the more light will pass through it. However, the two properties are not directly related.

For example, it is possible to have a material which scatters all of the light that strikes it, while still allowing a very high percentage of light to pass through. A common example is frosted or patterned glass. Although you cannot see a clear image through the glass, just as much light passes through the glass as through clear window glass. Another example is the plastic lenses commonly used for fluorescent lighting fixtures. The prismatic pattern in the

plastic prevents a clear view of the fluorescent lamp inside the fixture, but allows almost all the light to pass through, scattering it in the process.

The converse is also possible, with a transparent material obstructing most of the visible light that strikes it. All tinted glasses do this to some extent, with one extreme example (dark gray) transmitting only 14 percent of the visible light.

In general, the higher the visible transmittance of the material, the more efficiently the skylight can provide light to the room below. Diffusion of beam sunlight is important to avoid “hot spots”, where sunlight is more concentrated and creates areas that are both too bright and less comfortable due to the radiant heat of the sun. Highly diffusing skylights are needed to achieve uniform illumination, allowing the overall lighting system and controls to be more efficient.

### **2.3.2. Transmission of Heat**

The choice of glazing also affects the amount of heat that passes both in and out of the skylight. There are two important characteristics here: the relative proportion of the sun’s radiant heat that is blocked by the glazing material, measured by solar heat gain coefficient (SHGC), and the overall resistance of the skylight unit to all types of heat flow, measured by R-value.

How much of the sun’s radiant heat passes through a skylight is largely a function of the chemical structure of the glazing material. Various materials react differently to different portions of the sun’s spectrum. Some wavelengths will be reflected, some will be absorbed, and some will be transmitted. If most of the wavelengths in the infrared and ultraviolet portions of the spectrum are also largely transmitted, then the glazing material will allow almost all of the sun’s radiant energy to pass through into the space below, and it will have a very high SHGC. If more of the non-visible radiant energy is reflected, then the material will have a lower SHGC.

If the non-visible components of solar radiation are absorbed, rather than reflected or transmitted, then the glazing material itself will heat up. Part of the heat will be conducted downward into the space, raising the SHGC. The rise in temperature of the glazing material may also cause it to expand and deform, which is usually undesirable.

In general, the most efficient skylight glazing material will allow the maximum amount of light to pass through, while rejecting the non-visible wavelengths of solar radiation. Such a material maximizes useful light while minimizing unnecessary heat gain to the space below. The concept of an efficient glazing material for daylighting, based on a relatively high visible transmittance in conjunction with a comparatively low SHGC (or shading coefficient) is described by the term “glazing efficacy,” or light-to-solar gain ratio (LSG). Glazing efficacy is described in greater detail in Section 3.1.3.

There are many more products with efficient characteristics available for window glass than for plastic skylights. Plastics are currently limited in their chemical formulations by structural and forming considerations. Also, special coatings that help increase the daylighting efficacy of glass are difficult to use with the plastic materials suitable for making skylights. However, this is an area where advances in chemical engineering and manufacturing techniques may be able to improve the efficiency of skylights in the future.

The other way that glazing materials affect heat transmission is described by their R-value, or thermal resistance to all three forms of heat flow: conduction, radiation, and convection. Adding layers of glazing to create insulating air spaces is the most common way to improve a skylight's resistance to heat flow. Just as double- or triple-glazed windows decrease heat loss, so do double- or triple-glazed skylights. Double-glazed skylights are more common in colder climates and for houses, where heating loads are more important than in commercial buildings.

Bubble skylights can be manufactured with two layers of formed plastic. Plastic skylights can also be made with one shaped glazing layer and one or more flat layers below. Some skylight manufacturers use inner layers of transparent polyester film to add additional insulating layers to their units. Other options are double-walled, extruded plastic, or insulated panels. (See Section 3.1.5.)

Since each glazing layer inevitably represents additional cost and loss of light, there is obviously a point at which added insulation is not cost-effective. This balance point is highly dependent upon the local climate conditions, the design and operation of the building, and the relative costs of electricity and heating fuels. The *SkyCalc* tool is specifically designed to help you determine this balance point for your climate.

## 2.4. Daylight Distribution

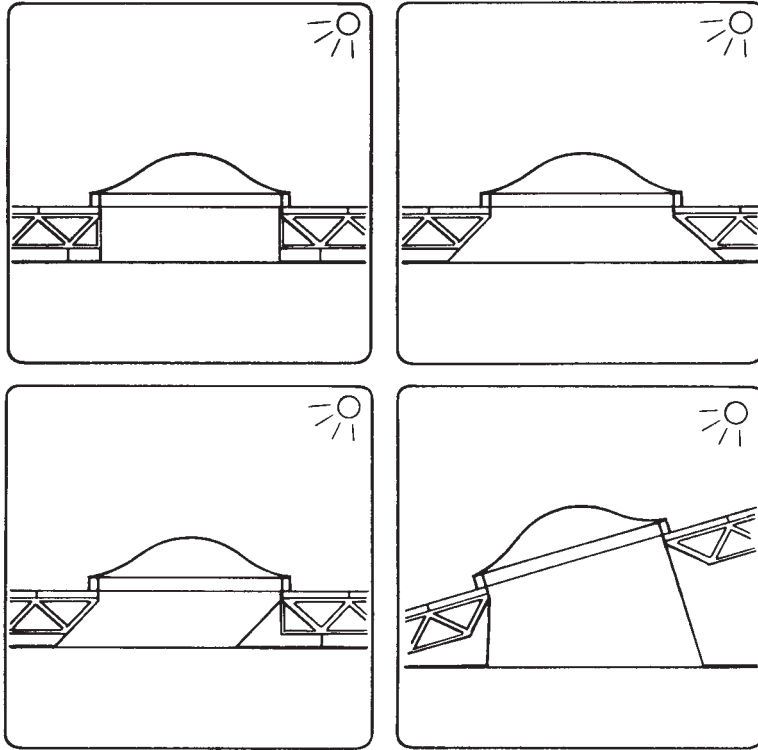
Once daylight has passed through the skylight glazing, it can be controlled and diffused by the shape and reflective properties of light wells, shading devices, and the surfaces of the room itself. Well-balanced lighting conditions are essential to the visual comfort of the building occupants.

### 2.4.1. Light Wells

Light wells are a primary component of skylighting systems. They bring the light through the roof and ceiling structure, and they simultaneously provide a means for controlling the incoming daylight before it enters the main space. A light well is similar to the housing of an electric light fixture. It is designed to distribute the light and to shield the viewer from an overly bright light source.



Light wells can be designed in a wide variety of shapes. The simplest are vertical-sided shafts, the same size as the skylight opening. More elaborate wells have splayed or sloping sides that spread the light more broadly through the space. Figure 2-8 shows some common well shapes.



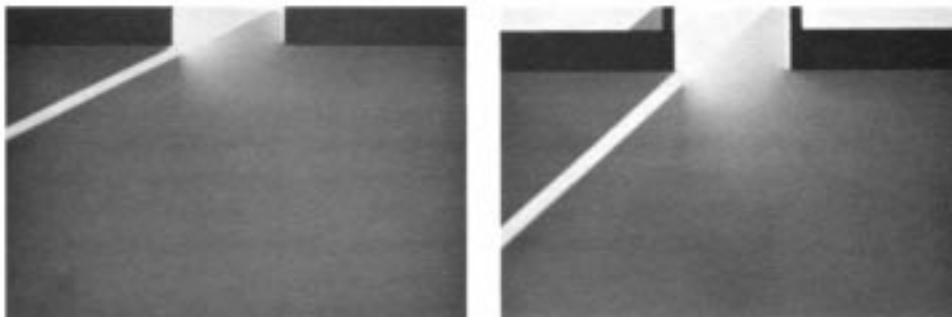
**FIGURE 2-8: TYPES OF LIGHT WELLS**

THE SHAPE AND SIZE OF THE LIGHT WELL IS OFTEN DETERMINED BY THE ROOF AND CEILING STRUCTURE. WELLS CAN BE MADE FROM WOOD, GYPSUM BOARD, CEILING TILES, OTHER CONSTRUCTION MATERIALS, OR PROPRIETARY LIGHT WELL PRODUCTS.

In some buildings, light wells consist only of the depth of the curb and the thickness of the roof structure, but in buildings with hung or dropped ceilings, the skylight well can become several feet deep. Deep wells are an opportunity for greater control of the distribution of the daylight from skylights.

In designing wells for skylights, a number of factors must be considered:

- *Solar geometry.* The height and orientation of the sun change both daily and seasonally. The direct sunlight that enters a transparent skylight can be prevented from penetrating down to the task surface by light wells; conversely, the wells can



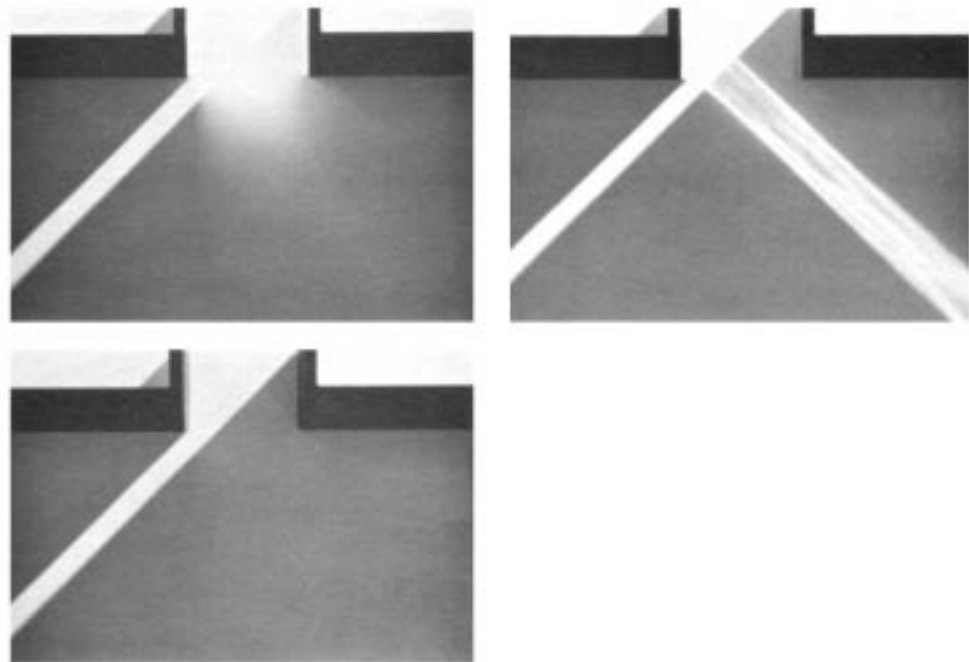
**FIGURE 2-9: SHADING OF DIRECT SUN BY LIGHT WELL**

IF TRANSPARENT GLAZINGS ARE USED, THE DESIGN OF THE LIGHT WELL MUST CAREFULLY CONSIDER SUN ANGLES. LIGHT WELLS CAN PROVIDE A MEANS OF CUTTING OFF DIRECT SUN PENETRATION. THE PHOTO ON THE LEFT SHOWS A SHALLOW WELL. THE DEEPER WELL ON THE RIGHT CUTS OFF HIGHER ANGLE SUNLIGHT.

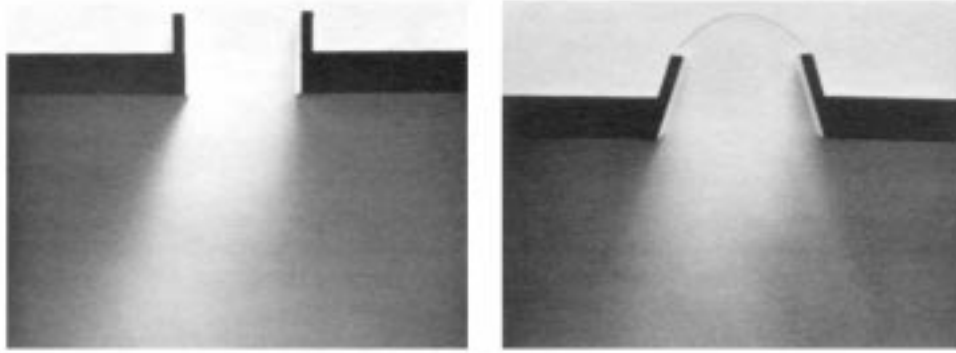
reflect the sunlight to a particular destination. To block high sun angles, the light well must be deeper than for low sun angles. Sun path studies are used to design for direct sun control. With diffusing skylights, the angle of the sun is less of a concern, but the amount of light and heat entering the space will still be affected by solar geometry.

- *Surface reflectance.* Light wells reflect and diffuse sunlight as it bounces from the skylight to the task surface. A highly reflective, diffusing surface (such as flat white paint) will help to provide a diffuse, broadly distributed light pattern below the skylight. On the other hand, a specular reflective surface, such as reflective foil, will not diffuse the light, but will reflect an image of the sun and sky onto a limited area below the skylight. Colored surfaces will distribute the light evenly, but will reduce its intensity and can dramatically shift the appearance of colors in the room below. For applications where uniform light distribution is desired, a matte white surface is best.

**FIGURE 2-10:**  
**REFLECTIVE PROPERTIES**  
**OF WELL SURFACES**  
 DIFFUSE WALLS (E.G.,  
 FLAT OR MATTE PAINTS)  
 REFLECT INCIDENT LIGHT  
 IN ALL DIRECTIONS,  
 SPREADING THE BRIGHT-  
 NESS (TOP-LEFT).  
 SPECULAR WALLS (E.G.,  
 MIRROR SURFACES)  
 REFLECT A DIRECT IMAGE  
 OF THE SUN OR SKYLIGHT  
 TO THE SPACE BELOW  
 (TOP-RIGHT). SEMI-  
 SPECULAR WALLS (E.G.,  
 GLOSS PAINTS) EXHIBIT  
 QUALITIES OF BOTH  
 DIFFUSE AND SPECULAR  
 REFLECTION (NOT  
 SHOWN). DEEPLY COLORED  
 WELL SURFACES REDUCE  
 NEARLY ALL LIGHT  
 SCATTERING, AND TEND TO  
 ADMIT ONLY DIRECT  
 SUNLIGHT (BOTTOM-LEFT).



- *Wall slope.* The slope of light well walls helps to determine the distribution of light in the space. The broader the base of the well, the larger the task area in the space having a direct view of the skylight. This is an advantage under overcast sky conditions or with a diffusing skylight, but it can be a serious disadvantage with a transparent skylight when direct sunlight is present. Deep wells with vertical walls prevent direct view of the skylight and block low angle beam sunlight, but tend to keep the light concentrated in a smaller area and provide less uniform light distribution.



**FIGURE 2-11:**  
**SPLAYED WALL EFFECT**  
 SPLAYED LIGHT WELL WALLS (RIGHT) ALLOW A LARGER AREA OF THE SPACE TO VIEW THE SKYLIGHT SURFACE. WITH DIFFUSING GLAZINGS, THIS HELPS PROVIDE UNIFORM ILLUMINATION. WITH TRANSPARENT GLAZINGS, SPLAYED WALLS ALLOW GREATER PENETRATION OF BEAM SUNLIGHT.

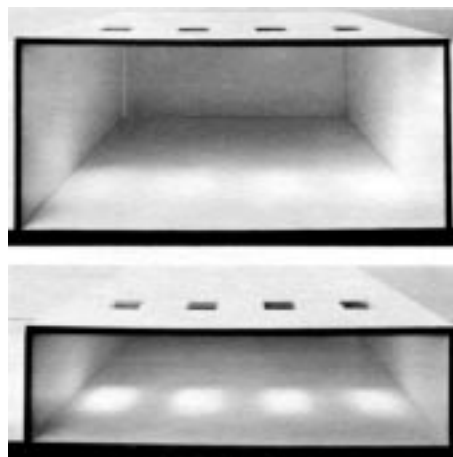
In addition to the surfaces of the light well, daylight can also be controlled and diffused with the use of additional vertical surfaces like banners, structural elements, or horizontal shading devices located under the skylight in the light well. Operable shading devices, whether manual or automatic, can also allow the amount of light reaching the room to be controlled, from full brightness to very dim. (Shading options are discussed in Section 3.2.)

### 2.4.2. Room Surfaces

Once the daylight has penetrated past the glazing, the light well, and the shading devices, it interacts with the interior of the building. There it can be absorbed and contained, or bounced and blended, depending on the building design and the intended use of daylight.

With skylights, ceiling height strongly influences daylight distribution within the space. Depending on skylight size, spacing, and light well design, varying the ceiling height may increase or decrease the uniformity of the daylight distribution. Keeping all the other parameters constant, as ceiling height is increased, the light transmitted by skylights is distributed over a larger floor area and working plane. This generally results in more uniform skylighting. Lower ceiling heights result in less uniformity, with brighter areas under the skylights and darker areas in between. As a rule of thumb, keep skylight spacing 1.0 to 1.5 times ceiling height. (See Section 2.2.2.)

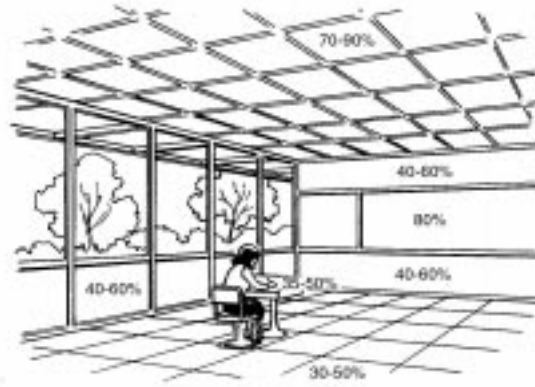
The surface reflectances of walls, floors, ceilings, and furnishings also have an impact on light distribution. Light-colored surfaces, which have high reflectances, will help to distribute brightness around the space, and this, in turn, will reduce the brightness contrasts that cause visual discomfort. It is especially important for ceilings to be light-colored, so that they are as bright as possible. This reduces the glare potential from having bright skylights next to darker ceiling areas. High-reflectance



**FIGURE 2-12: EFFECT OF CEILING HEIGHT ON LIGHT DISTRIBUTION**  
 FOR THE SAME SKYLIGHT SPACING, A HIGHER CEILING HEIGHT WILL RESULT IN MORE UNIFORM ILLUMINANCE LEVELS AT THE WORK PLANE (TOP). LOWER CEILING HEIGHTS EXHIBIT DARKER AREAS BETWEEN AND BRIGHTER AREAS UNDER THE SKYLIGHTS (BOTTOM).

floors and furnishings will also help in this regard, because they help to brighten the ceiling. (See Section 3.3.1. Well Factor, for specific values of reflectances of various colors and surface materials.)

**FIGURE 2-13: ROOM SURFACE REFLECTANCES**  
 AS A RULE, USE WHITE OR VERY LIGHT COLORS ON ALL PRIMARY SURFACES TO REFLECT AS MUCH LIGHT AS POSSIBLE. MORE SATURATED COLORS CAN BE USED ON SMALLER AND SECONDARY SURFACES WHERE LIGHT DISTRIBUTION IS NOT AS IMPORTANT.



It is important to use matte textures on major surfaces to further diffuse the light. Shiny, or specular, surfaces tend to reflect bright images of the skylights, which can be visually uncomfortable. For example, a highly polished dark-colored floor will reflect an image of the skylights (and electric lights) above, which can be quite glaring.

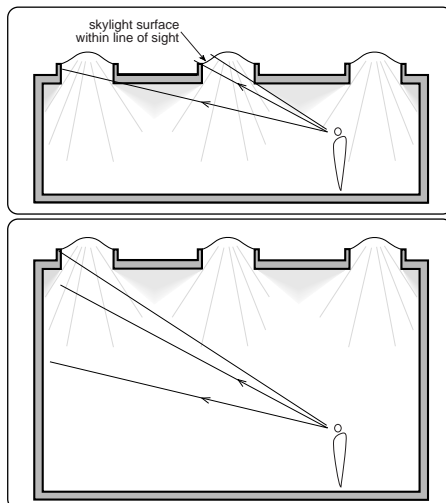
### 2.4.3. Visual Comfort

A primary objective in the design of any lighting system (daylight or electric light) is to provide the illuminance levels required for visual performance at the task, using a system that enhances visual comfort in the work environment. Both ceiling-mounted electric lights and skylights have the potential to cause visual discomfort, and the techniques for avoiding this are the same. There are two basic areas of concern:

- Avoid excessively bright sources within the occupants' field of view
- Avoid reflections from bright sources on the work surface

The surface of diffusing skylights can become very bright in sunlight, and is a potential source of glare to people working in the space. If the skylight is directly in their line of vision, it may cause visual discomfort, as their eyes try to adjust between the extremely bright skylight and less bright room surfaces.

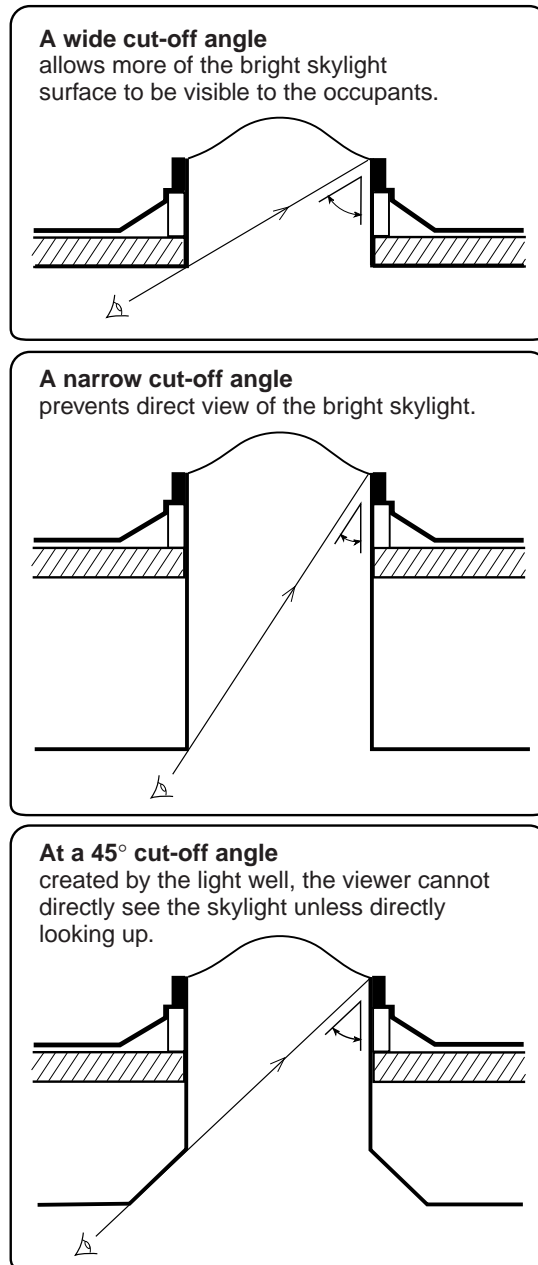
**FIGURE 2-14: VISUAL COMFORT EFFECT OF HIGH VERSUS LOW CEILINGS**  
 A HIGH CEILING KEEPS SKYLIGHTS OUT OF THE LINE OF VIEW, REDUCING THE NEED FOR OTHER GLARE CONTROL EFFORTS.



The height of the ceiling in relation to the proportions of the room affect the probability that the skylight may cause glare. If a room has a very low or very large ceiling, it is more likely that the skylights will be within the occupants' field of view. The higher the ceiling, the less likely this is to be a problem. Using a section drawing of the building to understand the angles of sight within the room is the best way to determine if there may be a potential problem.

Careful design of the light well can prevent direct view of the skylight, while still allowing wide distribution of the light. This is best understood in relation to the “cut-off angle” created by the light well. “Cut-off angle” is a term frequently used in relation to light fixtures. It describes the angle of a line of sight, such that a viewer cannot directly see the bright light source in a lighting fixture. For lighting fixtures in offices with computers, the IESNA recommends a minimum 55° cut-off angle from vertical. A similar principle is involved with skylights, where a proper cut-off angle for the light well prevents a viewer from seeing the bright surface of the skylight. In most skylit buildings, with less critical tasks, a more relaxed standard of 45° to 50° cut-off angle for the skylight is probably sufficient.

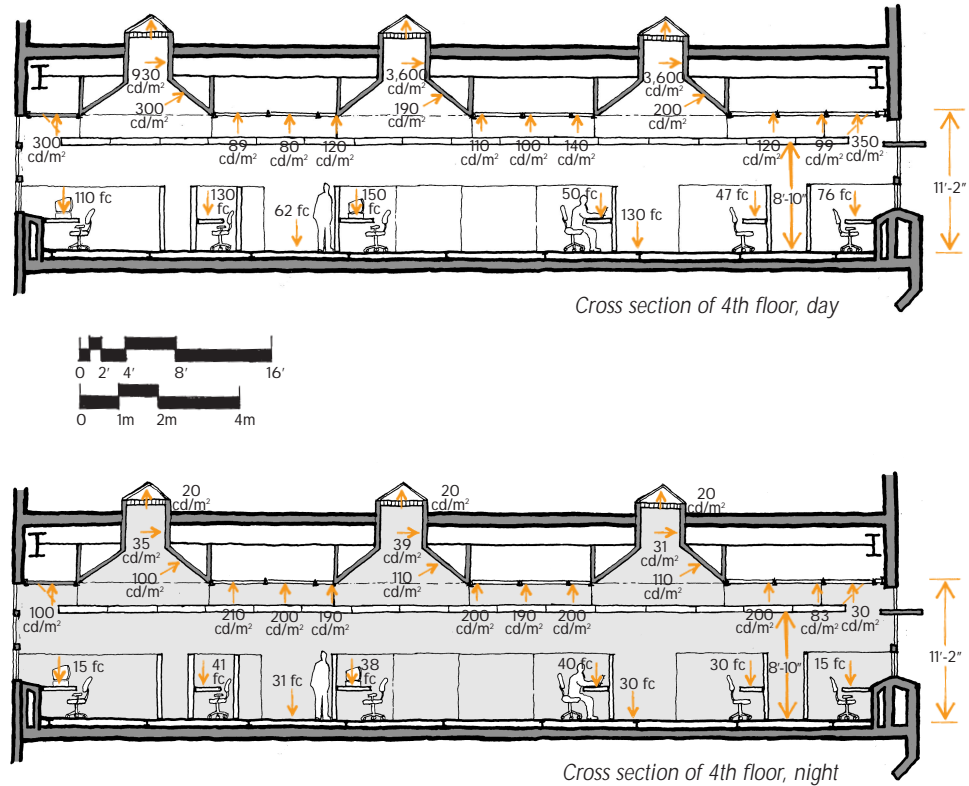
Some manufacturers and designers have created light wells that include a diffuser at the bottom to further spread the light. If the diffuser is dropped below the ceiling plane, it will contribute some daylight to brighten up the ceiling. However, it is also more likely to come into the field of view of the occupants. Since it will be the brightest object in the room, the probability of glare is very high. If the dropped diffuser is kept above the ceiling plane, it will be more removed from the occupants’ field of view (see Capistrano Case Study). With a splayed well, a recessed diffuser can still spread the light widely.



**FIGURE 2-15: CUT-OFF ANGLE FOR LIGHT WELLS**

A LIGHT WELL WITH A WIDE CUT-OFF ANGLE WILL ALLOW THE WIDEST DISTRIBUTION OF LIGHT, BUT WILL NOT PREVENT OCCUPANT’S VIEW OF THE SKYLIGHT. A LIGHT WELL WITH A VERY NARROW CUT-OFF ANGLE WILL PREVENT DIRECT VIEW OF THE SKYLIGHT; HOWEVER, IT WILL ALSO CONCENTRATE THE LIGHT INTO A SMALL AREA. A COMPROMISE BETWEEN THESE TWO CONFLICTING NEEDS CAN BE REACHED WITH A LIGHT WELL THAT HAS STRAIGHT WALLS AT THE TOP AND SPLOYED WALLS AT THE BOTTOM.

**FIGURE 2-16:**  
**LIGHT WELL DESIGN AT**  
**SACRAMENTO MUNICIPAL**  
**UTILITY DISTRICT OFFICES**  
 A LIGHT WELL DESIGN  
 WITH A VERTICAL SHAFT AT  
 THE TOP AND 45° SPLOYED  
 WALLS AT THE BASE WAS  
 USED VERY SUCCESSFULLY  
 IN THE SKYLIT AREAS FOR  
 THE SACRAMENTO  
 MUNICIPAL UTILITY  
 DISTRICT'S NEW DAYLIT  
 OFFICE BUILDING. THE  
 WELL DESIGN DISTRIBUTES  
 LIGHT EVENLY WITH NO  
 GLARE TO THE OCCUPANTS  
 BELOW. INDEED, EMPLOY-  
 EES WHO WORK ON THE  
 SKYLIT FLOORS GAVE THE  
 HIGHEST RATING TO THE  
 LIGHTING QUALITY IN  
 THEIR WORK SPACES.<sup>4</sup>



GRAPHIC COURTESY OF THE LIGHTING RESEARCH CENTER

Light well design also affects illumination levels, and so is an important factor in optimizing energy savings. See Sections 3.3.1. Well Factor, and 3.3.2. Skylight Efficacy, for a more complete discussion of the quantitative effects of light well design.

## 2.5. Integration with the Electric Lighting System

Even the most aggressively designed skylighting system will require a full electric lighting system—for those occasional dark days, and most especially for use of the space at night. In general, the electric lighting system should be designed to supplement the skylight system, and not vice versa. If the skylighting system is treated as the primary light source, it will be designed to optimize lighting conditions throughout the daylit spaces. The electric lighting system can then be designed to complement the skylighting, and the daylighting control strategy will be obvious from the start.

A common approach is to use the skylights to provide the basic ambient light for the building along with a back-up electric ambient system on photocontrols, while using specific electric lights to provide higher levels of task lighting in critical locations. This design approach is referred to as “task-ambient” lighting. Special task lighting can be provided at work counters, in shelving aisles, or at critical equipment, as shown in Figure 2-17.

Another aspect of electric lighting to be considered is the color temperature of the light sources. Daylight is generally a very cool source (although it varies considerably throughout the day). Many designers select light sources with cooler color temperatures, such as fluorescent lamps at 4100°K, to blend better with daylight. It should be remembered that when a lamp is a different color temperature than its ambient environment, it draws attention to itself. This may also be an aesthetic choice. Sometimes daylight is seen as a complement to a light source with poor color rendition, such as high-pressure sodium lamps in a daylight warehouse. In such a case, the presence of daylight greatly enhances the ability to see colors accurately.



**FIGURE 2-17:**  
**TASK-AMBIENT LIGHTING WITH SKYLIGHTS**  
AN EXAMPLE FROM A MANUFACTURING PLANT PROVIDES AMBIENT LIGHT WITH A UNIFORM GRID OF SKYLIGHTS AND METAL HALIDE FIXTURES ON PHOTOCONTROLS. STRIP FIXTURES WITH FLUORESCENT LAMPS PROVIDE HIGHER LIGHT LEVELS AT CRITICAL TASK AREAS AND IN ACTIVE SHELVING AREAS.

Three primary considerations in the integration of electric lighting systems with skylights are:

- How the system supplements the daylight provided from the skylights
- How the system lights the space at night, or when there is insufficient light from the skylights
- How the system supports the use of daylighting controls

### 2.5.1. Lighting the Room Surfaces

Skylights, and their associated light wells, can be quite bright. If the ceiling is not lit, then the contrast between the bright well and darker ceiling can be uncomfortable. Sometimes sufficient light from the skylights bounces off the floor and other surfaces to brighten the ceiling (see Section 2.4.2. Room Surfaces). Splayed light wells can also help reduce this effect by creating a surface with intermediate brightness.

Often designers choose to supplement any reflected daylight with an indirect component in the electric lighting fixtures, directing some portion of the light upwards to brighten the ceiling plane. Pendant-mounted direct/indirect fixtures are especially appropriate for high-value spaces with lower ceilings, such as offices or retail stores. (Note the direct/indirect fixture choice in Figure 2-16: Light Well Design at Sacramento Municipal Utility District Offices.) The fixtures, which can be selected for high cut-off angles to reduce glare, can also brighten both the ceiling plane and the light well walls at night.

Another issue in electric fixture layout is achieving proper levels of illumination on the room walls. In general, people prefer spaces that have well-illuminated vertical surfaces. Indeed, some researchers have found that, all other things being equal, people judge a space to be

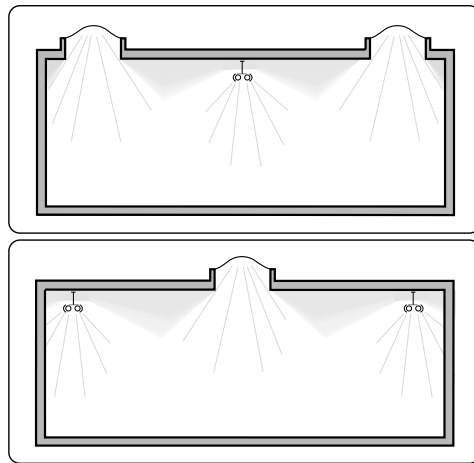


brighter and better lit overall if the walls are bright and uniformly illuminated. This makes a strong argument for directing light to the wall surfaces, which can either be done with the skylights or the electric lights.

If daylight is concentrated in the center of the room or building, then an effort should be made to direct additional electric lighting to the walls. This can be achieved by placing standard pendant fixtures closer to the walls, using lensed fixtures with a wide light distribution (such as “bat wing” lenses), and/or selecting special “wall wash” fixtures that are designed to provide even illumination on vertical surfaces.

An example of this approach is seen in the classroom design for the Capistrano School District featured in the case study section of this publication. There, a perimeter ring of recessed fluorescent fixtures provides even illumination on the walls of the classroom, while the skylights flood the center of the room with daylight. The electric lights can be switched to full power, half power, or off, depending on the classroom needs. Even though there are no fixtures in the center of the room, night illumination tends to be quite even due to reflections from the brightly lit walls.

**FIGURE 2-18:**  
**LIGHTING THE WALLS**  
PERIMETER SKYLIGHTS  
CAN PROVIDE ILLUMINA-  
TION TO THE WALLS WHILE  
ELECTRIC LIGHTS FILL IN  
THE CENTER (TOP) OR  
CENTRAL SKYLIGHTS CAN  
BE SUPPLEMENTED WITH  
FIXTURES THAT PROVIDE A  
WASH OF ILLUMINATION  
ON THE WALLS.



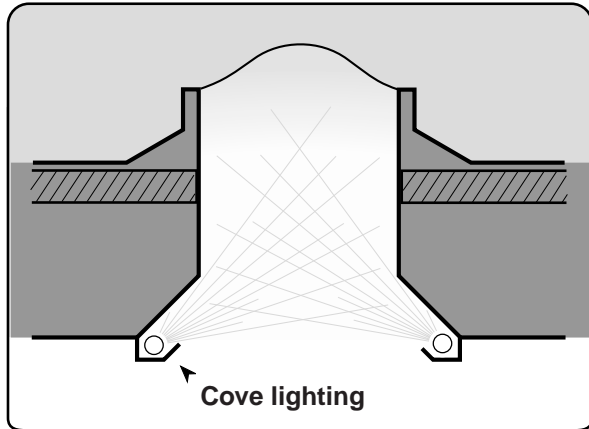
Alternatively, if the skylights can be located near the perimeter of the room, such that daylight is fairly evenly distributed across the walls, then the electric lighting system can be designed to fill in the middle during the day. However, nighttime appearance should also be considered, and it may be appropriate to include a special nighttime wall-washing system.

### 2.5.2. Skylights at Night

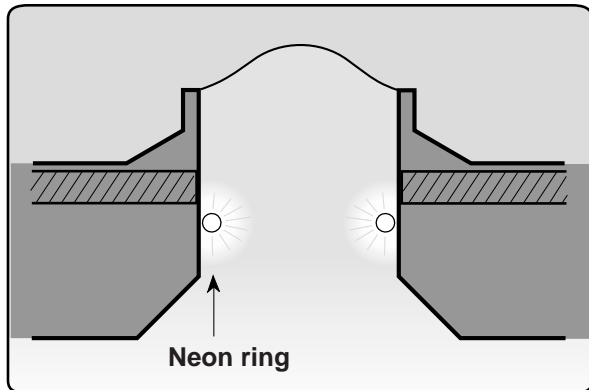
The skylight well can also become a dark hole in the ceiling at night if no light is directed up into it. When buildings are used extensively at night, this can be disconcerting. Some designers have addressed this issue by providing coved fixtures in the light well which directly light the well at night. However, fixtures placed in the well to light it at night may block some of the daylight during the day, and this conflict should be addressed. Other solutions include providing just a bit of light in the well with a narrow neon tube running around the perimeter of the well, or placing a direct/indirect light fixture directly under the well for night illumination. There is usually an efficiency tradeoff between allowing light to pass uninterrupted through the skylight and creating a comfortable and pleasant visual environment at night.



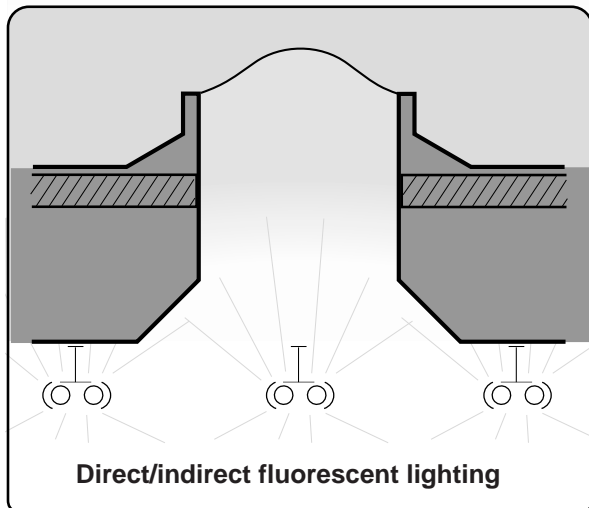
**FIGURE 2-19:**  
THREE APPROACHES  
TO BRIGHTEN LIGHT  
WELLS AT NIGHT



**Fluorescent cove lighting** around the skylight provides light into the well at night, but causes shadows during the day.



**A ring of neon** up in the well can provide low brightness sparkle at night in an otherwise dark hole.



**A fluorescent direct/indirect lighting fixture** suspended across a light well can brighten the well at night.

It is important to remember that at night, transparent glazing will allow all light from below to pass through, and thus will appear dark. Diffusing glazing, on the other hand, will reflect some of the light downwards. So a diffusing skylight that is illuminated at night will appear brighter<sup>5</sup>.

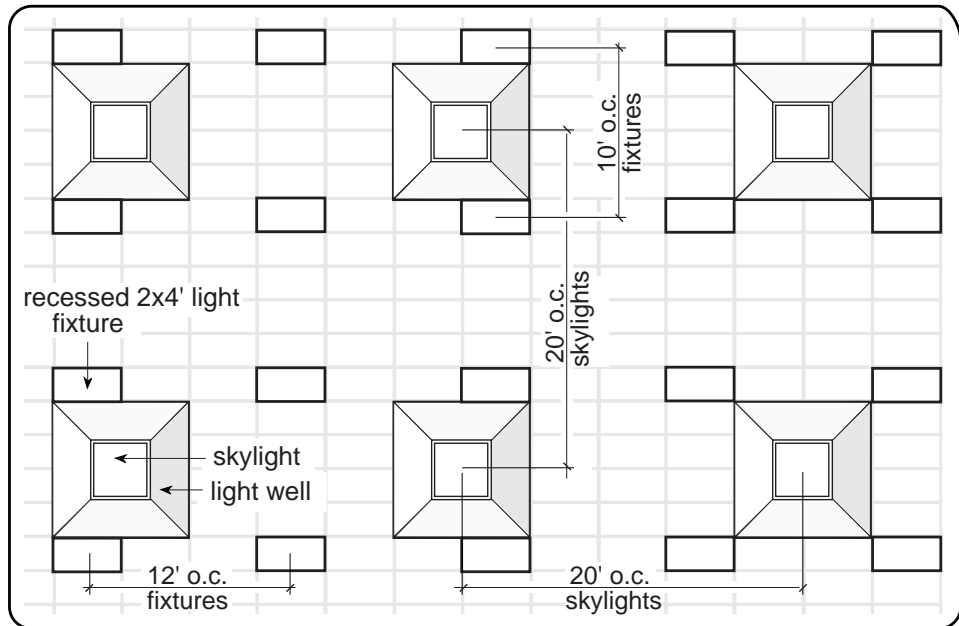
### 2.5.3. Spacing Criteria

For large open areas with high ceilings (20+ feet), the relationship of the skylights to the electric lights is usually not critical. Electric lights are typically pendant fixtures hung from the structural grid and skylights are generally uniformly spaced within the same grid. The two can be laid out fairly independently of each other with acceptable results.

Even with lower ceilings (12-20 feet) the use of pendant-mounted direct/indirect fixtures allows the skylight grid and electric light grid to be somewhat independent of each other. Pendant direct/indirect fixtures can be mounted directly under a skylight without interfering too much with daylight distribution.

Electric lighting systems that are recessed into the ceiling, however, present more of a challenge. A good rule of thumb to follow is that the skylights should be located on a direct multiple of the fixture spacing dimension, or vice versa. Also, the light well should not have greater dimension than the maximum spacing of electric lights, which is a function of the fixture type and the fixture mounting height. For example, if the maximum spacing for the lighting fixtures is 10 feet on center, then the skylights should be spaced at 20 feet on center, with a 10-foot-square well around each skylight.

**FIGURE 2-20:**  
**INTEGRATING A LIGHTING**  
**AND SKYLIGHTING GRID**  
THE MAXIMUM SPACING  
CRITERIA FOR RECESSED  
LIGHTING FIXTURES  
SHOULD SET THE MAXI-  
MUM WIDTH OF LIGHT  
WELLS. ALSO, SKYLIGHTS  
SHOULD BE LAID OUT ON A  
GRID WHICH IS SOME  
MULTIPLE OF THE  
LIGHTING SPACING.



While these two factors are easy to understand, layouts can be further complicated by other requirements on spacing, including the structural grid, the maximum spacing between the skylights for uniform lighting (rule of thumb =1.5 x the ceiling height), the ceiling grid, and requirements for HVAC duct runs. In general, the lower the ceiling, the more critical it is to coordinate all of the grids affecting the skylight location.

#### 2.5.4. Laying Out Circuits

Selecting a rational circuit design for the electric lights is also very important to the success of any photocontrols (see Timberland case study). It is assumed throughout these *Guidelines* that skylights will be laid out to create uniform lighting conditions. However, sometimes it is inevitable that there will be some form of daylighting gradient. Perhaps the building also has daylighting from windows, or the skylights are on an unequal grid. When this is the case, the lighting circuits should also be laid out along the same gradient so that the photocontrols can differentiate between regions of different brightness.

Another consideration for lighting layout is added with the presence of shelving aisles or storage racks. In the real world, the spacing of the shelves and the skylights are rarely coordinated, resulting in some aisles that get less daylight than others. There are two schools of thought on how to respond to this. If the aisle heights are relatively low compared to the ceiling height, then laying out the lighting system perpendicular to the shelves has a number of advantages. First, any shadowing from the skylights is negated by the perpendicular fixtures, and secondly, the aisles can be reconfigured without changing the locations of any fixtures.

If the shelves are relatively high, locating fixtures down the center of the aisles is going to be more efficient. In this case, it is also important that the lighting circuits run parallel to the aisles, rather than on a grid. Then if one aisle is darker than another, a separate photocontroller can be added to that aisle only. The expense of rewiring a few circuits is likely to be trivial compared to the potential savings. However, if the whole building has to be rewired because the circuits don't follow the aisles, it is not likely it will be done.

One last consideration is to include any requirements for special emergency circuits or controls that set lower light levels for stocking or maintenance. All of these issues may impact the control patterns.

## Integration with the HVAC System 2.6.

A mechanical system designed for a building with skylighting requires a few special considerations. None of these are difficult for the mechanical designer, but they may be different from the designer's standard practice. If the mechanical designer does not recognize some of the special characteristics of the skylighting system, then some of the benefits may be lost to the building owner. The mechanical system considerations fall into several categories:

- Equipment sizing to reflect varied loads
- Placement of rooftop equipment
- Location of ductwork
- Placement of supply and return registers

These considerations will be discussed in the following sections.

### 2.6.1. Equipment Sizing

Skylights affect the design loads on the mechanical system in four ways:

- Reduced cooling loads due to lights turned off during daylight hours
- Increased cooling loads due to increased conduction and solar heat gain
- Increased heating loads due to loss of roof insulation levels
- Increased heating system loads due to reduced internal heat gain from lights

These are listed in approximate order of significance, with the cooling load effects being most significant, although in a cold climate the heating load effects may be more significant.

#### Effects on Cooling Loads

The primary impact of skylighting on the HVAC system comes from turning off electric lighting, especially in climates with substantial air conditioning requirements. Skylit buildings should include automatic lighting controls with photosensors that measure the available daylight, and dim or turn off unneeded electric lighting (Lighting controls are discussed in Section 4.) While this leaves plenty of light for the occupants, it substantially reduces the electric lighting power in the space, with a concurrent reduction in the internal heat gain and loads on the cooling system. There is also, of course, an increase in solar heat gain and heat conduction through the skylights, compared with the opaque roof that they replace. If the architect or building designer has sized the skylights properly, the reduction in the lighting component of the cooling load will be substantially greater than the increase in solar heat gain and conduction load. The reduction in electric lighting due to skylighting usually coincides with the building's peak cooling load, which typically occurs under conditions of ample sunshine. It also occurs during the period of peak electric demand charges, when reductions in electric load are most beneficial.

This rule of thumb applies less frequently in very humid climates, where the magnitude of latent cooling loads far outweighs the magnitude of cooling loads created by the lighting system, and where peak loads are associated with the most humid summer days. In very humid climates (such as Louisiana), any changes to the cooling loads due to skylights tend to be trivial in comparison to the magnitude of loads due to the general humidity.

It is clear that skylights in combination with photosensor lighting controls can often reduce peak cooling loads. This potential should be investigated to see if the mechanical designer can reduce the peak capacity of the air conditioning system to realize first cost savings in that system. For these savings to become reality, the mechanical designer must have confidence that:

- 1) The skylights are not oversized, resulting in excessive heat gain (which can be verified with *SkyCalc*), and
- 2) The daylighting controls are correctly designed and will reliably turn off lights during peak cooling conditions (see Section 4).

The first issue requires coordination with the architect or building designer, and the second

requires coordination with the lighting controls designer, but this should not be difficult in a well-run design team.

### **Effects on Heating Loads**

The largest impact of skylighting on heating loads is the increase in heat conduction out through the roof. The opaque roof is typically insulated to values of R-19 or greater, while most skylights have an overall R-value of R-1 or R-2. These low insulation levels obviously increase the heat loss of the building, an effect that goes on day and night during the heating season. The heat losses can be mitigated with additional ceiling insulation and/or with insulating skylight designs using double or triple glazing, insulated curbs, thermal breaks, etc. Skylights produce some offsetting solar heat gains during daylight hours by allowing the sun's heat to penetrate through the roof. There is also a secondary increase in required heating when electric lighting is turned off by the photocontrol system during daylight hours. This is insignificant, however, because the heat of lights is easily replaced by heat from the building's heating system, which is more efficient and less expensive. The skylighting system may necessitate a modest increase in the size of the heating system because of these effects.

### **2.6.2. Placement of Rooftop Equipment**

Many skylit buildings also have rooftop-mounted mechanical equipment. The placement of both skylights and rooftop units require coordination with the structural system. Skylights should be located between structural members, while rooftop units must be located over structural supports sized to carry their concentrated loads. In a rationalized structural layout, the coordination of these placements is relatively straightforward. The skylights must be placed so as to provide uniform illumination and to avoid blockage of light by structural members. The rooftop HVAC units must be spaced to provide coverage to the spaces below (larger units will be placed farther apart than smaller units), and they must be positioned to allow the ductwork to be laid out efficiently.

Large centralized HVAC systems may have large cooling towers or equipment rooms which will create large shadows on the roof. The effect of these shadows on the performance of the skylights should be considered carefully. None of this is difficult, but it does require more coordination among the architect, the structural designer, and the mechanical designer than is typical in standard practice.

### **2.6.3. Location of Ductwork**

The layout of ductwork in a skylit building is probably a greater challenge than the placement of rooftop units, because ducts have the potential to block valuable daylight if they are run too close to the skylights. In a building without ceilings or light wells, ductwork should be located between the skylights so as to obstruct as little daylight as possible.

Buildings with dropped ceilings and light wells can create additional challenges for duct

runs. In many single-story skylit buildings, there is ample vertical dimension to run the ducts below the structure and above the suspended ceiling. However, light wells can become quite large if their walls are splayed, creating a bit of an obstacle course for duct runs. A common solution is to run the primary supply ducts around the perimeter of the building, with smaller branch ducts in between the light wells.

In buildings with less height between the structure and the ceiling, the ductwork must often run through the structural system. Here, the light wells are also smaller because they are shorter, but there may be more constraints on the duct locations.

An alternative approach was used in the Sacramento Municipal Utility District's new skylit office building where a raised floor allows duct runs and HVAC registers to feed the space from below. This system allowed very flexible wiring to all workstations, and kept the ducts from interfering with the direct/indirect lighting system and the daylighting from windows and skylights. (see Figure 2-16)

As with the placement of the units, the location of ductwork requires somewhat more coordination between designers and trades than usual. This is really only a problem when coordination is neglected. In general, the skylights and their light wells need to be positioned first, and then the duct runs can be worked out between them. In a new project, it is usually not difficult to work out a rational arrangement for the systems. In a retrofit project, the coordination may be more difficult because of existing locations of rooftop curbs and internal ductwork.

#### **2.6.4. Placement of Registers**

The final element of coordination between skylighting and mechanical systems is the placement of supply and return registers. In most skylit buildings, both supply and return ducts are typically located in the ceilings. In a well-designed system, the placement of the registers is coordinated with the skylight placement as well. We will discuss heating and cooling considerations in turn.

##### **Cooling Registers**

Cooling registers are usually concentrated near windows with substantial solar heat gains, and spread uniformly throughout the remaining interior spaces. With a skylighting system, there are potential warm spots below the skylights (although this will be minimized with good diffusing glazing materials). In buildings with light wells under the skylights, there is an opportunity to create a zone of stratified air up in the well. As solar gains enter the skylight, the heat is typically absorbed by the surfaces of the light well, which in turn heats the surrounding air. This warmed air will tend to rise and collect at the top of the light well. It is best to leave it undisturbed, and to direct both supply and return air flows down below the ceiling plane rather than up into the well. It is not a good idea to place return registers high up inside the light wells, because this will pick up the heated air and return it to the air conditioner.

## Heating Registers

Heating registers near skylights require a separate strategy. In cold locations, the skylights tend to create cold downdrafts as heat escapes through less insulated glazing. By placing heating supply registers at the base of the light wells, these downdrafts can be mixed with the heating supply air stream, and the cold drafts can be eliminated. An alternative strategy could be to place heating return registers at the base of the light wells, which would draw the cold downdrafts into the return system and mix them with the warm return air from the ceiling.

In a mixed heating and cooling system, it is usually best to apply the latter strategy. By placing return registers near the bottom of light wells, stratification leaves unwanted heat gains at the top of the well in the cooling season, and cold air falling from the skylights during the heating season is drawn into the system return air ducts before it can establish a pattern of cold air drafts on the occupants below. Under this scheme, the supply registers are distributed between the light wells, where the duct work would typically be run.

An alternative approach is to install a glazing layer to the bottom of the skylight well to prevent mixing of the room air with the air in the well. This additional glazing layer can also function as an additional diffuser for the skylight (see the Capistrano School District case study).

As this discussion illustrates, there are ample design opportunities for the architect and mechanical engineer to coordinate with the skylighting system. At the same time, they should consider the lighting system design, so they can devise a well-integrated solution. This will maximize occupant comfort and the performance and savings potential of the mechanical system.

## Footnotes, Chapter 2

<sup>1</sup> L. Schutrum and N. Ozisik, “Solar Heat Gains through Domed Skylights,” ASHRAE Journal, August 1961

<sup>2</sup> *SkyCalc* does not currently account for this difference in transmission as a function of angle of incidence and shape of skylight.

<sup>3</sup> Transparency is not typically reported for skylight glazing materials. However, there is an ANSI Standard Practice for Goniophotometry, E-167-96, which reports on the geometrical distribution of light transmitted through a glazing material.

<sup>4</sup> Lighting Research Center, Delta Report on Sacramento Municipal Utility District’s new office building, 1997. Workers on the skylit floors rated their lighting system higher (96 per-

cent satisfaction) than those working on floors with daylighting provided only from windows (67 percent satisfaction).

<sup>5</sup> One building owner also found that in the evening, transparent skylights which are brightly lit from below can attract birds, which attempt to fly through the skylight. Reducing the transparency of the view seems to prevent the problem.