MEASURE 8.3.1 Install skylights or light pipes.

RATINGS

New Facilities	Retrofit	O&M
B	C	

Skylights can provide satisfactory lighting for activities that can tolerate large variations in illumination level. Getting good performance from skylights is not as simple as it may appear. You have to satisfy a number of requirements, some of which may not be easily compatible with each other.

When considering skylights, also consider "light pipes." Light pipes perform the same function as skylights. They make it possible to transport daylight through thick roof structures and attics. They are easier to install in retrofit applications than skylights. For practical reasons, light pipes are limited to smaller light collection areas. They are still evolving.

In this Measure, we will use the term "skylights" to cover both skylights and light pipes, except when the distinction needs to be spelled out.

WESINC

Fig. 1 Effective skylights in a shopping mall The percentage of ceiling area is about right for the type of illumination needed. Light distribution is good. The diffusing skylights are installed at the tops of tapered recesses, minimizing glare.

SUMMARY

Skylights are an old source of free lighting that needs to be improved in the way it is applied. Light pipes are a new way of achieving the same purpose with greater flexibility. Desirable for many large, open, non-office environments. Retrofit is usually difficult.

SELECTION SCORECARD

Savings Potential	$ $ $
Rate of Return, New Facilities	% %
Rate of Return, Retrofit	%
Reliability	✓ ✓
Ease of Retrofit	☺

Where to Use Skylights and Light Pipes

Many types of activities can be illuminated well by skylights, but many others cannot be. In terms of illumination quality, the major advantage of skylights is the ideal color rendition of daylight. Their major disadvantage is large fluctuations in illumination intensity caused by movement of clouds across the sun. This annoyance varies with location.

Experience indicates that skylights can be effective for retailing, even in posh environments, because sunlight has excellent color rendition and brilliance. See Figures 1, 2, and 3.

Skylights are also effective for many manufacturing and maintenance operations. Warehousing can be a favorable application. Skylights can be used to provide a sense of natural ambience, which is valuable in applications such as restaurants (Figure 4), transportation centers, and other public areas.

Skylights are less likely to be satisfactory where paperwork occurs, as in offices, drafting areas, and reading rooms. The wide range and fluctuations of sunlight intensity are more noticeable in applications that require concentration on text. Also, daylighting makes it more difficult to avoid veiling reflections, which are a problem especially with paperwork. See Reference Note 51, Factors in Visual Quality, for more about veiling reflections.

With current technology, skylights and light pipes are limited to illuminating the area directly underneath them. The roof structure must allow penetrations to be made without undue expense. Therefore, skylights are most likely to be worthwhile in industrial-type buildings and in large single-floor spaces, such as gymnasiums. Future types of light pipes may be able to transport sunlight far into the building interior.

Skylights must be located where the sun can shine on them directly. A skylight does not produce a useful amount of daylight if it is shaded by adjacent structures or foliage. Similarly, skylights are not worthwhile in areas that have heavy cloud cover for a large fraction of the time, unless the climate is mild and the structure can accommodate a large area of skylights. Clouds typically reduce solar illumination by a factor of five to ten.

When individual clouds pass in front of the sun, they cause abrupt changes in illumination level. The abruptness of the change is usually more objectionable than the reduction of light level. The large, quick variations of light level make skylights unacceptable for certain applications.

Retrofitting skylights in existing buildings is often impractical because of cost and structural interference. Even though skylights require only a relative small fraction of total roof area, installation usually requires structural changes, such as cutting through rafters and purlins.

If the building has an attic, installing skylights in the roof requires building a reflective enclosure to pass the light through the attic. Unless the attic is empty, this may be difficult. Light pipes are easier to pass through attics. In effect, a light pipe is a small skylight with an integral reflective enclosure.

Energy Saving Potential

In single-floor buildings, skylights may provide a large fraction of illumination requirements. Sunlight is so intense that skylights can provide virtually any illumination level that is required. Of course, artificial lighting is still needed at night.

Sunlight has a better ratio of light to heat than any type of electric lamp. Therefore, if the light from skylights is distributed efficiently and the skylights are not oversized, they may not substantially increase the cooling load. However, this ideal is difficult to achieve.

Skylights can provide significant passive heating during cold weather. This advantage is offset by conductive heat loss at night. In all but the coldest climates, there is a net heat gain if the skylights are located so that they collect the maximum amount of sunlight. On the other hand, skylights that face away from the sun may suffer a net heat loss even in relatively mild climates.

Surface Area Required for Daylighting

Outdoor sunlight from a clear sky produces an illumination of about 60,000 lux, most of which comes directly from the sun. Using this fact, you can easily calculate the fraction of the ceiling area that needs to be converted to skylight. (For a quick introduction to "lux" and other measures of light intensity, see Reference Note 50.)

For example, consider an application that needs an illumination level of 500 lux. To account for losses in reflection and diffusion within the skylight assembly, assume that 40% of the sunlight entering the skylight makes its way into the space. Thus, on a bright day, about 2% of the ceiling area needs to be skylights. To compensate for low sun angles, hazy conditions, dirty skylights, etc., double this to about 4%. To account for average cloudy conditions, increase this to 10% or 15%.

The installation in Figures 1 and 3 have skylights that are sized for approximately the latter percentages of ceiling area. The installation in Figure 2 has a much higher percentage, with the result that the glazing must be darkly tinted to avoid glare. The unusual installation in Figure 4 has a variable amount of skylight area.

These figures assume that the skylights are installed where they remain exposed to direct sun throughout most of the day. In some older industrial buildings, large skylights were installed facing north to avoid glare. This unnecessary practice is still followed in some new buildings, as shown in Figure 5. This greatly increases the glazing area required, which also increases heat loss in cold weather. To keep skylights as small as possible, install them so they face the sun as much as possible. Control glare with diffusion and careful space layout, as discussed below.

In predominantly warm climates, select the skylight area to give the best compromise between savings in lighting energy and extra cost for cooling energy. If the space is air conditioned, design the skylights for a clear sky. This means, keep them small.

In predominantly cold climates, the balance usually shifts toward larger skylights. This makes it more important to select the skylights for low conductive heat loss. If you want to exploit passive heating, the skylights must be much larger, and the whole arrangement

Super Sky Products, Inc.

Fig. 2 Large, attractive skylight This is a large amount of glazing area in relation to the illumination requirement.

becomes expensive and elaborate. For more about passive heating, see Reference Note 47, Passive Solar Heating Design.

Use the minimum total skylight area that you need to provide good illumination, and if appropriate, passive heating. This is because surface area increases heat loss, cost, and structural problems. Therefore, make all skylights as transparent as possible, subject to the need for diffusion, multiple glazing, reinforcing fibers in plastic material, etc. Do not use skylight materials with tints, and do not use skylight materials that reflect sunlight.

Efficient distribution of daylighting within the space is as important as the skylight area. Skylights should deliver their light where it is needed, and they should avoid creating visual problems. You achieve these characteristics by effective layout of the skylights, and by using diffusion. We will cover these two topics next.

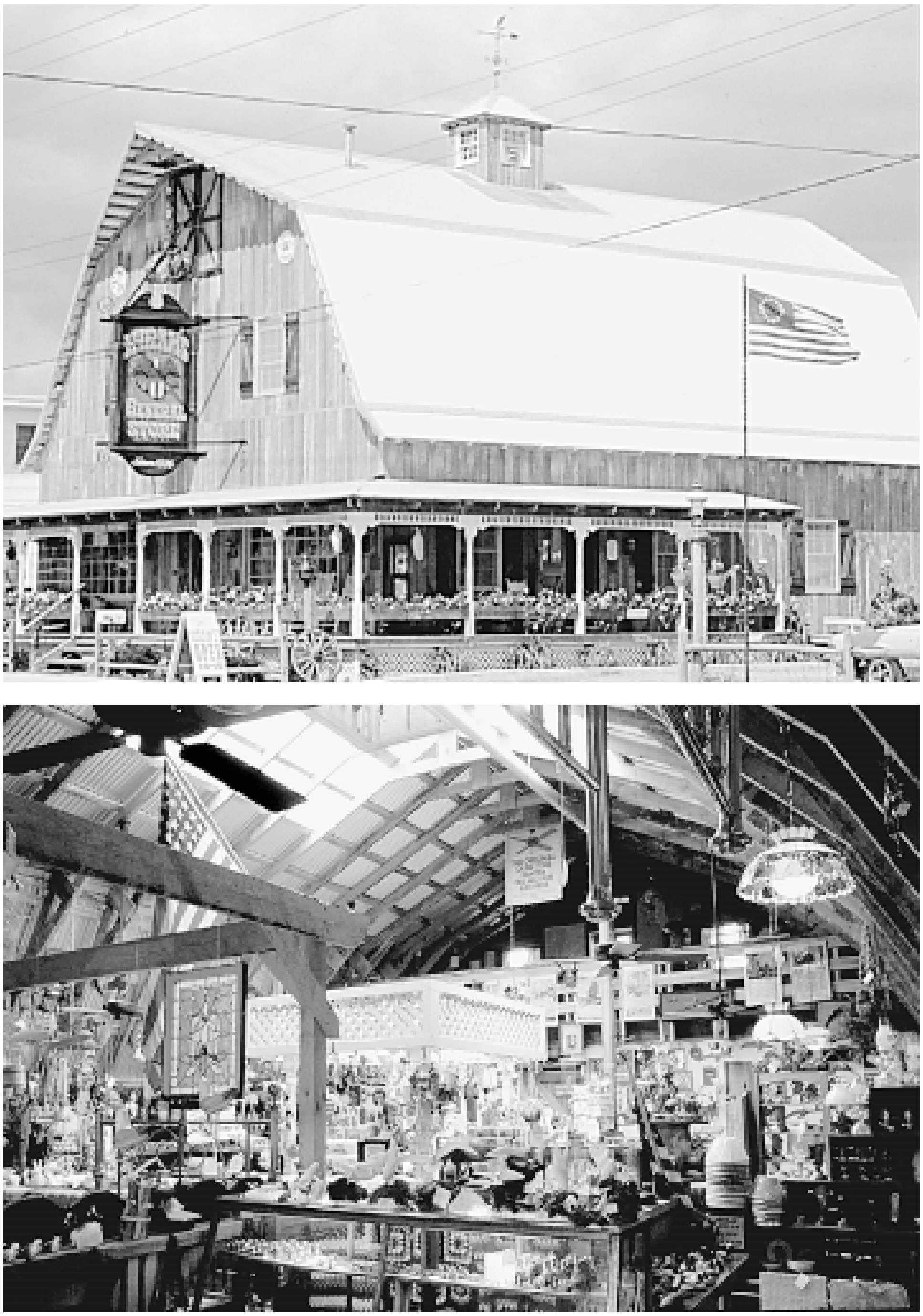

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Fig. 3 Skylighting for a variety store The skylight consists of a small area of translucent panels surrounding the cupola. The lighting is effective for the colorful merchandise. The geometry of the skylight does not extend sufficient daylight into the ends of the space, so artificial lighting is needed there. Daylighting of this space was later abandoned, for unknown reasons.

Kalwall Corporation

Fig. 4 Adjustable skylight In this restaurant, insulated translucent panels with low light transmission can be retracted to provide a variable amount of skylighting. The layout must keep direct sunlight from entering the occupied area of the space, or diffusion must be used with the skylight glazing.

Skylight Layout

In general, it is better to use a larger number of smaller skylights, rather than one or a few large skylights. There are many examples of horrible daylighting in which someone attempted to illuminate a space with only one big skylight. Figure 6 shows a good distribution of skylights for a space with a tall ceiling. Figure 1 in Measure 8.3.2 shows the interior of this space. Using smaller skylights has several important advantages:

- ***you can tailor the light distribution within the space more accurately***. The skylights do not have to be installed in a regular pattern. In general, the size of skylights, and the spacing between them, should be proportional to the ceiling height. Stated differently, skylights should not have to throw light far to the side.
- ***an array of smaller skylights provides illumination that is much more uniform*** than the light from a single large skylight. Installations with large skylights commonly suffer from excess brightness directly below the skylight, accompanied by gloomy dark areas surrounding the skylight.
- ***less modification of the roof structure is needed***. Large skylights require special roof design to carry the roof loads around the skylight. In existing buildings, it is often possible to retrofit small skylights, but not large ones.
- ***it is easier to avoid leakage problems with small skylights***, for the reasons discussed below.

It helps to think of skylights as a class of light fixtures. They must obey the same rules of physics and lighting quality as electric light fixtures.

Compare the skylight installation in Figure 1 of Measure 8.3.2 with the skylight installation in Figure 7. The former provides better distribution of light throughout the space, with less glare. (However, it lacks proper diffusers, as we will discuss.)

Another useful guideline is that the dimensions of the skylight should be a small fraction of their height above the floor of the space. Thus, a large skylight over an atrium may be satisfactory, but not a large skylight over a dining room. The central skylight in Figure 3 is satisfactory because it is high above the floor. However,

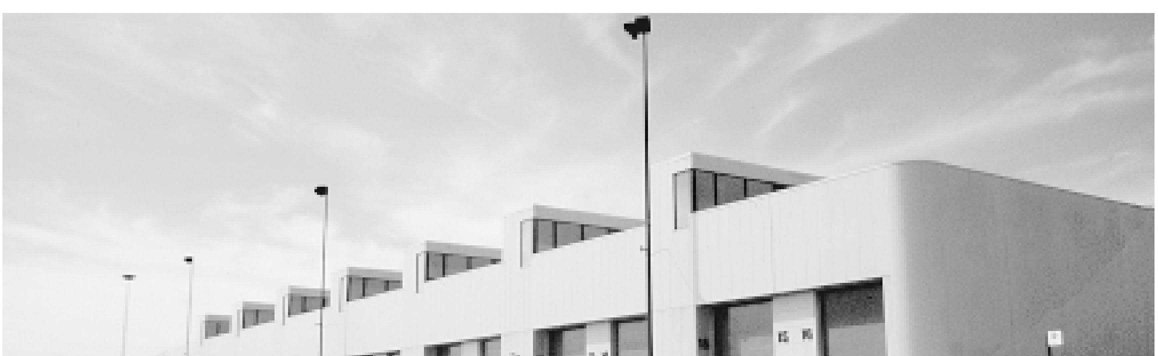

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Fig. 5 Inefficient skylight orientation The skylights on this bus garage face north. This avoids glare problems and excessive solar heat gain, but it provides little light in relation to the heat loss from the glazing. Overhead equipment keeps much of the daylight from penetrating into the space.

WESINC

Fig. 6 Good skylight sizing and layout This shows the small fraction of roof area that is needed for typical illumination levels. These skylights are for a gymnasium, and the repetitive layout provides uniform illumination within the space. See Figure 1 of Measure 8.3.2 for the inside.

Vistawall Architectural Products

Fig. 7 Gymnasium daylighting with a single large skylight Compare this to Figure 1 of Measure 8.3.2. The barrel roof of this building makes it difficult to install distributed skylights.

the daylighting does not penetrate well to the perimeter of the space.

Skylights that are large with respect to the ceiling height may be decorative, but they are not optimum for daylighting, and they may be overwhelmingly bright. Figure 8 shows large clusters of skylights installed in a library. The brightness inside the space can be excessive. Figure 9 shows a huge skylight that covers an entire office.

Effective Diffusion is Essential

Skylights generally need diffusion. Direct sunlight through skylights is not suitable for illumination. It is

WESINC

Fig. 8 Large skylight arrays These illuminate areas of a public library with relatively low ceilings. The areas immediately beneath the skylights receive too much illumination and heat gain in bright daylight, while the light is unable to disperse to the rest of the space.

much too intense, it forms localized bright spots, and it shines on the wrong places. Diffusion corrects or reduces these problems by distributing sunlight in a fairly uniform pattern. It also minimizes changes in illumination caused the motion of the sun. Daylighting was abandoned in favor of electric lighting largely because of unsatisfactory illumination resulting from lack of diffusion.

For example, consider a space that has many small skylights. If the skylights are clear, they produce intense bright spots on the floor, surrounded by darkness. See Figure 1 in Measure 8.3.2. As a result of this oversight, the skylights produce no useful illumination, and the electric lights must be turned on to compensate for the glare. On the other hand, if the skylights diffuse the light, it is spread throughout the space.

You can make any surface of the skylight glazing a diffuser by selecting the material for this purpose. Or, you can install separate diffusers either above or underneath clear glazing. It is easier and usually preferable to make the diffuser an integral part of the skylight, unless you are also trying to accomplish passive solar heating.

Diffusion introduces its own set of issues to consider. The main ones are limiting glare, dealing with solar heat gain, and limiting light loss.

■ Limit Glare

The term “glare,” as we use it here, means an area of intense brightness within the visual field. (Reference Note 51, Factors in Lighting Quality, explains glare in greater detail.) Diffusion has the potential of creating serious glare because it makes skylights look like bright light sources. For example, small skylights are similar to flat-faced fluorescent ceiling fixtures in appearance and light distribution pattern, although they can be significantly brighter.

Glare is a problem only when the bright surface is within the field of vision. Fortunately, people tolerate bright light sources that are overhead. As with other light sources, the solution to glare is to locate skylights well above the line of sight. In spaces with very tall ceilings, such as gymnasiums and manufacturing plants, the height of the ceiling alone may be sufficient to keep glare within acceptable limits.

If the skylight is installed at the top of a shaft or recess in the ceiling, this keeps the skylight out of normal lines of sight. For this to minimize glare in a space with a low ceiling, the shaft or recess should be at least as tall as the maximum dimension of the skylight. In other words, the recess needs to be taller with bigger skylights.

■ Locate Diffusers to Minimize or Exploit Heat Gain

The solar heat gain into the space is strongly affected by how the diffuser is installed, and by the characteristics of the diffuser. Heat gain is lowest if diffusion is limited to the outer surface of the glazing. In that case, a large fraction of the heat absorbed by the diffuser itself is carried away be the outside air. Heat gain is greatest if the innermost surface is used as the diffuser.

Heat gain is increased even more by locating the diffuser farther inside the space, so that less of the entering light is reflected back out. To capture solar heat for passive heating, install a separate diffuser inside the space that is made of absorptive material. Measure 8.4.2 explains this arrangement in detail.

■ Where to Locate the Diffuser if the Skylight is Installed Above a Ceiling Recess

The location of the diffuser matters most when there is a recess or shaft between the skylight and the interior of the space, typically to create a path for the daylight through the roof structure.

The location of the diffuser in a shaft radically affects the light distribution pattern. Installing the diffuser at the bottom of the shaft produces a broad pattern. Installing the diffuser high in a tall shaft produces illumination similar to that of a downlight.

Installing a diffuser higher in the shaft keeps people from seeing it, except when it is more nearly overhead. This reduces the possibility that glare will be a problem.

The surface of the shaft absorbs light. A diffuser installed high in the shaft deflects more of the light toward the shaft surface, making it especially important for the shaft surface to be highly reflective. A specular surface saves more light than a diffuse surface, because it reflects all the light downward. However, a diffuse surface may give better light distribution. It depends on the relative geometry of the skylight, the shaft, and the space.

If you install a separate diffuser, make sure that no sunlight leaks around the diffuser directly into the space. Direct sunlight is an intense source of glare, and it is useless for illumination.

Avoid Nasty Surprises: Heat Loss and Condensation

The heat loss of skylights may be much higher than you expect. Hidden away in the technical literature is the fact that heat loss through glazing is two to three times higher when the glazing is installed in a horizontal or steeply slanted orientation than when it is installed vertically. Thus, the double glazed skylight that you expected to have an R-value of 2 actually has an R-value less than 1.

One of the unpleasant surprises that results from this low thermal resistance is a tendency for skylights to sweat profusely. The condensation can damage or disfigure the surrounding structure. Poorly insulated skylights may drip heavily on the space below.

In cold climates, it is worth going to great lengths to limit the heat loss of skylights. These are your possible solutions:

Super Sky Products, Inc.

Fig. 9 An illustrative example Analyze this skylight installation, which illustrates most of the issues of daylighting. How suitable is the skylight for the activities? How appropriate is the glazing area from the standpoints of glare, solar heat gain, and conductive heat loss? How effective are the controls for the electric lights? What should be the transparency of the glazing? Should diffusers be used? Internal shading? How would these issues be affected by the location of the building? Overall, is this effective daylighting or primarily an esthetic feature?

- ***select multiple glazing.*** Up to three or four sheets of glazing are practical. Light transmission is reduced somewhat, and weight and cost are increased.
- ***use a glazing material that includes translucent insulation.*** Translucent glazing systems are now available that offer R-values as high as 10. These systems combine a plastic or composite glazing material with a layer of translucent insulation, which may be glass fiber or foam. See Measure 8.3.3 for the details. There is a strong compromise between R-value and light transmission, so skylights using this material must be larger than skylights that use conventional glazing.
- ***install movable insulation,*** which can greatly reduce heat loss without reducing light transmission. Movable insulation is challenging to design and to install. For an introduction to movable insulation, see Reference Note 47, Passive Solar Heating Design.

All skylight frames should include gutters to catch condensation that flows off the interior surface of the glazing. This is important to keep the condensation from rotting or disfiguring the structure around the skylight. The gutters should be large enough to hold all the condensation until it can evaporate back into the space.

Skylight Materials

Skylights are commonly made from glass, glass composites, plastics, and plastic composites. All these materials can be treated to reduce light transmission and cooling load, either by adding dyes that absorb light or by adding a reflective surface. All glazing materials can be provided with diffusing properties. As discussed previously, the thermal insulation value of skylights can be increased by installing multiple sheets of glazing and by installing translucent insulation between the sheets.

All diffusing materials absorb a significant amount of the entering sunlight because there are multiple reflections within the material. Absorption is greatest with milky diffuser, and lowest with prismatic diffusers. Absorption is also increased by fibers, pigments, and other materials that are embedded in the material.

The advantages of glass include unlimited life, high light transmission, hardness, and rigidity. Glass can be treated to reduce cooling load by selectively absorbing the infrared portion of sunlight. At present, this capability is available only with glass, not with plastic. See Measure 8.1.3 for details. The infrared absorbing surface should be outermost.

The main disadvantage of glass is its vulnerability to breakage, along with the safety hazard that falling glass creates. Glass can be made more resistant to breakage by increasing its thickness, by heat treating it, and by combining it with reinforcing materials. All safety improvements for glass add cost, and they usually add weight.

Plastic materials are much lighter in weight, and they are resistant to shattering, so they pose only a minimal safety hazard. An entire skylight assembly can be molded from a single piece of non-reinforced plastic. Smaller plastic skylights can be molded so that they overlap a mounting curb, providing excellent resistance to water leakage and greatly reducing the cost of the frame. Plastic skylights can easily be fabricated with multiple layers of glazing to improve thermal resistance.

Plastics can be reinforced with fibers of various materials, including glass, to increase strength and service life. The fibers cause some light loss. They also diffuse light, which is useful in most applications. Reinforced plastic is more difficult to mold into compound shapes. It is normally made in flat sheets, which can be curved in one direction.

The plastics commonly used for glazing are acrylics and polycarbonates. Polycarbonates are stronger, but acrylics are more resistant to degradation by the ultraviolet component of sunlight. All plastics deteriorate in strength and light transmission over a number of years. The main causes of deterioration are ultraviolet light, heat, and oxidation, in that order.

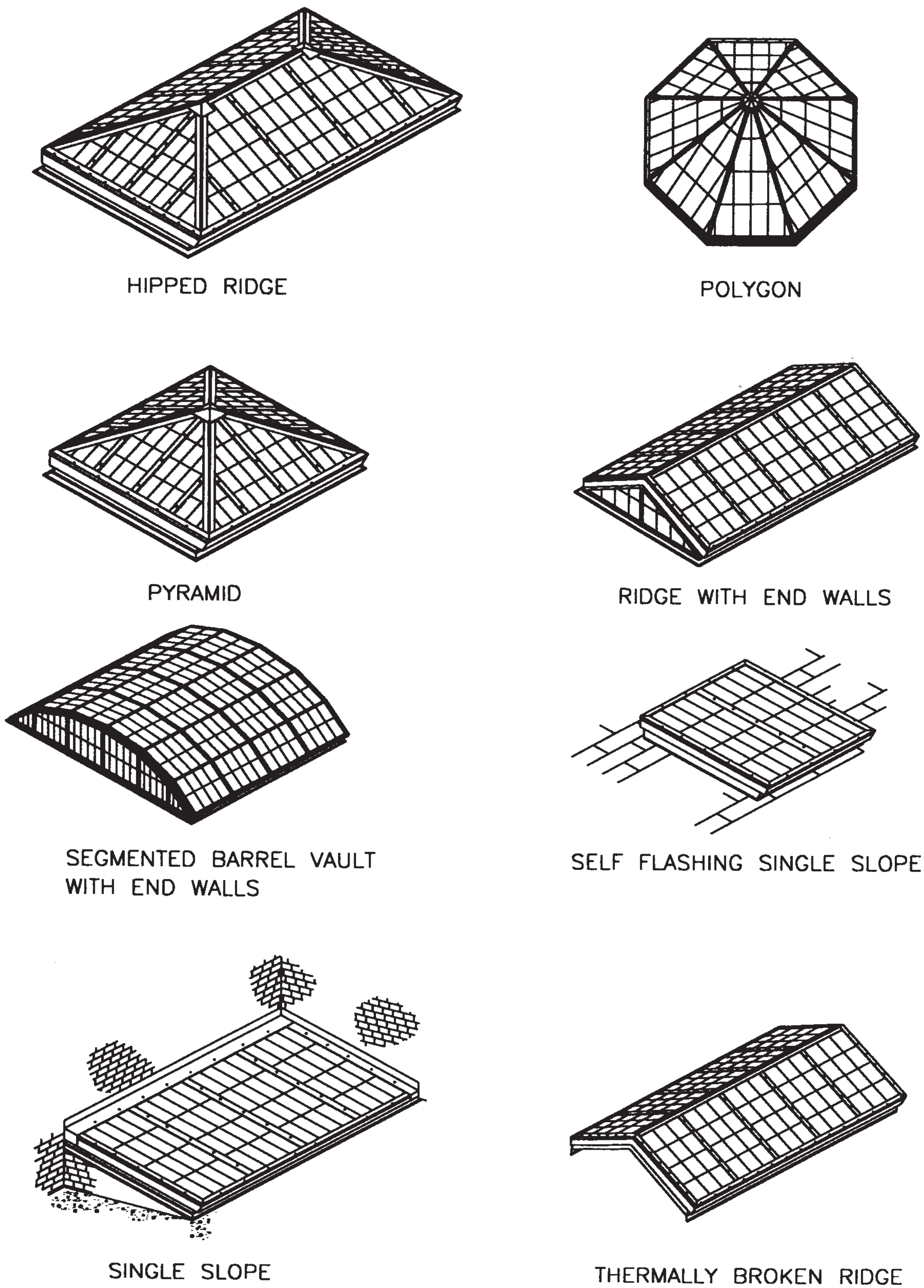
The service life of plastic glazing can be extended greatly with additives. Unfortunately, you cannot judge the long-term performance of a plastic material except from manufacturers' claims, so purchase skylight material from a credible manufacturer. If you buy skylights as prefabricated assemblies, first examine the plastic manufacturer's data. If possible, investigate actual field experience with the particular products you are considering.

Flat plastic glazing material buckles as it ages. This can be quite noticeable when the material is observed from the outside, but not when looking at the skylight from the interior.

Glass and plastic can be combined in larger skylights to minimize their respective weaknesses. Glass is used for the outer sheet, where it can provide considerable protection to the plastic, while the inner plastic sheet protects against glass breakage. Ordinary window glass strongly absorbs the damaging ultraviolet portion of sunlight, so a plastic material will survive longer if it is installed inside glass. Design or select combination skylights so that the plastic elements can be replaced separately without a great deal of effort.

Skylight Configurations

Skylights are available in almost any configuration that you could want. Skylights made of glass and composite are usually built up from flat sections. Figure 10 shows a sampling. Plastic skylights can be molded into virtually any desired shape. Skylights made of reinforced plastic materials can easily be curved in



Major Industries, Inc.

Fig. 10 Built-up skylights These can be made in virtually any size. Materials that cannot be bent easily, such as glass and fiber-reinforced plastic, are usually made into skylights this way.

one direction. Figure 11 shows a sampling of the latter two types.

How to Prevent Water Leakage

Water leakage is a common problem with skylights. Do not select a skylight design that depends primarily on sealants to prevent leakage. The most reliable method of avoiding leaks is to use one-piece molded skylights that overlap the curb. Unfortunately, molded skylights are limited in size.

If a skylight must have joints, design it so that the joints are steeply sloped to shed water. Ideally, no joint or sealant should face uphill, but this condition cannot be met everywhere in built-up skylights. Instead, the frame extrusion should be designed so that it conveys any water that leaks through seals to the outside of the skylight.

Pay attention to the curb on which the skylight is mounted. The curb should be sealed to the roof as effectively as curbs used for installing scuttles or rooftop air handling units. If a curb is installed on a sloping roof, install an eave on the uphill side of the curb to shed water to the sides of the curb.

Control the Electric Lights to Exploit Daylighting

A skylight or light pipe is useless unless it reduces the energy consumed by electric lights. This is not just a matter of turning off the electric lights in daylighted areas. You also have to avoid the tendency to increase the electric lighting levels in adjacent parts of the space that are not daylighted to compete with the brightness of the daylighted areas.

See Measure 9.5.3 for methods of controlling electric lights in response to daylighting. Combine these

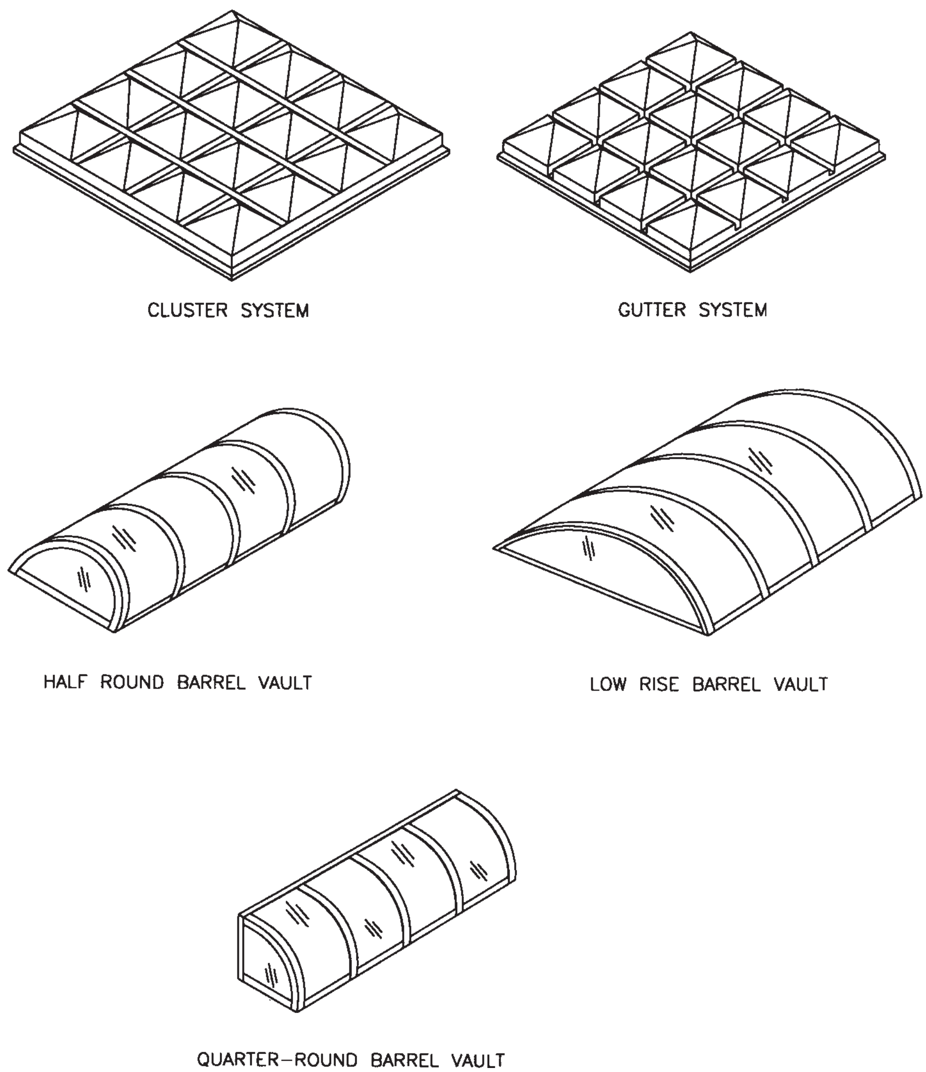


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Fig. 11 Molded and curved skylights Molded units are limited in size, but they can be ganged together to create a skylight of any size. Individual units can be molded to overlap curbs, an excellent method of avoiding leaks. Large skylights can be made of sheets of reinforced plastic that are curved in one direction.

with the other automatic lighting controls of Subsection 9.5 that are appropriate for the activities that occur in the space.

Compatible Types of Electric Lighting

Fluorescent lighting is generally the best type to use in combination with skylights because its output can be adjusted efficiently to supplement reduced sunlight. Modulating dimmer systems are available for fluorescent lighting, and these work well with daylighting. Also, fluorescent lamps can be turned on and off repeatedly to respond to changes in daylight. However, frequent cycling reduces lamp life and annoys occupants.

It is common to use high-intensity discharge (HID) lighting in combination with skylights. (HID is the class of lamps that includes mercury vapor, high-pressure sodium, and metal halide.) This is because HID lamps have high output, so they can be installed at the height of the skylight in limited numbers, matching the light output of the skylight. Unfortunately, HID is usually a poor choice to combine with skylights. HID lamps take as long as ten minutes to reach full brightness, and they cannot restart for several minutes after being turned off. This makes them inappropriate for use with daylighting, where passage of clouds in front of the sun may require the output of the electric lights to change continually. A newer type of HID lighting is available that turns on instantly. These operate by keeping the lamps hot continuously, which sacrifices efficiency. HID dimming does exists, but it is limited by problems that are described in Reference Note 56, HID and LPS Lighting.

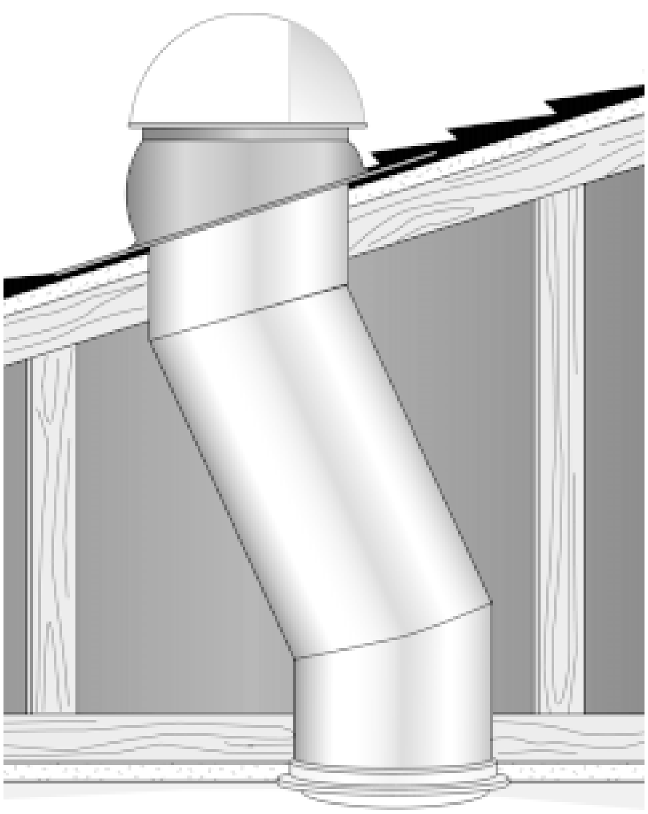
There is a tendency to believe that fluorescent lighting cannot be used with tall ceilings. This is not true. However, individual fluorescent lamps are limited in light output. As a result, lighting a space with fluorescent lighting typically requires many more fixtures than with HID lighting. See Measure 9.3.3 for a comparison of HID and fluorescent lighting.

It makes no economic sense to use incandescent lighting as a complement to skylights, even though this is done often. The saving in lighting cost by daylighting is eliminated by the higher cost of incandescent lighting during the periods of time that it operates.

Special Features of Light Pipes

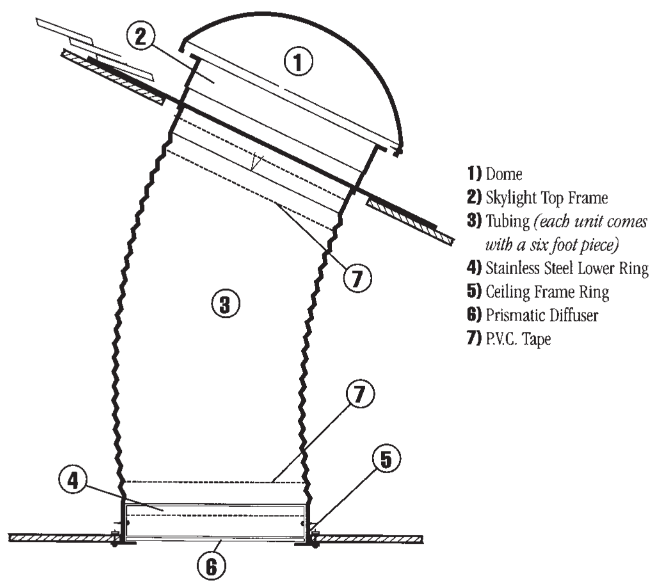
The desire to gain the benefits of skylights without suffering their disadvantages created an interest in "light pipes." As the name implies, light pipes convey light to locations within the building where it is needed. Many types of light pipes have been designed, but only a few are commercially available.

Some claims made for light pipes defy the laws of physics. A light pipe cannot deliver more light energy to the space than it collects on the outside of the building. At present, commercial light pipes do not concentrate sunlight from large exterior collectors into smaller pipes. Understand the principles of light pipes so that the installation will yield the results you expect.



Huvco, LLC

Fig. 12 Rigid wall light pipe This unit has a reflector in the back of the dome to capture more daylight at low sun angles. A diffuser is installed at the ceiling.



Sun Tunnel Skylight

Fig. 13 Flexible wall light pipe This type is easier to install than rigid wall light pipes. However, light losses are greater because of the corrugated surface of the tube.

Light Loss from Reflection Inside the Pipe

The efficiency of fixed light pipes suffers from absorption that occurs when light is reflected from the walls of the pipe. Unless the sun is lined up with the axis of the pipe, the light is reflected repeatedly as it travels through the pipe. Even if the surfaces of the pipe have high reflectance, say 90%, a large fraction of entering light is lost with a few reflections. The light loss is proportional to the length-to-width ratio of the pipe. Therefore, efficiency is sacrificed if the pipe is long in relation to its width.

Simple Light Pipes

Most light pipes that are available commercially consist of an exterior transparent dome, a reflecting metal pipe, and a diffuser for installation at the ceiling level of the space. The pipe may be rigid or flexible. Flexible pipes are easier to install, but they suffer more light loss from increased reflection and scatter inside the pipe. Figure 12 shows a rigid light pipe, and Figure 13 shows a flexible light pipe.

Sun Trackers

A movable mirror or refracting system can be used to align the incoming sunlight with the axis of the light pipe, minimizing reflection losses. A light pipe with this feature is called a "sun tracker."

Sun trackers have been built commercially. Figure 14 shows a number of installed units, and Figure 15 shows a cross section of the unit.

If mass produced, sun trackers could be relatively inexpensive. Their main limitation is that they lose effectiveness if the sky does not remain clear. The system is designed to collect light from the sun, which is a point source. The light reflecting apparatus gets in the way of the whole sky when the sun is obscured. Another disadvantage is the need for occasional maintenance.

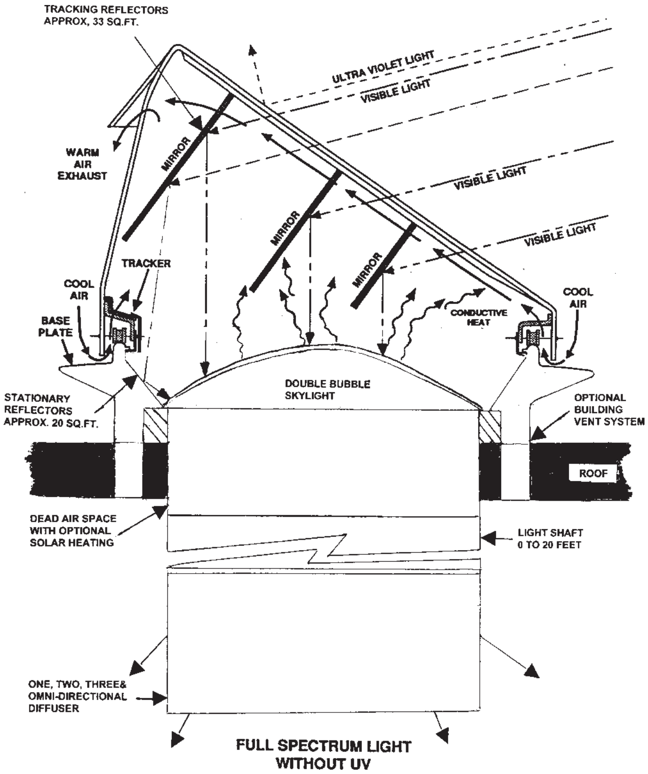
Future Developments

An ideal light pipe would have a large exterior collecting surface, it would funnel the light into a narrow conduit, and it would deliver the light wherever it is needed.

A small conduit is desirable to minimize heat loss and to make the light pipe easy to install. Funneling the light from a large collector into a small pipe requires a tracking mirror and a lens system. These do not have to be precision components. For example, light can be concentrated with flat fresnel lenses made of molded plastic. Both the tracking mirror and the lens system should be able to adapt to changes in sky conditions, from direct sunlight to a diffuse sky.

LightScience Corporation

Fig. 14 Sun tracking light pipes The rotating head contains mirrors that reflect direct sunlight straight down the pipe, minimizing losses. However, sun trackers may be less effective than simple light pipes for collecting sunlight from a diffuse sky.



LightScience Corporation

Fig. 15 Cross section of sun tracker The light shaft is sealed. The tracker head reflects sunlight through a double-glazed dome on top of the shaft.

Light pipes can avoid light loss by using the principle of fiber optics, which is an optical phenomenon called "total internal reflection." This requires the light pipe to be made of a solid transparent material, such as glass or plastic. The light pipe can be long, and it can have any number of bends.

To make this economical, all the light has to be squeezed into a light pipe of small diameter. The small diameter is a major advantage in itself, but it involves complication at each end of the light pipe. This concept is presently used with high-intensity electric lamps as the light source, for special effects. Present light pipes of this type are too expensive for daylighting.

ECONOMICS

SAVINGS POTENTIAL: *In the most favorable cases, skylights can provide a majority of lighting needed during the daytime. However, skylights increase heating cost. In mild climates, the heating cost penalty is not serious if the skylights are sized properly. Skylights may increase cooling cost, but this penalty should be minor if the skylights are sized and laid out properly.*

COST: *The major cost components are the skylights themselves, the roof penetrations, framing for the skylights, and electric lighting modifications. Molded plastic, double-glazed skylights cost $15 to $30 per square foot, depending on size. Large, self-supporting skylights with plastic composite glazing typically cost from $30 to $60 per square foot. Double-glazed glass skylights with safety glazing may cost up to $100 per square foot. Small, simple light pipes can be installed for less than one thousand dollars, even in retrofit. See Measure 9.5.3 for the cost of the electric lighting controls.*

PAYBACK PERIOD: *Up to several years, in new construction. Several years or longer, in retrofit.*

TRAPS & TRICKS

MAKING THE COMMITMENT: *Skylights do not disappear if you decide not to use them. They can create serious permanent problems, including glare, uncomfortable heat gain, heat loss, condensation, and water leakage. Do not use them unless you make a commitment to design and install them properly.*

DESIGN: *Skylight design is not something to do in a hurry. Consider the light distribution pattern, the effect on decor, the effect on cooling and heating, avoiding condensation problems, and avoiding water leakage. Provide effective controls to coordinate the electric lights with daylighting, or else the effort is wasted.*

SELECTING THE EQUIPMENT: *There are major differences between prefabricated units. Some have much better longevity and leakage resistance than others.*

INSTALLATION: *Even with the best design, avoiding water leakage requires good installation workmanship. See Measure 9.5.3 about installing the daylight-sensing lighting controls.*