energy design resources

# design brief

## SKYLIGHTS WITH SUSPENDED CEILINGS


## Summary

Traditionally, skylight wells in large, low-rise commercial buildings have been custom designed and site built, an expensive and labor-intensive process. This design brief explores the benefits of a better alternative: splayed modular skylight wells specifically designed for use with suspended ceilings. These prefabricated systems, which consist of a two-part light well with a throat and a splay, are a relatively new design concept. Although they are not yet commercially available, there is considerable market interest in these systems thanks to their potential to provide superior lighting quality, increase energy efficiency, improve occupant comfort, and lower installation costs.

This design brief provides four conceptual examples of prefabricated skylight well systems. Each of these proposed designs integrates suspended ceilings and traditional skylight systems to introduce daylight into commercial spaces with finished ceilings.

As a new concept, splayed modular skylight wells can solve many issues faced by designers who wish to provide daylight in large, low-rise buildings. The following key issues need to be addressed when designing with these systems:

- Design to achieve the best light quality for optimal energy savings while working with conventional building systems, construction processes, and standards.
- With each skylight well component, satisfy minimum performance goals for illumination, energy use, fire safety, structural integrity, and assembly sequence.


A splayed modular skylight well is a cost-effective and energy-efficient way to introduce high-quality daylight into schools, retail stores, offices, and other low-rise buildings with suspended ceilings.

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The glossary at the end of this design brief provides definitions of common skylighting terminology.

- Treat skylighting design as an iterative process. Refine the skylighting design as other building systems are designed. The skylighting design can start with simple assumptions and be fine-tuned along the way using sophisticated design tools.

## Introduction

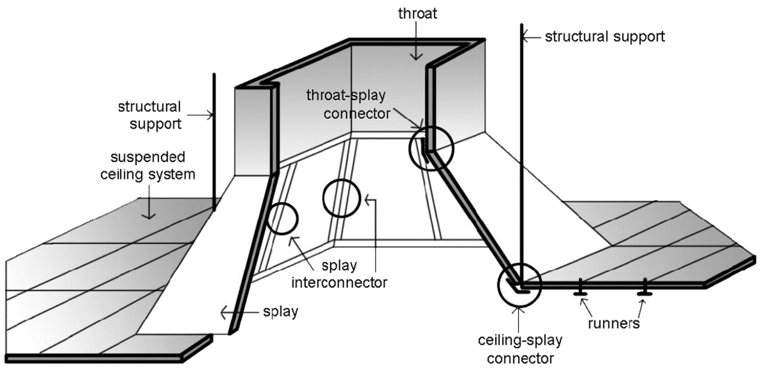
This design brief shows how a splayed modular skylight system can reduce skylight installation costs, provide reliable performance and construction quality, facilitate coordination with other building systems, and make maintenance easier. Architects and contractors, as well as school district administration, retailers, and other building owners, can benefit from such a prefabricated system that easily integrates with suspended ceilings and can be marketed and distributed through existing industry channels.  A number of manufacturers are currently developing modular skylight systems for the commercial building market; in the meantime, the content in this Design Brief will help reduce your time spent on creating effective skylighting designs.

### What is a Splayed Modular Skylight Well System?

This relatively new design concept consists of a two-part light well system with a throat and a splay. The throat is the upper part of the well directly below the skylight. Its primary purpose is to channel light efficiently through the plenum. The splay is the lower part of the well that connects to the ceiling. Its primary purpose is to allow the daylight to spread as widely as possible, while reducing glare from overly brigh surfaces. Thus, a splay will improve light distribution and overall lighting quality in a space. It can also reduce the cost of a skylighting system because fewer and larger skylights can be used to provide a given amount of daylight illuminance and energy savings. Figure 1 shows a throat and splay for a basic modular skylight well.

**Figure 1: Cut Section of a Splayed Modular Skylight Well**

The throat and splay with structural supports and connector system form the basic splayed modular skylight well.




## Benefits of Skylights

Daylight is often considered the highest quality light source. It provides flicker-free light, and has excellent color rendering qualities. There is increasing demand for daylight in low-rise buildings such as retail stores, office complexes, and schools. Skylights can bring daylight into the center of these buildings to provide better lighting quality and more reliable energy savings than daylight designs relying solely on windows.

**Increased sales and performance.** A good skylight design provides relatively uniform illumination throughout a space while introducing pleasant variation in lighting quality over the course of a day and from season to season. In retail stores, daylighting may result in better color rendition and increased sales.

Two separate studies show that stores with skylights experienced higher sales that those without.[1] Recent research also links daylight to improved occupant performance. A study surveying the performance of elementary school students in Seattle, Washington, Fort Collins, Colorado, and Capistrano, California, showed students in classrooms with more daylight achieved higher test scores or made faster learning progress.[2]

Daylight from skylights serves as a reliable daytime lighting source, resulting in increased building safety and reduced business risk in the event of electricity outages.

Industry names for suspended ceilings include finished ceilings, T-bar ceilings, acoustic tile ceilings, and modular ceilings. This design brief uses the term "suspended ceilings" for all these systems.

**Greater energy savings.** Skylights combined with photocontrols can dramatically reduce the need for electric lighting during the day. In a study of 12 retail stores in Southern California, a 27 percent average reduction of lighting energy consumption resulted when skylights were combined with lighting controls.[3] When appropriately sized and specified, skylights also reduce the cooling needed to counter heat gain from electric lights. Reduced lighting and cooling loads substantially increase energy savings.

## Why Suspended Ceilings?

The simple modular nature of a suspended ceiling system serves many architectural needs in commercial buildings. A typical suspended ceiling consists of a structural grid of metal T-bar runners that support lightweight, detachable acoustic tiles. The regular grid system allows several building systems to be easily organized with minimal coordination effort, including heating and cooling vents, luminaires, fire sprinklers, audio speakers, structural systems, and plumbing, electrical and mechanical supply.

The modular nature of suspended ceilings increases building flexibility, facilitating tenant changes in office and retail spaces. Suspended ceilings also reduce ceiling height, thereby reducing the effective volume of conditioned space and bringing the lighting and ventilation delivery systems closer to the occupants. The sound-absorbing surfaces of ceiling tiles reduce ambient noise, which can improve productivity in workplaces and performance in schools. A new standard from the American National Standards Institute (ANSI) now requires strict acoustic specifications for educational spaces, which may increase the use of suspended ceilings in classrooms.[4]

Aesthetics is another important issue. A suspended ceiling creates a clean, uniform appearance. With so many positive attributes, suspended ceilings systems are the preferred solution in many commercial buildings.

## Current Market and Building Practices

Low-rise commercial buildings such as offices, grocery stores, other retail spaces, and schools can take advantage of skylighting. These four building types make up 54 percent of all new and retrofit construction area in California. Calculations based on the national Commercial Building Energy Survey suggest that 68 percent of all existing nonresidential floor space is directly below a roof and thus potentially suitable for skylights. In addition, suspended ceiling systems are installed in 68 percent of all educational facilities, 45 percent of all office space, and 46 percent of all retail space.[5] This suggests that approximately 121 million square feet of commercial space built each year in the United States can use integrated skylights and suspended ceilings, including 16.5 million square feet in California alone.[6]

Current building techniques typically use custom-designed, site-built skylight wells. However, onsite fabrication can compromise construction quality, building aesthetics, and even occupant safety. Skylight well parts often need to be special ordered, or cut or bent during installation, thereby increasing design and labor costs. A splayed modular skylight system offers designers a more effective solution.

As of 2004, some manufacturers are beginning to develop some modular skylight products. They may eventually market either complete systems or interchangeable components.

Approximately 121 million square feet of commercial space built each year in the United States could potentially benefit from integrated skylights with suspended ceilings.

# Design Criteria for Modular Skylight Wells

The design quality of a skylight system profoundly affects its efficiency and effectiveness. An effective skylight system addresses the five fundamental design principles described below.

1. **Lighting quality:** The main purpose of a skylight system is to provide useful light. Skylights should provide adequate, uniform illumination with minimum glare. They should produce gentle variation in brightness among adjacent surfaces while eliminating excessive contrast between them. Daylight

## Title 24 and Skylights

The 2005 California Energy Code (Title 24) requires skylights as a prescriptive measure for low-rise nonresidential buildings with spaces larger than 25,000 $ft^2$ that are directly under a roof and have a ceiling height greater than 15 $ft^2$.[8] The 2005 Code also requires dimming or multi-stepped automatic lighting controls in skylit spaces larger than 2,500 $ft^2$.[9]

from skylights should meet the same criteria for lighting quality as required for electric lighting systems. Chapter 10 of the Handbook of the Illuminating Engineering Society, 9th edition, provides a summary of electric lighting quality criteria.[7]

2. **Energy savings:** A skylight system can pay for itself through energy savings alone by providing sufficient daylight and ensuring that electric lights are switched off in response to the daylight. Automatic lighting controls with photosensors will help ensure the energy savings. The skylight system should be designed to minimize its impact on building heating and cooling loads, while maximizing daylight delivery.

3. **Dimensional adjustment:** Skylight wells connect the skylight openings in the roof's structural grid with ceiling openings in the suspended ceiling grid. The roof and ceiling grids seldom match. In addition, all roofs, including flat roofs, have some slope. This means that the plenum space between the ceiling and roof continuously changes over the span of the roof. Within the plenum, the vertical penetrations of skylight wells may conflict with the horizontal runs of other building systems. Moreover, the space below the finished ceiling may be remodeled, which may alter the ceiling height or grid position.

   Flexible well designs that can adjust up to 1 foot in any horizontal direction and 4 feet in vertical directions should resolve these conflicts. Flexible connections can also provide construction tolerances of up to 2 inches to resolve dimensional inconsistency in finished surfaces.

4. **Construction coordination:** All professions and trades involved in construction need to be kept informed of the plenum, ceiling, and roof spaces to be occupied by skylight wells. Skylight well installations should coordinate with the construction schedules of other systems. Installation information should conform to the industry's standard communication channels. Once installed, the wells need to be protected until all construction is complete.

5. **Safety and verified performance:** A skylight well system must address applicable building safety standards. This includes fire ratings, insulation locations, and seismic ratings. Architects and building owners should be able to predict the performance of these systems using verified testing protocols.

The modular throat and splay systems described in this design brief provide construction flexibility, thereby reducing conflicts with other systems. These systems allow dimensional adjustments between roof and ceiling grids. The connection between the throat and splay provides for final construction tolerances. In addition, manufacturers can prefabricate the components to be compatible with each other. Prefabricated components can be installed in phases to accommodate other jobsite schedules. A system of interconnecting, adjustable modular parts provides a great range of design options, reduces handling and installation costs, and may accelerate wider use of skylights in buildings with suspended ceilings.

## Component Requirements

Skylight system components include the unit skylight, glazing, throat, splay, and daylight control devices. Each component should satisfy minimum performance goals for illumination, energy use, fire safety, structural integrity, and assembly sequence. The basic purposes and design options for each component are described below.

**Figure 2: Skylight Components**

A cross-section showing the various components of a splayed skylight well.

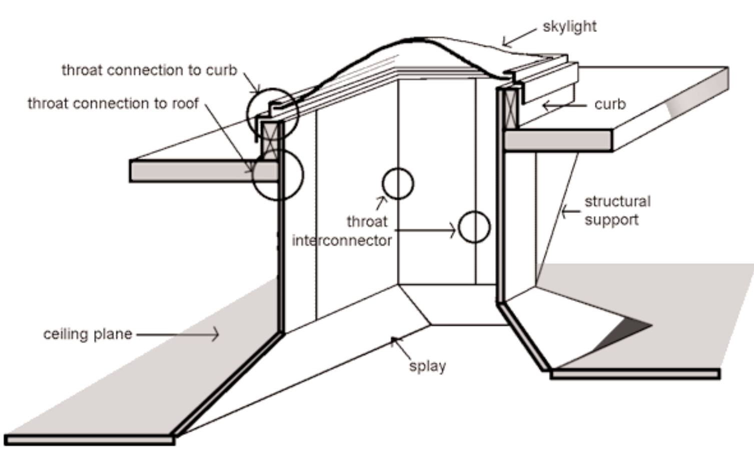


**Figure 3: Daylight As Hot Spots**

Non-diffusing skylights create intense, glaring pools of light or "hot spots." Hot spots make adjacent surfaces seem darker, raise local temperatures, and create visual discomfort.

## Unit Skylight

A skylight is a roof opening that admits light. Its primary task is to optimize transmitted daylight. It should do this without unduly increasing building heating and cooling loads. Other considerations related to the unit skylight are described below.

- **Reducing surface condensation.** A thermal break in the skylight frame will mitigate temperature differentials, reducing heat exchange and surface condensation. Surface condensation collects on the underside of cold skylight glazing when warm moist interior air rises at night. Water stains from minor condensation drips are often mistaken for leaks. The skylight frame should include a condensation gutter to contain this small amount of water.

- **Ensuring safety and durability.** The skylight opening should be protected to prevent people on the roof from falling through. Connections to the roof should be strong enough to withstand high winds and storm damage.

- **Preventing leaks.** A well-designed curb with proper flashing and sealed roof membrane is the primary defense against skylight leaks. Fabricating the curb out of the same material as the roof structure reduces movement due to thermal differentials. Leaks can be further prevented by not puncturing the frame with fasteners. The National Roofing Contractors Association has a Roofing and Waterproofing Manual for detailed installation directions.

- **Using shape to increase efficiency.** A skylight's shape affects its efficiency. Raised three-dimensional shapes such as domes and pyramids capture low-angle light in the mornings and evenings, extending the effective hours of daylighting. Flat surfaces have high reflective angles that reduce efficiency during the morning and evening hours. Photometric reports for various skylight shapes are available for use in developing daylighting designs.[10]

- **Diffusing sunlight.** To increase efficiency and avoid the creation of "hot spots," skylights need to diffuse sunlight as broadly as possible. Hot spots are intense, glaring pools of light that make surrounding surfaces look darker, raise local temperatures, and cause discomfort. Sunlight can be diffused in several ways, such as selecting appropriate glazing material, using diffusing throat materials and appropriate light well geometry, or adding secondary diffusing elements.

## Skylight Glazing

**Glazing properties.** Skylight glazing properties largely determine the efficiency of a skylight system. Materials with high visible light transmittance (VLT), low solar heat gain coefficient (SHGC), and low coefficient of conduction (U-factor) maximize light transmission while minimizing heating and cooling penalties. Increasing system efficiency with a high VLT is almost always the most important performance parameter. Reducing solar gains with a low SHGC is secondary in importance, and reducing heat loss via a low U-factor is least important. SkyCalc® is a sophisticated, Microsoft Excel®-based program that can calculate the energy balance of different skylight systems with respect to glazing material and climate zone.[11]

**Diffused vs. clear glazing.** Diffused glazing, which scatters light, is generally preferable to clear glazing. Diffused glazing can be made of pigmented glazing, composite surfaces such as fiberglass, optical surfaces such as prismatic or Fresnel lenses, or micro-optical surfaces such as holographic films. Diffusion is best measured by photometric testing, which describes the three-dimensional distribution of light through a skylight system. A simpler metric defined as "haze," which describes the scatter of light through a single glazing layer, can also serve as an approximate diffusion measure.

**Glazing materials.** Skylights typically contain either plastic or glass glazing. Plastics are lighter, can include optical surfaces, and are easy to mold into three-dimensional shapes. The three-

**Figure 4: Diffuse Daylight**

Diffusing skylights provide uniform daylight distribution, making the entire store look brighter.

dimensional shapes can incorporate gravity-based water shedding designs at the perimeter, allowing less dependence on waterproofing sealants. On the other hand, glass is more durable and stable. Low-e glass allows higher light transmission with lower heat exchange; some products offer the option of spectrally selective coatings.

## Throat

The throat's primary purpose is to convey light from the skylight to the interior space. Important considerations include the throat's structure, dimensions, and surface materials.

**Throat structure.** The throat structure consists of frames, braces, and hangers. Flexible surface connectors attach adjacent surfaces and allow for angular, vertical, and lateral adjustments. In addition to supporting the throat surface, the structure must meet structural and seismic requirements.

The throat must be flexible enough to navigate around other systems occupying the plenum and provide for construction tolerances and lateral displacements. It should also serve as a fire and smoke retardant, an acoustic buffer between the plenum and interior spaces, and an attachment surface for other systems such as fire sprinkler heads, light controls, diffusers, or electric lights. As per ASTM E84 or ANSI/UL 723, throats in the return air plenum are allowed a maximum flame spread index of 25 and a maximum smoke index of 50.

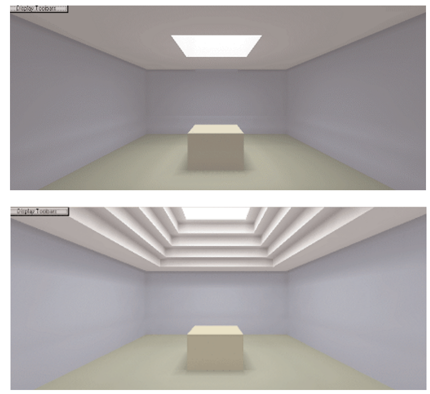
Ideally, the throat should be constructed of materials that are easy to replace. Prefabricated circular throats of adjustable metallic tubes have fewer joints and allow angular navigation around other plenum systems. However, each bend reduces light transmittance, and the circular form needs a shape transformer for rectangular connections.

**Throat dimensions.** Light transmission and well efficiency improve as the ratio of throat width to throat height increases. Short, wide throats are more efficient than long, narrow throats.

**Throat surface materials.** The throat surface should be highly reflective, thin, and lightweight, and compatible with rectangular skylights and ceiling grids. Highly reflective materials such as bright white paint and specular materials improve well efficiency. Common throat surfaces include gypsum board, sheet metal, various Mylar-coated fabrics, insulating composite boards, and acoustic tiles. Gypsum board provides seamless corners, but is heavy and inflexible, and requires extra labor. Acoustic tiles are easy and cheap to install, but don't readily accommodate plenum adjustments.

**Figure 5: Daylight Distribution With Splays**

Photometric analysis shows that a splayed skylight well provides broader light distribution and better illumination than a same sized skylight using a well with vertical walls placed in a flat ceiling.



## Splay

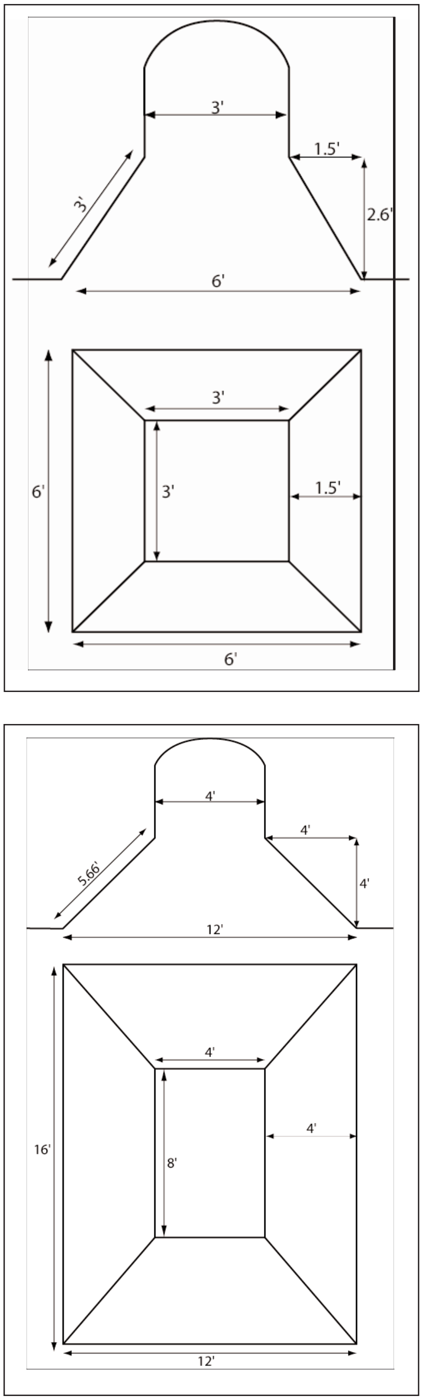
The splay—a highly recommended, but optional transitional component of the skylight system—connects the throat to the ceiling. Splayed skylight wells have several advantages. They provide wider light distribution and improved illumination uniformity (Figure 5). Thus, even though they are difficult to install and increase the total construction material, skylight systems with splays can reduce the number of skylights required, and thus reduce roof penetrations and installation costs. The modular splayed light well systems recommended in this design brief are intended to reduce these associated costs and simplify installation.

**Splay surfaces.** Splays can create an attractive coffered effect in the ceiling. And as an intermediary visual surface between the bright throat and the darker ceiling, splays improve visual comfort. Splays should have a light-colored, matte surface to better diffuse light. Specular, reflective surfaces should never be used for a splay that will be visible to occupants. Gypsum board, acoustic tiles, sheet metal, and fabrics are common materials used to surface the splay. Advantages and limitations of gypsum board and acoustic tiles are the same as those for the throat.

**Splay requirements.** Splays have the same requirements as throats for component replacement, building system penetration, fire resistance, and structural support. In addition, a

**Figure 6: Standard Skylight Dimensions**

These drawings show sections of skylight wells with varying splay dimensions.




splay should generally have a bottom dimension that is a multiple of the ceiling grid.

**Splay structure.** Photometric research shows that diffusion is optimal for splay angles between 45 to 60 degrees from the horizontal. Splayed light wells are typically larger than regular light wells and need extra planning to coordinate with other building systems.

The throat interconnector connects the throat to adjacent splay members and has a locking mechanism to prevent them from shifting. It can also provide for attachment of diffusers and other structural support systems.

## Daylight Control Devices

Common daylight control devices include diffusers, reflectors, louvers, shutters, and baffles. These devices can be added to a skylight well to modulate light by improving distribution, controlling the quantity of light entering a space, or both. They can redirect light to select surfaces, reduce glare from bright skylight surfaces, or block out all light. The devices may also reflect electric light back into the interior, reducing nighttime light pollution. Light control devices are not essential, but they are often a good option because they improve light control and are typically easy to install.

- **Diffusers.** Diffusers include prismatic acrylic sheets, Fresnel lenses, and holographic plastic films. Typically, diffusers are thin plastic sheets with optical properties that scatter light while maximizing visual transmittance. They are usually placed at the top of the splay, out of the normal line of sight. This avoids glare problems and increases the spread of light through the splay. Diffusers are not needed in a white throat combined with a diffusing skylight, but are generally necessary at the base of a specular throat. Diffusers can conceal unfinished skylight wells, do not need operable controls, are relatively lightweight and inexpensive, and to some extent reduce heat loss and surface condensation.

- **Reflectors.** Reflectors are surfaces designed to redirect daylight. They can be specular or matte; flat or three-dimensional; translucent or opaque; and static or operable. Their primary purpose is to provide directional control, but they may also diffuse light. They are usually placed inside the splay or suspended from the ceiling. Electric light can be reflected off the underside of a reflector to reduce contrast between the darker underside and brighter skylight surfaces. Reflectors can also be used as an aesthetic, architectural element. Common reflector materials include metal, plastic, wood, and fabric. Perforated or translucent materials can help balance contrast ratios.

- **Louvers and shutters.** Generally, louvers and shutters are opaque, rigid, operable blades or panels with manual or automatic controls such as timers, photosensors, or thermostats. Flexible and translucent designs are also available. Wood louvers reduce heat gain and can redirect, diffuse, or block daylight. Designs include roller blinds; mini-blinds suspended from HVAC dampers or horizontal tracks; hinged, rigid, folding, or sliding shutters; and flexible designs of plastic mesh, foil-faced Mylar, or insulating fabrics supported on wire tracks.

- **Baffles.** Baffles are stationary vertical surfaces suspended within or below the splay in a linear, circular, or rectangular formation. They prevent direct vision of bright skylight surfaces and may be opaque, translucent, rigid, or flexible. They are often made of lightweight fabric, painted sheet metal, wood, or perforated metal and are designed to form an attractive architectural element. Their geometry may constrict daylight distribution, requiring more closely spaced skylights. Baffles may need additional structural support and frequent maintenance to keep them clean.

**Figure 7: Linear Flourescent Lighting System**

This modular ceiling illustrates a well-integrated lighting system with two luminaires for each skylight well. Linear fluorescent industrial luminaires are spaced 10 ft on center on either side of the skylight wells spaced 20 ft on center.

**Figure 8: Pendant Flourescent Lighting System**

Pendant luminaires in this office allow the electric luminaires to be spaced independently of the skylight spacing.

## Skylight Well System Integration

The modular skylight well system must be carefully integrated with the electric lighting system, including lighting controls, as well as with other building systems. Important design considerations are described below.

### Electric Lights and Skylight Wells

Placing electric lights directly inside skylight wells is not recommended. The electric fixtures would not only block some of the daylight, thus reducing the skylight system efficiency, but might also require separate optical controls that are difficult to combine with skylight controls.

Electric luminaires usually have different spacing criteria than skylights. Often two or four luminaires are required per skylight to provide equivalent illumination. Spacing criteria for surface-mounted or recessed fixtures may conflict with skylight spacing. Linear pendant luminaires that span across the skylight well solve this problem by allowing more flexibility in the placement of luminaires.

### Electric Light Controls

**Photosensors.** Photosensors are electronic sensors that detect visible light. They provide a signal to the photocontrol system, which instructs the electric lights to dim or switch off in response to the presence of sufficient daylight. Photosensors should be located so that they measure light levels that are representative of the space. They should not be blocked, shaded, or easily dirtied or damaged. It is useful to mark the photosensor location in the lighting control panel so that building operators can find them in the future.

There are two basic types of photosensors: photoconductive and photodiode. Title 24 does not allow photoconductive cells for interior use.

**Photosensor control logic.** There are also two basic control logics that determine the placement of photosensors: open-loop and closed-loop:

- **Open-loop controls** use a sensor that responds only to the amount of daylight entering a space. Photosensors for open-loop controls are often placed in skylights so that they look up at the sky. In this situation, a wider sensor acceptance angle gives more accurate readings. Open-loop controls are generally easy to calibrate and work well with both switching and dimming controls.

- **Closed-loop controls** respond to the combined levels of daylight and electric light in a space. They typically look down into the space. They are called closed-loop because they control the same system that they measure (that is, the electric light level). Photosensors providing input to closed-loop systems should face walls or task surfaces with steady daylight conditions to avoid false responses to temporary reflections or shadows. To provide accurate response to daylight levels, closed-loop controls should provide both offset and sensitivity adjustments.

**Dimming vs. switching.** Photocontrols have different output signals based on how the electric lighting system responds to daylight—by dimming the lamp output or by switching between lamps or fixtures:

- **Dimming.** Fluorescent lamp dimming is done in two ways. Continuous dimming systems vary the lamp light output continuously from a threshold level (such as 5 percent or 20 percent) to full light output (100 percent). Step dimming varies lamp light output by discrete increments to pre-set levels, such as 20 percent, 50 percent, and 100 percent. Both methods require special electronic ballasts that can operate fluorescent lamps at lower light output.

Currently, dimming ballasts are more expensive and less efficient than nondimming electronic ballasts. Dimming controls may require additional wiring, depending on the type of system. Dimming ballasts often require lamps to be "seasoned" at full light output for some hours before they are dimmed. Without proper seasoning, lamps may become unstable and fail early. Lamp and ballast manufacturers provide seasoning procedure recommendations. Photocontrol systems and dimming ballasts are rapidly evolving, and many new features may be available soon.

- **Switching** can also provide multiple levels of light output from an electric lighting system while the control remains at lamp or fixture level. Uniformity of light distribution can be maintained by switching individual lamps within a fixture. For example, in a standard three-lamp fixture, light output of 0 percent, 33 percent, 66 percent, and 100 percent is achieved by switching off one, two, or three lamps. Achieving multiple levels of light output with switching is usually called step switching. According to a general rule of thumb, light level changes of less than one-third of the existing level will be below the human perception threshold. The smaller the increment, the better the system.

  Step switching does not require special ballasts, but will require some additional wiring and may use more ballasts per system. Turning lamps completely off with switching will usually extend the service life of both the lamp and ballast. Some daylighting systems with step switching have seen a doubling of lamp life, which can provide noticeable maintenance savings. Ideally, the photocontrol system should automatically rotate the lamp to be first turned off in response to increasing daylight levels so that all lamps have about the same number of hours of operation per year.

  Step switching systems are generally very efficient and cost effective, and most appropriate for spaces where building occupants continuously move around, as in retail and warehouse environments. In spaces where occupants have stationary tasks, such as offices and schools, continuous dimming will generally be better accepted. Switching systems perform very well in climates with steady sky conditions, such as Southern California, while dimming systems tend to save more energy in climates with variable sky conditions, such as Denver.

**Calibration and commissioning.** For best performance, photocontrols should be calibrated and commissioned after a space is occupied and furnishings and space dividers are in place. Once properly commissioned, photocontrols should rarely need adjustments. A recent field study of 33 photocontrol systems in top-lit commercial buildings found that all systems were functioning after five years, and overall the systems were saving 98 percent of the energy savings predicted by engineering estimates.[12]

Ideally, the building operator should be provided with a document that explains the design intent of the daylighting system and the adjustment procedure for the controls. A simple guide attached to the building's electric control panel should endure over the years.

For more information on daylighting photocontrol systems, see the publication, *Photocontrol Systems: Design Guidelines*.[13]

## Integration with Other Building Systems

Skylight systems must be integrated with other building systems such as HVAC diffusers, sprinkler heads, smoke detectors, and security cameras. Placing HVAC supply and return grilles in skylights wells is not recommended. The skylight well shape disrupts air distribution from supply ducts, return vents pick up excessive heat due to the warm air stratification in the well, and onsite coordination becomes more complicated. Some jurisdictions require sprinkler heads within skylight wells that exceed certain dimensions; a local code official should review the specifications for location, output, and spray direction.

### Coordination Checklist

- Designate an exclusion zone that will reserve the necessary volume for the light well and the splay during both design and construction.
- Make sure that the skylight exclusion zone is properly designated on the roof plan, ceiling plan, sections, and structural, mechanical, and electrical drawings.
- Incorporate skylight details and installation guidelines in the plans and specifications.
- Physically mark light well locations onsite to reserve the space during construction and to help coordinate with other building systems.

## System Design

The skylight well design is an iterative process that begins with simple assumptions and rule-of-thumb guidelines. It is then refined through more comprehensive design analysis and feedback on interaction with other building systems. Important considerations include system coordination, the design process, and photometric analysis.

### System Coordination

Establishing a coordination strategy will facilitate design and construction processes.

- **Design stage.** In the design stage, it is essential that the designer inform other project teams about the intent to use skylights. The designer should designate exclusion zones that marks the location and maximum spread of each skylight well. These should be called out in all building sections and plans for roof, reflected ceiling, structural, mechanical, electrical, and plumbing. Skylight notations should be added as a drawing layer in computer aided design (CAD) in accordance with guidelines from the American Institute of Architects.[14] Skylight wells may require detailed drawings to describe joints and connections, especially at points where two construction trades interface to make connections between parts.

  Specifications should include description of materials, geometry, installation methods, and performance criteria. Unit skylight assembly is addressed in the Construction Specification Institute's (CSI) Section 08620. Skylight wells can be addressed under Section 08620 for light wells integrated with skylights. Light wells to be installed by the ceiling installer can be included in Section 09120 for suspended ceilings. They can also be treated as a specialty feature under Section 10700 if the profession of the installer is unclear.

- **Construction stage.** In the construction stage, light well locations should be physically designated using ribbons or other markers to delineate the area occupied by the throat and splay. This should include an allowance for worker access to the well. Alternatively, scheduling throat and splay construction before installation of other building systems reserves the well space but will require protection of the well surfaces.

## Design Process

A schematic design phase precedes the design development phase. The schematic design phase establishes basic criteria and relationship for the skylight system. Several resources are available to assist with this process:

- *Advanced Lighting Guidelines: 2003 Edition* provides general guidance on design and specification for both electric and daylighting systems.[15]

- *Skylighting Guidelines* provides skylight design guidance for engineers and architects.[16]

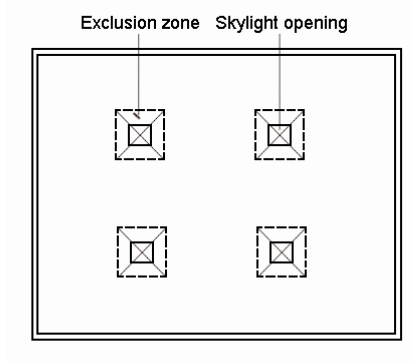
- SkyCalc®, a sophisticated Microsoft Excel® spreadsheet, estimates annual whole building energy savings and illumination levels for various skylight systems. It generates simple graphs and reports based on local climate data and building dimensions; HVAC system types and energy costs; lighting system and control strategy; skylight sizes, quantity and glazing material; and skylight well depth and surface materials.[17]

During schematic design, important considerations include skylight sizing and spacing and the effect of interior surfaces. These are described briefly below.

- **Skylight sizing and spacing.** Size and locate skylight wells to optimize uniform light distribution. Key decisions for spacing and sizing include structural spacing, ceiling height, location of other building systems, splay and throat

**Figure 9: Skylight Exclusion Zone**

This figure shows how to designate skylight exclusion zones in a CAD drawing, using a dotted area larger than the rough skylight opening. This exclusion zone provides for splay location and construction tolerances.



geometry, and cost effectiveness. Skylight dimensions will depend on roof framing. Skylight spacing should be in multiples of the framing module. A simple rule of thumb, illustrated in Figure 10, based on ceiling height helps estimate appropriate center-to-center spacing between skylights.

There will always be a trade-off between the number and size of unit skylights for a given area of skylight opening in a roof. Compared to large skylights, small skylights require more roof penetrations to light an equivalent space. However, they can provide more uniform lighting, are easier to locate within the plenum and are more appropriate for spaces with lower ceilings heights. Large skylights are more economical and have fewer roof penetrations but provide less uniformity, given the same ceiling height.

- **Room surfaces.** The amount of light reflected off of room surfaces has a very important impact on the efficiency of a daylighting system. White and light-colored walls, floors, ceilings, and furnishings are the best choice to increase the daylight utilization.

## Photometric Analysis

Photometric files describe the three-dimensional distribution of light from an electric luminaire or a skylight system. These data files are used in lighting design software to predict lighting patterns, uniformity ratios, isolux contours, and create renderings of visual lighting effects. Photometric analysis of skylight designs should be generally done for at least six lighting conditions: at noon on a clear sunny day in summer and winter, early to mid-morning in summer and winter, a fully overcast day, and nighttime.

The California Energy Commission's PIER program recently published photometric files for sixteen common skylight and well combinations under a range of sky condition and solar positions.[18]

**Figure 10: Rule of Thumb for Skylight Spacing**

A simple rule of thumb shows that spacing between skylights can increase with larger skylight openings at the finished ceiling level. The figures below show that skylights without splays need to be placed closer than splayed skylights to provide a similar uniformity of illumination.

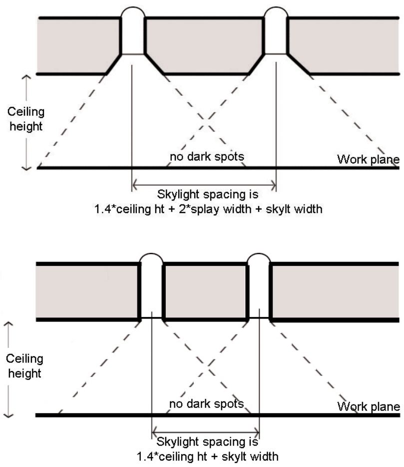
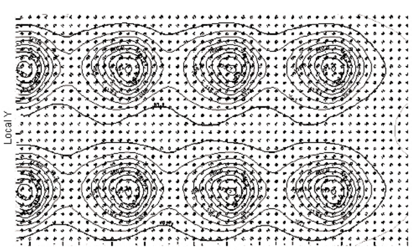



**Figure 11: Isolux Contours**

Photometric data is often used to generate reports of isolux or iso-footcandle contours for a given design. For skylights, this pattern will change every hour.



## Conceptual Examples

The four examples described below are conceptual prototypes for the design and construction of modular skylight systems. These prototypes will assist designers with creating more effective skylighting designs and are also intended to spur continued innovation in the skylight and ceiling system marketplace.

### Pivoted Threaded Rod System

In this system, a flexible throat framed by pivoted, threaded metal rods allows vertical and angular adjustments. The rod-holder connections to the roof deck pivot in three directions and allow angular adjustments. Angle-iron connectors attached to the bottom of the rods provide for splay attachments. The rods and angle irons can be installed before the duct and plumbing systems to delineate the volume reserved for the skylight well.

The throat can use a reflective, lightweight, planar material and be sheathed just before the ceiling tiles are laid to close off the plenum. The fixed splay may be prefabricated for 2 ft openings at 45- or 60-degree splay slopes.

**Figure 13: Conceptual Diagram of a Pivoting Threaded Rod (Fixed Splay) System**

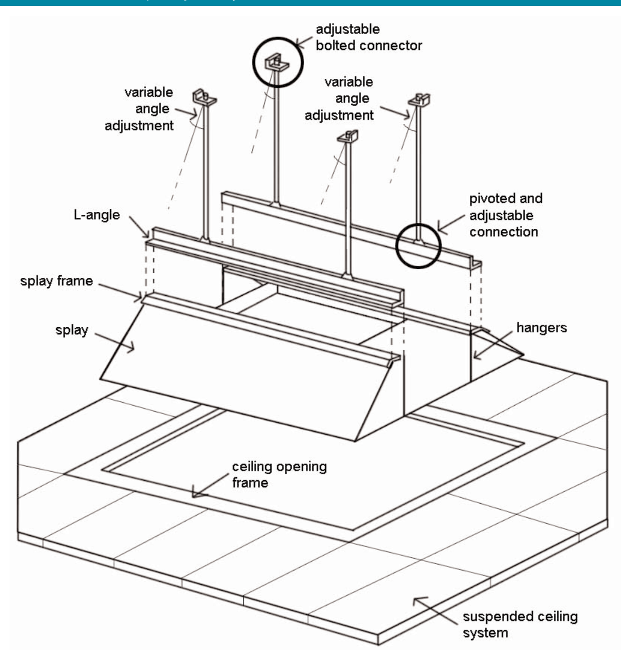
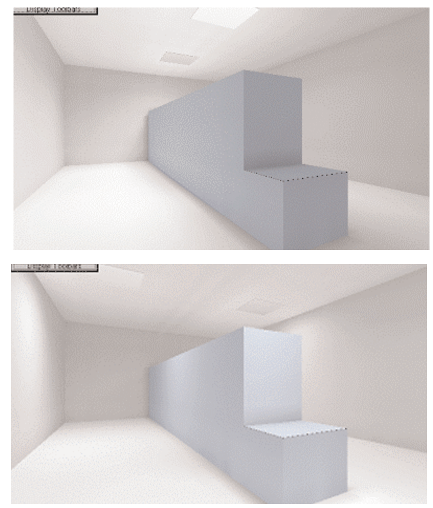



**Figure 12: Photometric Analysis**

Uniformity is not always desired. In a retail store, highlights on shelf ends and vertical surfaces may be desirable.

The images below use photometric renderings to illustrate that placing skylights directly above a shelf (top) will leave some vertical surfaces in shadow. Moving the skylights to the side (bottom) will do a better job of providing highlights on the vertical surfaces.

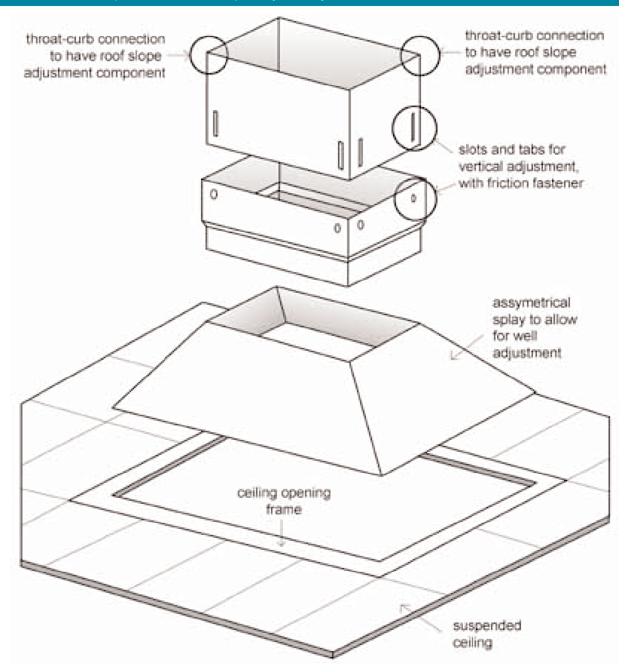


## Fixed Metal Throat System

This system uses a rigid metal throat suspended early in construction to delineate well space. It is placed vertically to provide a horizontal rectangle at the bottom to connect with the splay. A sliding mechanism between sections of the throat allows for vertical adjustments. Connectors to the roof can provide for roof slope adjustments. The metal throat can have a high reflective index and should be sturdy enough to resist abuse from other construction processes.

With this system, it's possible to use an asymmetrical splay to make horizontal adjustments to accommodate changes in the ceiling's dimensions. The splay is constructed at the same time as the ceiling. For an asymmetrical splay, ceiling runners and tiles should be cut on site. Final vertical adjustments to the sliding throat can accommodate variations in splay height.

**Figure 14: Conceptual Diagram of a Fixed Metal Throat (Adjustable Splay) System**

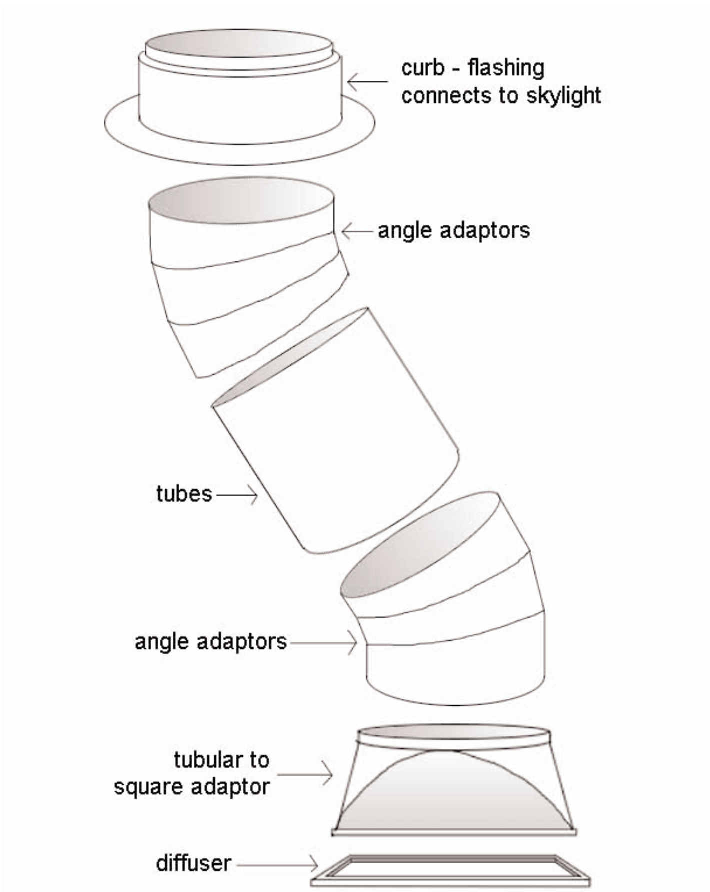


## Tubular Adjustable Throat System

This system, which uses a tubular sheet-metal throat, accommodates all angular, horizontal, and vertical offsets. Circular angle adaptors, commonly used for ductwork and plumbing, are twisted to create an appropriate angle offset. Two complementary angles are used to provide horizontal offsets and to return the shaft to the vertical. Shaft members of different lengths with latitude for slippage allow vertical adjustments. A shape adaptor is mounted on the bottom of the shaft to change the shaft's circular cross section into a square one.

Light distribution can be improved by mounting a diffuser on top of the splay. A square splay can be added at the bottom of the circular throat by using a shape adaptor or a square diffuser.

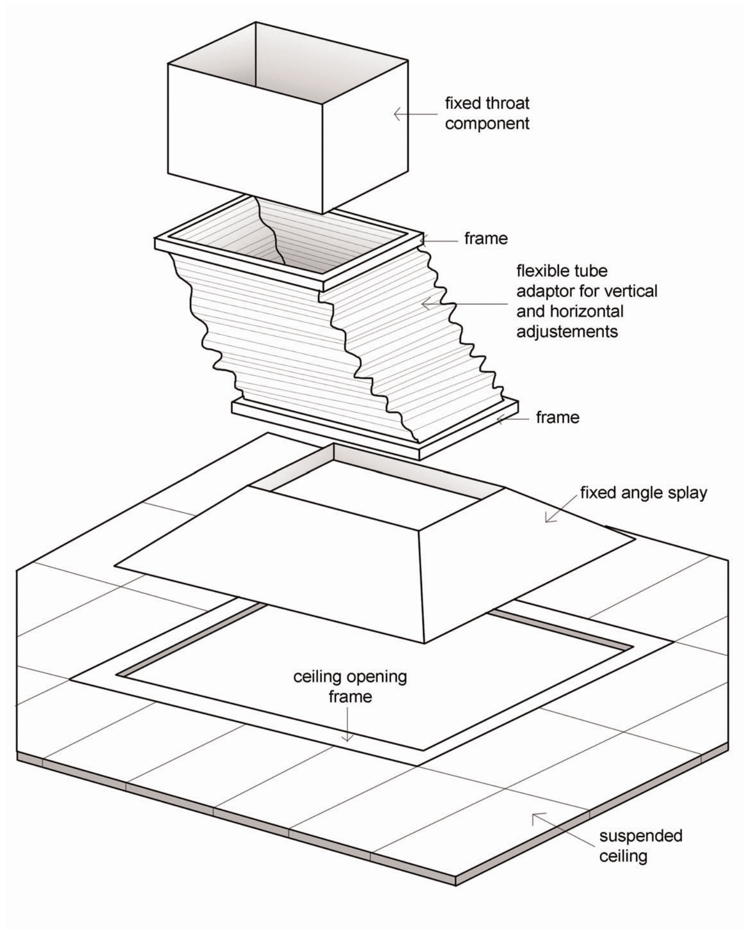
**Figure 15: Conceptual Diagram of an Adjustable Tubular Throat (Fixed Splay) System**



## Fixed-Throat, Flexible-Connector System

In this system, a flexible throat-splay connector accommodates all angular, vertical, and horizontal differences. The connector can be rectangular, circular, or amorphous in section. The fixed splay is prefabricated to different grid sizes. The system will be more efficient with a straighter throat and a smoother inner surface. The throat can be rigid with a flexible connection only between the throat and the splay, or the entire throat can be flexible using materials such as HVAC flex duct, fabric, or an elastic membrane.

**Figure 16: Conceptual Diagram of a Fixed-Throat Flexible Connector (Fixed Splay) System**



## Glossary

*Note: Italicized words are also defined within the glossary.*

**Acoustic Ceiling Tile:** Prefabricated ceiling panel made of materials such as mineral fiber with a textured finish appearance, designed to absorb sound.

**Baffle:** Type of *light control device* made of opaque or translucent surfaces to reduce glare by preventing direct view of the bright light source or surface.

**Diffuser:** Glazing material placed in light wells to diffuse or control light distribution. Example: prismatic acrylic lenses.

**Footcandle (fc):** The imperial unit of illuminance, equal to one lumen per square foot or 10.76 *lux*.

**Illuminance:** Density of the luminous flux incident on a surface, measured per unit area in *footcandles* (fc) or *lux*.

**Isolux/Iso-footcandle Contour:** Line graph of spaces with equal illuminance, expressed in *lux* or *footcandles*.

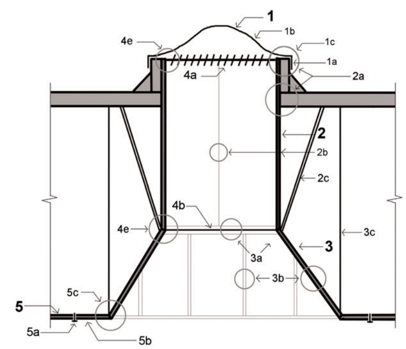
**Light Control Device:** Attachments to the light well that modulate the amount of daylight coming through it. They can be located anywhere from just under the *skylight glazing* to below the ceiling plane.

**Louver:** Type of *light control device* made of adjustable slats attached to the *throat*. Can be installed as an integral part of the skylight frame.

**Luminance:** Amount of visible light leaving a surface in a given direction. The light can be reflected, transmitted, and/or emitted, and is measured in candles per meter squared ($cd/m^2$).

**Lumen:** Luminous flux emitted within a unit solid angle by a point source having a uniform luminous intensity of one candela.

**Figure 17: Section of Skylight Well**




1. **Skylight:**
   1a. Frame
   1b. Glazing
   1c. Skylight-curb connector
2. **Throat:**
   2a. Throat attachment to structure
   2b. Throat interconnector
   2c. Throat structural support
3. **Splay:**
   3a. Splay-throat connector
   3b. Splay interconnector
   3c. Splay structural support
4. **Light control devices:**
   4a. Louvers
   4b. Interior diffusers
   4e. Device connectors
5. **Suspended ceiling:**
   5a. Runners
   5b. Ceiling tile
   5c. Ceiling-splay connector

**Lux:** The SI unit of illuminance, equal to one lumen per square meter, or xx foot candles.

**Offset:** The difference between the photosensor illuminance setpoint and the desired illuminance in the space. It is needed for closed-loop controls because a photosensor sees light from the electric light system. Without offset, the photocontrol can become erratic.

**Photocontrol:** Lighting control system that adjusts the use of electric lighting power in response to the amount of interior light or ambient daylight available.

**Photometrics:** Description of the magnitude and radial direction of light distribution from a source; used to predict the behavior of a light source in a space.

**Photometry:** The science of measuring visible light weighted according to the sensitivity of the human eye.

**Photosensor:** Electronic device that detects the presence of visible light.

**Plenum:** The space between the *suspended ceiling* and the floor or roof above it.

**Prescriptive Measure:** A nonresidential building can comply with the California Energy Code by using the prescriptive or performance method for energy calculations. The prescriptive measure is the base case condition against which building calculations by performance method are compared.

**Runners:** Cold-rolled metal channels used to support *acoustic ceiling tiles*.

**Safety Grate/Burglar Bars:** Safety devices made of metal wire (safety grate) or bars that prevent workers from falling through skylight openings.

**Sensitivity:** Slope of the dimming curve in terms of dimming percentage per *footcandle* of light received by the *photosensor*. High sensitivity means it takes little to dim light while a low sensitivity means it requires more light for the same amount of dimming.

**Skylight-Curb Connector:** Interface between the *skylight frame* and the rooftop curb. It includes accessories such as fasteners and flashing used to attach and waterproof the skylight.

**Skylight Frame:** Structural frame that supports the *skylight glazing*. It includes condensation gutters, seals, and gaskets.

**Skylight Glazing:** Glass or plastic surface used to cover skylight openings.

**Skylight-to-Floor Ratio (SFR):** Ratio of the rough or nominal skylight opening area to the daylit floor area.

**Solar Heat Gain Coefficient (SHGC):** Fraction of solar radiation admitted through a *skylight glazing* assembly. It is the sum of the transmitted solar energy and the portion of absorbed solar energy that flows inward. It measures the ability of a product to block solar heat. It is expressed as a ratio between 0 and 1, with 0 as the lowest heat transmittance.

**Splay:** Angled transitional surfaces of the light well that start at the bottom of the *throat* and connect to the ceiling.

**Splay Angle:** Angle between the *splay* and the *suspended ceiling,* or a horizontal plane.

**Splay Interconnector:** Member that joins two pieces of *splay* material. It may be a rigid member or a component that allows for adjustments.

**Splay Structural Support:** Support that provides lateral and seismic stability to the *splay*. It may be a rigid brace, hanger wire, or other type of support system.

**Splay-Throat Connector:** Member that attaches the *splay* to the *throat*. It can incorporate an adjustable assembly that allows for horizontal, vertical, or angular displacements.

**Suspended Ceiling:** Ceiling system hung from overhead structural framing.

**Throat:** Vertical surface connecting the skylight to the *splay* or *suspended ceiling*. It may be rectangular or circular in section, and uses a reflective material for its inner surfaces to maximize daylight transmission.

**Throat Attachment to Structure:** Interface between the *throat* and the building structure.

**Throat Interconnector:** Component that attaches two pieces of *throat* material together.

**Throat Structural Support:** *Throat* member that provides gravity, lateral and seismic stability. It may be a rigid brace, hanger wire or any other type of support system.

**Uniformity:** Even distribution of light levels in a space, often quantified as the ratio of maximum to minimum, or maximum to average, *illuminance* in a space.

**Unit Skylight:** Premanufactured, standardized, glazed opening in a roof that admits light.

**Visible Light Transmittance (VLT):** Fraction of visible light energy that is transmitted through a material or system.

**Well Cavity Ratio (WCR):** Measure of the geometric shape of the well, used to calculate light *well efficiency*.

**Well Efficiency/Well Factor (WE):** Ratio of the amount of visible light that leaves the skylight well to the amount of visible light that enters from the skylight.

## For More Information

**California Energy Commission Public Interest Energy Research (PIER) program**
The PIER Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. The Buildings Program Area seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods. In addition to the skylight photometric reports and other documents referenced in this brief the *Daylight and Retail Sales* [online] – Publication #500-03-082-A-5 [cited July 2004] is an excellent source of information on the impact of daylight on retail sales. Available from World Wide Web:

www.energy.ca.gov/pier/reports. Attachments 3 through 10 and 13, 14, 15. Also available at http://www.newbuildings.org.

**Ceilings & Interior Systems Construction Association (CISCA), Ceiling Systems Handbook**
Ceilings & Interior Systems Construction Association is an international trade association dedicated to providing quality education, resources and a forum for communication among its members. It publishes Interior Construction, a bi-monthly magazine, and the internationally specified *Ceilings Systems Handbook* is a good source of information on ceiling systems. Available through:

http://www.cisca.org

**KnowHow Series: Skylighting for Retail.**
DesignLights is a collaboration of community-based utility companies and regional public service organizations committed to raising commercial awareness of the benefits of efficient lighting. They have developed a series of lighting design guides called the *Knowhow Series* [online], which includes information on skylighting applications in retail structures. DesignLights: Knowhow Guides, Retail skylights [cited July 2004]. Available from World Wide Web:

www.designlights.org

**Illuminating Engineering Society of North America (IESNA)**
IESNA's objective is to communicate information on all aspects of good lighting practice to its members, the lighting community, and consumers through a variety of programs, publications, and services. A useful resource is the "Photometric Test System for Skylights and Luminaires," available in the *2002 IESNA Annual Conference Proceedings*. Available through:

http://www.iesna.org

**Sacramento Municipal Utilities District DELTA Case Study Report**

The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute is a leading university-based research center devoted to lighting. *The Delta Case Study Report* [online] (Demonstration and Evaluation of Lighting Technologies and Application) featuring Sacramento Municipal Utilities (SMUD) is a useful document available from World Wide Web [cited July 2004]:

http://www.lrc.rpi.edu

**Retail Applications Case Study: Ralph's Grocery**

Pacific Gas & Electric's (PG&E) *Retail Applications Case Study: Ralph's Grocery* [online] provides an excellent insight into real time energy savings and costs from skylights in retail stores. PG&E: Pacific Energy Center, Daylight [cited July 2004]. Serving approximately 14 million people throughout a 70,000 square-mile service area in Northern and Central California, PG&E is one of the largest combination natural gas and electric utilities in the United States. Available from World Wide Web:

http://www.pge.com

## Notes

For detailed publication information, see "For More Information."

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3 Southern California Edison (SCE). 2003. *Photocontrol System Field Study*. A report prepared by HMG for Southern California Edison. Copies available through becky.warren@sce.com.

4 American National Standards Institute (ANSI) S12.60–2002. *Acoustical Performance Criteria, Design Requirements and Guidelines for Schools*. Also available through http://www.ansi.org.

5 HMG. 2003. *Modular Skylight Wells: Design Guidelines for Skylights with Suspended Ceilings* [online]. California Energy Commission (CEC): Publication #500-03-082-A-13 [cited July 2004]. Developed for the California Energy Commission's Public Interest Energy Research (PIER) program. This detailed report on modular skylight systems is the primary source document for this design brief. Available from World Wide Web: http://www.energy.ca.gov/pier/reports, or http://www.newbuildings.org.

6 Armstrong Ceiling Systems. 2002. *Architect's Reference for Ceiling and Suspension Systems.*

7 Illuminating Engineering Society of North American (IESNA). 2001. *Lighting Handbook, Reference & Application*. Ninth Edition. Chapter 10.

8 CEC. 2003. *2005 Building Energy Efficiency Standards: Standards for Residential and Nonresidential Buildings*. Section 143c.

9 CEC. 2003. *2005 Building Energy Efficiency Standards: Standards for Residential and Nonresidential Buildings*. Section 131c.

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12 Southern California Edison (SCE). 2003. *Photocontrol Systems: Design Guidelines* prepared by HMG on behalf of SCE. An educative guide on photocontrols. Available through becky.warren@sce.com.

13 Ibid.

14 American Institute of Architects (AIA). 1997. AIA CAD Layer Guidelines.

15 New Buildings Institute, Inc. 2003. *Advanced Lighting Guidelines* [online]. White Salmon, Washington: New Buildings Institute, Inc., Lighting [cited July 2004]. Available from World Wide Web: http://www.newbuildings.org/lighting.htm or on CD-ROM from: http://www.iesna.org.

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17 See Note 11

18 See Note 10

Pacific Gas and Electric Company™

SDG&E
A Sempra Energy utility℠

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL℠ Company

Southern California Gas Company
A Sempra Energy utility℠

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This design brief was prepared for Energy Design Resources by the Heshong Mahone Group, Inc., and New Buildings Insitute.