System Design

This section lists the important information required to make decisions regarding the skylight well design. It can be used as a reference for site-built system installation or for a manufactured product.

Design is an iterative process and skylight system design is no exception. It requires constant refinement due to a more comprehensive and intensive design analysis, or it may be a result of feedback from other associated building systems. This only leads to a better-designed skylight system that will provide optimal daylighting benefits.

SYSTEMS COORDINATION

The plenum space and ceiling plane houses the different building services systems, such as the structural, HVAC, fire protection, and lighting required in a building. For the most efficient skylight well, coordination of trades and industries during the design and construction phases is necessary.

The range of spacing and dimensions for the plenum and ceiling varies according to the systems used, but they will typically be within the ranges illustrated in Figure 9 and Figure 10\(^{22}\), respectively, for the building types considered here.

![Figure 9. Typical spacing of systems within the plenum.](image)

\(^{22}\) These figures are based on case studies evaluated for the research report entitled “Integrated Design of T-bar Ceilings with Skylight Wells”. It can be accessed through the New Buildings Institute website: http://www.newbuildings.org.
Coordination Strategies During the Design Phase

The most essential thing to remember during the design phase is to inform the project team members that skylights are to be installed in the project. The early warning allows them to consider allowances in their preliminary design to account for the modular skylight well placement.

1. Designation of the Exclusion Zone

The exclusion zone is the maximum penetration area of a skylight well. It will correspond to the space being occupied by the skylight well on the roof, within the plenum space and on the ceiling. It communicates to the project designers that this zone is reserved for the light well. Any trespass into this area will require communication with the skylight designer.

2. Notation of Exclusion Zone on drawings

Skylight notations should be done on the appropriate CAD drawing layer, according to guidelines set by the American Institute of Architects (AIA).

The skylight well “exclusion zone” should be laid out properly on the following drawing sheets:

- Roof plan
- Reflected ceiling plan
- Structural plan and section
- Mechanical plan
- Electrical plan
3. Specification in Contract Documents

Skylight details and installation guidelines should be incorporated in the corresponding sections in the specifications book. It should include specifications on materials, system, geometry, and installation methods.

Unit skylight assembly is addressed in the specifications book under Section 07810 for Skylights or Section 07820 for Metal Framed Skylights. At present, no independent section addresses skylight well construction. A skylight well system supplied by one manufacturer (e.g. as a kit) can be addressed in the same section as the relevant skylights, Section 07810 or Section 07820. Custom-made skylight wells or skylight wells with components supplied by different manufacturers can have individual components specified on different sections of the document according to the material or construction methods used (e.g. ceiling systems section).

Coordination Strategies During the Construction Phase

1. Marking of Light Well Location On-Site

During construction, the use of a marker system to block-out the location of the throat and splay installation will prevent the encroachment of other building services system into the space. This space reservation can be accomplished by incorporating ribbons or similar markers in the area of the throat and splay installation, with their approximate dimensions.

2. Proper Scheduling of Construction Activities

An alternative solution is to schedule construction activities to allow throat and splay work to be completed before other building services systems. This blocks-out the space required for their installation. See Appendix for alternative scheduling solutions.
CHECKLIST FOR SYSTEMS COORDINATION

<table>
<thead>
<tr>
<th>Item</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designation of exclusion zone: Assign and include an exclusion zone of skylight opening and skylight well opening in roof and reflected ceiling plans so that other systems designers are aware of it during coordination.</td>
<td>v  Marking of light well location on site to reserve space and to help coordinate with other mechanical systems</td>
</tr>
<tr>
<td>Skylight details and installation guidelines to be incorporated in the specification books to make skylight well construction easier to install.</td>
<td>v  Marking of light well location on site to reserve space and to help coordinate with other mechanical systems</td>
</tr>
</tbody>
</table>

DESIGN PROCESS FOR SKYLIGHT WELLS

This section deals with the design process involved in skylight well design. The first part deals with the steps involved in the process. The second part describes in details the considerations to be taken in skylight well sizing, geometry and photometric analysis.

The design process for skylight well design can be broadly categorized into two phases: the schematic design phase and the design development phase. Details regarding skylight designs are further described in ‘Skylighting Guidelines’23. The diagram below indicates the steps involved in skylight design that are described in detail below. Details of each of the components mentioned in legend are described in the following sections.

Design Process Flowchart

Figure 12: Flowchart showing design process of skylight wells
Schematic Design Phase

The schematic design phase involves entering the following information in a skylight spacing and sizing Microsoft Excel™-based software program called “SkyCalc”\textsuperscript{24}, that would result in giving a skylight to floor ratio (SFR) and skylight well efficiency. This Microsoft Excel™ spreadsheet application helps building designers determine the optimum skylighting strategy that will achieve maximum lighting and HVAC energy savings for a building. SkyCalc can be used in conjunction with the ‘Skylighting Guidelines’ to help designers select the best skylighting system for a given building. Following data should be entered in the program:

- Building details like building type (office/retail/school), occupancy and dimensions of the rooms, heights of roof, ceiling and plenum.

- Design assumptions for a skylight well like opening size, well dimensions (throat and splay angle, width, length and height), plenum height, splay and throat reflectance. These light well assumptions are subject to change after the skycalc results.

- These details are then entered in the “SkyCalc” program in order to give the skylight to floor ratio (SFR) and skylight well efficiency (see section “Skylight Well Sizing and Geometry” in this chapter)

- Spacing of skylights is to be designed based on the SFR, room dimensions and skylight size (see section “Skylight Well Sizing and Geometry” in this chapter).

Design Development Phase

Once the SFR and well efficiency have been calculated for the light well, it is important to finalize the following based on the schematic design:

- Final design decisions:
  - Finalize the skylight dimensions, number and spacing and light well reflectance
  - Coordinate the skylight spacing with spacing of electric light, sprinklers, and diffusers.
  - Decide on photocontrol set points along with electric lighting layout to make maximum potential through skylighting
  - Finalize the skylight glazing type like number of layers, transparent or translucent, color, etc. The optical properties of the glazing materials influence daylighting quality and lighting savings
  - Decide on light control devices like adding louvers, reflectors or diffusers.

- If the spacing and sizing are to the satisfaction of the designer, the design can proceed to the next stage: photometric analysis. If the spacing and sizing are not to the satisfaction of the designers, go back to the first step of “assumptions of light well dimensions” and re-enter them into the “SkyCalc” software.

- After the skylight well spacing and sizing are established, a photometric analysis is recommended in order to get the magnitude and direction of light falling in the room. A guide to photometric analysis is given in the later section of this chapter.

- Reserve the lightwell space by putting the skylight opening and well dimensions on the CAD drawings of roof and reflected ceiling plan

\textsuperscript{24} SkyCalc - Skylighting Tool for California. It can be downloaded free of charge from the Energy Design resources website at the following URL: http://www.energydesignresources.com/tools.html
The final step in the design process is to specify component requirements, such as geometry, material specification and minimum performance standards, for each skylight component. These requirements are described in detail in the next chapter “Component Requirements”.

**Skylight Well Sizing and Geometry**

The layout and spacing of skylights in a roof are important determinants for the uniform light distribution characteristics of the skylighting system. 'Skycalc™' calculates the skylight to floor ratio (SFR) that helps in deciding the size and number of skylights in a given space.

There are some design aspects that drive the decision of spacing and sizing. These are:

- Roof structural spacing
- Ceiling height
- Coordination with other building systems
- Sizing: Large versus small skylights
- Splay geometry
- Throat geometry

**Roof Structural Spacing**

- Typically, low-rise commercial buildings have either a wood or steel roof deck. In both conditions, the spacing of the secondary structural members such limits the size and spacing of skylight units.
- To avoid penetrations through structural elements, skylight dimensions should be designed to be spaced in dimensions that are multiples of the secondary and tertiary roof framing module.

![Diagram](image-url)

Figure 13: Plan showing primary and secondary structural members
Ceiling Height

- Ceiling height is a major determinant of skylight spacing. Light distribution has to be even on the work plane. Work plane is typically measured at 30” above finished floor. The skylight spacing should be so that there are no dark spots on the work plane due to too much distance between skylights.

- Recommended end to end spacing between two skylights should be a dimension less than 1.4 times the ceiling height. (See Figure 14 and Figure 15.)

- Rule of thumb for calculating skylight spacing (on center) = 1.4 x ceiling ht + 2 x splay width + skylight width. (See Sample Project in next chapter for more details).

![Figure 14. Skylight spacing with splay.](image)

![Figure 15: Skylight spacing without splay.](image)

Coordination with other building systems

Ideally for skylight spacing, the skylight designer should keep in mind the spacing layout of the electric lighting with photocontrols, sprinklers, HVAC diffusers and ceiling tile dimensions in order to avoid site adjustments after construction. The photocontrol system should be designed such that it dims or switches light fixtures in areas with adequate daylight, while keeping the light fixtures in areas without daylight at the design output. Coordinating the daylighting and electric lighting also makes controlling the electric lighting systems more effective.
Skylight Sizing

- The amount of daylight in a space is a factor of the size of the skylight opening and the number of skylights. These two factors trade-off each other to provide the optimum lighting conditions according to the architectural limitations set by each project.

- For a fixed percentage of the skylit roof area, designers could select anything from a single large skylight or many small skylights distributed uniformly across the roof. For the same total area, the tradeoff is typically between large skylights far apart versus smaller skylights arranged closely.

- Listed below are the advantages and disadvantages of large versus small size skylights to assist in the decision-making process. Appendix A gives a list of possible sizes of skylights and splays, and their spacing.

![Figure 16: Large versus small skylights](image)

Table 3: Tables showing differences between small and large skylights

<table>
<thead>
<tr>
<th>Small Skylights</th>
<th>Large Skylights</th>
</tr>
</thead>
<tbody>
<tr>
<td>More costly to install.</td>
<td>Usually most economical to install - less labor and installation cost</td>
</tr>
<tr>
<td>More number of skylights required to provide an equivalent amount of daylight</td>
<td>Fewer skylights are required to provide an equivalent amount of daylight</td>
</tr>
<tr>
<td>More roof penetrations. A smaller light well is easier to redirect and manipulate within the plenum space</td>
<td>Less roof penetrations, and therefore, less potential for leakage</td>
</tr>
<tr>
<td>Applicable for high or low ceilings</td>
<td>More applicable for higher ceiling heights</td>
</tr>
<tr>
<td>More potential for light well to provide cut-off from glare. Small, closely spaced skylights provide more uniform lighting conditions and greater energy savings.</td>
<td>May produce bright conditions under the skylights and relatively dark conditions in between, resulting in uneven light distribution, reduced energy savings and possible glare problems.</td>
</tr>
</tbody>
</table>

Splay Geometry

Skylight design decisions also include presence or absence of splay in the light well design. Splay dimensions also affect skylight spacing. Wider splays would mean wider light distribution, and thus, would mean a wider center-to-center spacing required. Given below are some characteristics of skylights with and without splay. See Figure 17 and See Figure 18.
Without Splay | With Splay
--- | ---
Easier and faster installation | No so easy installation
Less cost associated since no splay | More costs due to addition of splay
Light distribution not very regular | Better and wider light distribution
More number of skylights (but smaller in size) for a given area of space | Less skylight (but larger in size) installations required to achieve an equivalent light level
Can create glare points | Reduces glare
May have brightness contrast between skylight diffuser and ceiling | Minimizes brightness contrast between skylight diffuser and ceiling
May not be as aesthetically pleasing as with splay | Aesthetically more pleasing – add to the “Architectural Experience” of space
Less coordination needed with other systems | Needs more coordination with other systems

Table 4: Comparison of skylight wells with and without splay.

Figure 17. Skylight without splay results in darker surfaces.

Figure 18: Skylight with splay has better light distribution with well-lit walls.

Splay Dimensions
Splay dimensions also affect skylight spacing. Wider splays would mean wider light distribution, and thus, would mean a wider center-to-center spacing required.
• Studies conducted\textsuperscript{25} have shown that there is little incremental improvement in skylight performance by creating splays wider than 30°. Typical angles of splay are 45°-60°.

45 deg - 60 deg. splay angle

• In designs where ceiling tiles are used for splays, the opening sizes are recommended to be multiples of 2' or 4' to correspond to ceiling tile sizes. This reduces the need for site cutting of ceiling tiles.

Throat Geometry
• The shallower a light well is relative to its width, the less light is transmitted. This needs to be kept in mind while deciding the height of the throat.
• The inside surface of the throat should ideally be a reflective material, like white paint, that would enhance the light that enters the light well.
• A throat that has angle connectors or has several offsets/ wrinkles in its design (for example a tubular throat) may affect the light quality that enters the light well. The angle connectors or adjusters should be designed keeping in mind the amount of light that enters the light well.

Well Efficiency and Well factor
• The well efficiency depends on the well cavity ratio (WCR) and reflectance of light well material. The well efficiency of the skylight well can also be calculated using the equation as per the 2005 Building Efficiency Standards\textsuperscript{26}:

\begin{equation}
\text{Well Cavity Ratio (WCR)} = \frac{2.5 \times \text{well height} \times \text{well perimeter}}{\text{Well area}}
\end{equation}

Based on the WCR and reflectance of light well, well efficiency can be calculated.

Well efficiency of a light well with splay and diffuser: \( = \text{WE}_{\text{throat}} \times \text{WE}_{\text{splay}} \times \text{Tvis} \times \text{diffuser} \)

• When the ratio of depth to width is high, well efficiency drops.
• Higher the well surface reflectance results in higher well efficiency.
• Well efficiency drops down for taller light wells.


Details on calculation of well efficiency have been shown in section “Sample Project” of chapter “Conceptual Systems”. More details on well efficiency can be found in the “skylighting Guidelines” under section “Well factor”.

**Room Specifications**

The lighting quality of the skylight system is also dependent on the room geometry, and surface reflectances of walls, floors, ceilings and furnishing. Light colored surfaces with high reflectance will help distribute brightness around the space and reduce glare potential.

**Light Control Devices**

Light controlling devices like diffusers, louvers, reflectors or clouds enhance the quality of light reaching the work surface (see section “Light Control Devices” in the next chapter).

**Photometric Analysis**

Photometric analysis can be done using electric light design software and skylight photometric files. These programs provide isolux contours (see Figure 19), light summaries and reports (Figure 21) and sometimes rendering or visualization. Lighting summaries includes average foot candles and min to max foot candles. The visualization (Figure 20) or rendering helps determine what the room looks like with a given light system. This allows one to readily identify strange patterns of light that either enhance or degrade the quality of the space. These patterns include “hot spots”, luminance patterns on walls or other surfaces.

![Figure 19. Isolux contour.](image-url)

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28 Photocontrol Systems Design Guidelines, submitted by HMG to Southern California Edison- report in progress
Figure 20. Detailed skylight visualization using Radiance simulation software\textsuperscript{29}.

Figure 21. Photometric report for a skylight.

Daylighting Design Qualities

1. Luminance

Luminance is the amount of visible light leaving a point on a surface in a given direction. Some guidelines to remember when evaluating luminance in building applications are:

- Proper placements of skylight can highlight products in retail applications.
- Placement of skylights in classroom should not highlight surfaces other than the teaching surface.

To illustrate, we use the case of a retail store. Skylight placements in a daylit space need to provide the appropriate luminances on the surfaces. In the photometric analysis shown in Figure 22, skylights are used to highlight certain products on the shelves. The two sets of visualization results below show the effects of different skylight locations in providing proper light levels on the display shelves. Option 1 shows 2 skylights placed in a linear arrangement. Option 2 shows 3 skylights placed in a staggered arrangement that gives a better distribution of light.

**Option 1**

**Option 2**

![Figure 22. Using photometrics to evaluate appropriate luminance levels.](image)

### 2. Uniformity

Uniformity refers to the even distribution of light levels in a space and is a factor of daylight diffusion and skylight spacing.

Guidelines to remember when evaluating daylighting design for uniformity in spaces are:

- In office, big-box retail stores, and classroom applications where ambient lighting is required, a ratio of 3:1 or less can be achieved\(^3\).
- Increasing skylights will improve uniformity.
- Uniformity can also be affected by scale. A non-uniform light distribution can be acceptable if the distance between the brighter and darker areas is of a certain dimension that it is beyond an occupant’s angle of vision.
- Uniformity can be achieved by supplementing daylighting with electric lighting.

In the photometric analysis shown in Figure 23 the lighting effects of skylights in an open space is analyzed. The results showed that by increasing the number of skylights, a more uniform light level is achieved.

![Figure 23. Evaluation of uniformity using photometric analysis.](image1)

Uniformity can also be achieved by using electric lighting to supplement daylighting. The photometric analyses in Figure 24 shows the difference in lighting effects due to the use of electric lighting. One important fact to keep in mind is that the use of electric lighting will reduce the energy savings potential of daylighting with skylights.

![Figure 24. Photometric analysis of uniformity due to skylights and electric lights.](image2)

Using photometrics to refine skylight design will result in a more effective daylighting design solution. It requires a higher level of analysis, but can make the difference between an ineffective project and a successful one.

### CHECKLIST FOR SKYLIGHT WELL DESIGN

| Building and light well characteristics assumptions to be defined | Decision making: finalize building and light well dimensions, skylight spacing, sizing, light well characteristics. |
| Use Skycalc or similar software based on building and light well assumptions to get SFR | Coordinate with other building systems |
| Calculate Well efficiency of light well: Well efficiency = WE_{throat} x WE_{splay} x \text{Tvis} x \text{diffuser} | A photometric analysis for uniformity and magnitude of light from skylights to be performed. |
| Spacing of skylights (on center)= <1.4 x ceiling ht + 2 x splay width + skylight width (keeping in mind lighting, sprinkler, HVAC spacing) | Reserve space: Indicate skylight opening and well dimensions in roof & ceiling plans |