Skylight Selection and Daylighting Design Guide including Unit Skylights, Tubular Daylight Devices (TDD) and Sloped Glazing
# TABLE OF CONTENTS

0.0 INTRODUCTION ..................................................................................................................................... 1
1.0 SCOPE .................................................................................................................................................... 1
2.0 REFERENCED DOCUMENTS ............................................................................................................... 1
3.0 DEFINITIONS ......................................................................................................................................... 3
4.0 THE ROLE OF SKYLIGHTS ................................................................................................................... 4
5.0 PRODUCTS FOR CONSIDERATION .................................................................................................... 5
6.0 DESIGN CONSIDERATIONS AND SELECTION CRITERIA ............................................................... 6
7.0 GLAZING OPTIONS ............................................................................................................................. 18
8.0 DAYLIGHTING SOLUTION DEVELOPMENT ...................................................................................... 21
9.0 CODES & REGULATORY CONSIDERATIONS ................................................................................... 31
10.0 SKYLIGHT FALL PROTECTION ........................................................................................................ 41
11.0 SKYLIGHT SELECTION GUIDE ....................................................................................................... 43
12.0 EMERGING DAYLIGHTING / GLAZING TECHNOLOGIES .............................................................. 47
APPENDIX A: SIMULATION AND DESIGN TOOLS .................................................................................. 48
APPENDIX B: DAYLIGHTING DESIGN PRODUCT SELECTION BY EXAMPLE CASE STUDIES ........ 50
0.0 INTRODUCTION

This document is part of a suite of documents generated to educate interested parties in the proper design, selection, specification and use of skylights. The reader is encouraged to explore all the skylight publications for a complete understanding of the properties associated with skylights. Below Following is a list of all current AAMA skylight documents.

- AAMA PSSG-196, Selection and Application Guide for Plastic Glazed Skylights and Sloped Glazing
- AAMA 1607-14, Voluntary Installation Guidelines for Unit Skylights
- TIR-A7-11-, Sloped Glazing Guidelines
- AAMA SSGPG-1-17, Structural Silicone Glazing (SSG) Design Guidelines
- AAMA GDSG-1-87, Glass Design for Sloped Glazing and Skylights

1.0 SCOPE

This document is intended to assist the user in understanding the nature of fenestration products and systems which provide features and performance characteristics necessary for effective use on sloped or “horizontal” building envelope surfaces. It is further intended that the user will gain a fuller appreciation of the ability of such products and systems to be valuable elements of high performance buildings, learn more about where their use is appropriate, and obtain useful information that enables intelligent decision-making about the optimal way to connect building occupants with their environment. Figures 1 and S2 illustrate the use of a large monumental skylight solutions to provide both effective daylight in addition to playing pivotal roles in defining the architecture of the spaces.

A review of the Window and Door Selection Guide (AAMA WSG-11) affords the user extensive information about how windows and doors are designed and selected, but it does not address daylighting considerations in sufficient breadth or depth. This document attempts to fill this gap, as indicated by the inclusion of “Daylighting Design” in the title. Users of the WSG are strongly advised to consult this document for daylighting considerations when their task includes selection of any products and systems for the purpose of achieving optimal daylighting design.

2.0 REFERENCED MATERIALS
2.1 References to the standards listed shall be to the edition indicated. Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

2.2 American Architectural Manufacturers Association (AAMA)

AAMA 1607-14, Voluntary Installation Guidelines for Unit Skylights

AAMA AG-13, AAMA Glossary 2013

AAMA GDSG-1-19, Glass Design for Sloped Glazing and Skylights

AAMA PSSG-16, Selection and Application Guide for Plastic Glazed Skylights and Sloped Glazing

AAMA Skylight Page, https://www.aamanet.org/skylight


AAMA SSGPG-1-17, Structural Silicone Glazing (SSG) Design Guidelines

AAMA TIR-A1-15, Sound Control for Fenestration Products

AAMA WSG-11, Window and Door Selection Guide

TIR A7-11, Sloped Glazing Guidelines

AAMA WSG-11, Window and Door Selection Guide

2.3 American Society of Civil Engineers (ASCE)

ASCE/SEI 7-16, Minimum Design Loads and Associated Criteria for Buildings and Other Structures

2.4 ASTM International (ASTM)

ASTM D635-187, Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position

ASTM D1003-13, Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics

ASTM D1929-16, Standard Test Method for Determining Ignition Temperature of Plastics

ASTM D2843-16, Standard Test Method for Density of Smoke from the Burning or Decomposition of Plastics


ASTM E108-17, Standard Test Methods for Fire Tests of Roof Coverings

ASTM E413-16, Classification for Rating Sound Insulation

ASTM E1332-16, Standard Classification for Rating Outdoor-Indoor Sound Attenuation

2.5 Illuminating Engineering Society (IES)

IES RP-5-13, Recommended Practice for Daylighting Buildings

IES HB-10-11, The Lighting Handbook, 10th Edition

2.6 International Code Council (ICC)

International Building Code (IBC) 2018

International Residential Code (IRC) 2018
2.7 Other Referenced Material

*A Literature Review of the Effects of Natural Light on Building Occupants*: L. Edwards and P. Torcellini, National Renewal Energy Laboratory, July 2002


*Daylight Dividends Case Study, Smith Middle School, Chapel Hill, NC*: Rensselaer Polytechnic Institute, 2004

*Daylight and Retail Sales*: California Energy Commission, October 2003


*Daylighting in Schools*: Heschong Mahone Group, August 20, 1999

*The Impact of Light on Outcomes in Healthcare Settings*: Anjali Joseph, Ph.D., The Center for Health Design, August 2006

National Institute of Building Sciences, [www.nibs.org](http://www.nibs.org)


*The Benefits of Daylight through Windows*: Peter Boyce, Claudia Hunter, and Owen Howlett, Lighting Research Center, Rensselaer Polytechnic Institute, September 12, 2003

UL 790, Standard for Standard Test Methods for Fire Tests of Roof Coverings

2.8 Referenced Software


EnergyPlus [replacing DOE 2.2 – whole building simulation engine]


For more building energy and lighting software, see [https://buildingenergysoftwaretools.com/](https://buildingenergysoftwaretools.com/)

3.0 DEFINITIONS

3.1 Please refer to the most current AAMA Glossary for all definitions and see Sections 6.2 and 9.2 for definitions that only apply to this document.
4.0 THE ROLE OF SKYLIGHTS

Skylights have always been desirable elements of good building design. The dramatic and pleasing appearance of designs which creatively utilize skylights have often been exploited by architects. The positive psychological effects of admitting a portion of the outdoor ambience to the cloistered recesses of buildings, especially in congested urban and suburban settings, are well known. The beneficial qualities of daylighting as utilized where possible for indoor task lighting are also recognized. Skylights are common components in award-winning designs which achieve these effects in particularly pleasing ways. Architects and builders, therefore, have historically not required much urging to include skylights - indeed, large glazed areas of all types - in their creative concepts for human living and working environments.

However, recent developments in the strive for net-zero buildings and reduction of the earth’s natural resources have forced architects and builders to evaluate almost all building components from the standpoint of energy conservation and renewable materials.

Skylights offer quantifiable advantages for the energy-conscious architect, building owner/manager, etc. Well thought-out designs can take maximum advantage of passive solar heat gain through skylights in winter to supplement fuel-consuming heating systems. Year-round, a carefully planned skylight installation will supply natural daylighting which can cut the need for electric lighting. For air-conditioned buildings, this provides the added advantage of reduced lighting heat load on cooling systems in summer. These benefits can be fine-tuned through creative and competent designing to offset the traditionally
considered losses of thermal transmittance and air infiltration, and to provide net positive energy benefits that make skylights more cost effective than any other solar device.

A prime example is in the area of fenestration. Overtly simplistic analyses which consider only the thermal transmission of the building envelope have led the hasty to conclude that glazed areas of all types must be reduced to optimize energy efficiency. However, recent studies, which quantify the beneficial effects of the "passive" utilization of solar energy, arrive at a different conclusion. These studies have demonstrated that fenestration components have an important role in the energy balance equation. The effects of ventilation, daylighting and beneficial solar heat gain all have a demonstrable role in offsetting the use of energy by mechanical and electric systems.

There was a great deal of confusion surrounding efforts to extend inherently prescriptive building standards and codes to include energy use parameters. Wasteful heat gain and loss were attacked through the setting of prescriptive U-value ratings, proposals for limiting total glaz ed area in buildings, and other direct actions. Contradictions soon appeared when prescriptive recommendations were examined for an overall "systems" point of view. For example, early conservation recommendations advocated increased use of natural daylighting (to offset the need for as much electric lighting), while advocating reduction or elimination of glazed areas (to cut thermal conductance losses). In addition, much of the construction industry has questioned the advisability of limiting design alternatives through such prescription, when improvement of the total energy performance of buildings is the goal.

Consequently, recent years have seen a growing recognition of the synergy of all building components in the energy equation. More and more, designers are turning to the concept of energy balance, wherein a building and all its components are viewed as a total, interrelated system which must be optimized. Possibilities for beneficial utilization of solar energy, which do not rely upon expensive collection, concentration and redistribution — but upon utilization in its natural form — are being rediscovered.

With green and sustainability developments as well as building and energy codes driving for net zero buildings, the use of free natural daylight can be a major contributor to the reduction of a buildings carbon footprint. It should be noted that energy codes are now requiring skylights along with lighting controls in certain types of buildings to reduce energy consumption.

While not intended as a textbook, it is the purpose of this publication to identify the major design parameters and to provide general architectural design guidelines for the effective and energy-efficient use of skylights as well as explore the effects of daylight on the well-being of the human mind and body.

Proper daylighting design can provide multiple benefits to the building occupants. Daylighting can reduce the lighting energy, reduce heating and cooling energy, and provide a multitude of health benefits to the occupants of the building as well as productivity for building and business owners.

5.0 PRODUCTS FOR CONSIDERATION

5.1 Windows and Doors

This selection guide includes a range of skylight products designed for overhead glazing. For guidance on window product selection and other forms of vertical fenestration, please refer to AAMA WSG-44.

5.2 Skylights

Products in this selection guide include unit skylights, sloped glazing, tubular daylighting devices, roof windows and light-transmitting smoke vents. The following are the Construction Specifiers Institute (CSI) specification numbers and titles
associated with these products. For full definitions of these product types, refer to the AAMA Skylight Glossary at https://aamanet.org/pages/skylight-glossary-of-terms.

5.3 CSI Specification Format

- **07 72 30 - Light Transmitting Smoke Vent**
  At a glance it is similar in appearance and function of a unit skylight with an incorporated design to fully open (or drop out) to allow heat and smoke evacuation in the event of a fire
- **08 60 00 - Roof Window**
  Similar to a unit skylight yet designed to be installed within reach of the occupant with similar style and function to that of a window
- **08 62 00 - Unit Skylights**
  Fixed or operable (venting) skylights with just one glazed opening, no rafters or mullions
- **08 62 70 - Tubular Daylighting Device (TDD)**
  Typically includes a self-flashing round dome skylight with an integral light reflecting conduit to an internal diffuser
- **08 63 00 - Metal Frame Skylights**
  Multi-lite skylights with rafters or mullions, which includes configurations such as pyramids, barrel vaults, ridges, hip ridges and so forth. Despite the title, not limited to metal framed products.

6.0 DESIGN CONSIDERATIONS AND SELECTION CRITERIA

Skylights can be used to provide significant energy savings and enhance the aesthetic appearance of a building as well as the appeal of its interior spaces, flooding them with the warmth and illumination of natural daylight. This section will provide the guidance to best leverage skylights’ advantages by giving sound technical information on the various aspects and considerations that need to be taken into account when applying skylights as an enhancement to a building design. It should be emphasized that the chosen skylight manufacturer should be consulted, in combination with this document, and as the primary resource for answering your questions and for providing technical assistance regarding their products.

6.1 Defining the Occupancy/Intended Use

When designing a daylighting solution, determining and fully understanding a space’s occupancy schedule and its intended use are critical factors that determine whether daylighting with skylights for interior illumination is an appropriate solution for the space, and will ultimately guide the selection and placement of skylights in order to provide the best daylighting design. Relative to the space’s occupancy schedule, it is important to remember that the daylight resource will vary depending upon time of day, season of the year, and weather conditions. These three time-dependent factors affect daylight availability and the ability of skylights and toplighting systems to harvest the daylight resource and displace the need for electric lighting equipment during daylight hours. In order to maximize the benefits of daylighting as a source for interior illumination, the best candidates are those spaces that are used primarily during daylighting hours, meaning that the expense of adding quality daylighting fenestration elements to a space will ensure maximum energy and qualitative benefits.

The space’s intended use must also be considered since the types of visual tasks being performed within the space will drive the design of the combined daylighting and electric-lighting solution in order to provide the appropriate visual environment. These factors drive the daylighting design’s selection and placement of skylights and toplighting systems, which determines the resulting quality, consistency, and quantity of daytime illumination, whether provided solely through daylight, or an artful integration of daylighting elements and electric lighting equipment using daylight-harvesting electric lighting control systems. Skylights can also provide an opportunity for natural ventilation as demonstrated in Figure S3.
6.2 Skylight Performance Attributes

6.2.1 Visible Transmittance (VT): The amount of the available visible light spectrum delivered into the building by the skylight. Perhaps the number one reason for adding skylights to a project, VT is typically expressed as a percentage of the light which falls on the skylight that passes through it. Be aware that the maximum amount of VT is not always the best option for a project. Know what the light level requirements are for the occupancy of the space. Recommended light levels for various buildings and tasks can be found in the Illuminating Engineering Society (IES) handbook. A few more common ones can be found in this document (Table 7). Some materials that diffuse light can seem brighter because they spread the light over a larger area. Large skylights which can cover a large portion of the daylight zone can require less visible transmission to satisfy the occupants. Also consider that skylights can deliver more intense light, bring it deeper into a building space, and do it all for longer periods of the day compared to vertical fenestration due to the skylight’s exposure to the sky. Another consideration is that more visible light also means more solar heat, which can be beneficial or detrimental depending on the geographical location of the project, and the orientation of the skylight, and the accessories chosen to limit the detrimental heat as well as reduce glare.

6.2.2 Solar Heat Gain Coefficient (SHGC): Essentially the amount of available solar heat that enters the building, expressed as a unitless number representing the percentage of solar heat striking the assembly that enters the building. The lower the number, the more heat it blocks from being transmitted. Although all portions of the full spectrum of light contain heat, the infrared portion is that portion which carries the most. Glazing products continue to advance with coatings and products which can block infrared wavelengths and therefore control the amount of heat being delivered by the skylight product. Again, based on the climate zone of the project, heat gain can be a benefit to the heating system of a building.

6.2.3 U-factor: A rating that reflects the rate of heat flow through a material or an assembly of different materials. All homogeneous materials have a U-factor or R-value. (The R-value is simply the reciprocal of the U-factor.) Since heat transfer always occurs from a region of high temperature to a region of lower temperature, this factor is especially important in climate zones which are dominated by colder temperatures. Higher heat flow out of the building can increase the load on the building heating equipment. Again, in predominately warm climate zones, the U-factor is not as important to the energy performance of the building.
6.2.4 Haze Factor: This term is used to describe the amount of the light that passes through a material that is "scattered" or "diffused". Diffused light tends to provide a more even lighting effect over a larger area than a product that does not diffuse light such as clear or tinted glass or plastic. Diffusing products can also help control glare by reducing light to dark contrast. As of this publication, building codes require a 90% haze value on skylight glazing in order to increase the area of usage from 3% to 5% of the roof area. Local codes should be consulted for additional requirements for increased skylight usage.

6.2.5 Performance Grade: This is a level of structural performance assigned to unit skylights. It indicates the design pressure for which the skylight has been tested and certified to achieve. An example would be a performance grade of 30 which would indicate that this product has a structural resistance of 30 PSF positive or negative. The design pressure rating can often be higher in one direction versus the other for a skylight.

6.2.6 Glare: A primary objective in the design of any lighting system (daylight or electric light) is to provide the illuminance levels required for visual performance at the task, using a system that enhances visual comfort in the work environment.

Both ceiling-mounted electric lights and skylights have the potential to cause visual discomfort. The techniques for avoiding this are the same. There are two basic areas of concern:

1. Avoiding excessively bright sources within the occupant’s field of view, and
2. Avoiding reflections from bright sources on the work surface.

Bright light sources in the field of view can cause discomfort glare. This is the result of a large brightness contrast between the light source and the surrounding field of view. The eye has difficulty accommodating the contrast differences. The basic solution, for both electric lighting and skylighting, is to increase the brightness of the surroundings and to decrease the apparent brightness of the source by dimming, blocking or diffusing the light. With skylights, this is accomplished with lower transmittance glazings, light-colored walls, diffusing shades, bright surface reflectance, and the other design techniques that achieve better light distribution.

6.2.7 Sound Transmittance - Sound transmission can be an important factor to consider when designing for exterior glazing exposed to the most common sources of exterior environmental noise: aircraft, highway traffic and rail transportation lines. This, coupled with greater building owner/user expectations for noise control and wider use of lightweight, lower-cost building materials, has heightened the importance of designing buildings that effectively address exterior environmental noise considerations and how it impacts the occupants and the functionality of the interior space. There is no national code governing sound control. However, it is advisable to check the local municipality for any sound transmission restrictions on exterior glazing, which often originate in High Performance Building standards and “green” codes.

6.2.7.1 Sound Transmission Loss is the ability of a material or system to block or attenuate the transmission of sound from one area to another. Sound transmission loss (TL) can be measured from the outside to the inside of a building or it can be measured from a room to an adjacent room inside a building. There are two sound transmission performance measurements. It is important to understand the difference between them and their proper application. They are sound transmission class (STC) and outdoor-indoor transmission class (OITC) and it is important to understand why one is preferred over the other when it comes to specifications.

6.2.7.2 Outdoor-Indoor Transmission Class (OITC) Rating

- Calculated in accordance with ASTM E1332
- Created to provide a single number rating for exterior walls and facade elements (windows & doors) subjected to transportation noises.
- Calculated over frequency range of 80 to 4000 hertz
- Applies to products and assemblies tested in the laboratory.
- Apparent Outdoor-Indoor Transmission Class (AOITC) rating applies to products and assemblies tested in the field.

6.2.7.3 Sound Transmission Class (STC) Rating
• Calculated in accordance with ASTM E413
• Created to provide a single number rating for interior building partitions that are subjected to noises from speech, television, radio and office equipment.
• Calculated over the frequency range of 125 to 4000 hertz.
• Applies to products and assemblies tested in the laboratory.
• Apparent Sound Transmission Class (ASTC) rating applies to wall and floor/ceiling assemblies tested in the field.

NOTE 1: ASTM E413 specifically states that the STC calculation should not be used to evaluate partitions exposed to machinery, industrial and transportation noise such as motor vehicles, aircraft and trains.

6.2.7.4 Design guidelines for architects relative to exterior environment, interior function, application and acoustic performance

When designing a building for acoustical performance the architect or consultant should always consider the existing noise sources and the expectations of the occupants inside the building. A site assessment of the exterior noise levels should be conducted if the proposed building lies:

- Within 300 m (1000 ft) of a fire station, fuel dispensing facility, factory, industrial or manufacturing zone or facilities, commercial storage facility, or sports arena or stadium.
- Within 150 m (500 ft) of a roadway containing 4 or more traffic lanes.
- Within the published DNL 65 dBA noise contour associated with a commercial airport, or where such information is lacking, within 8 km (5 miles) of a commercial airport.
- Within 900 m (3,000 ft) of an elevated railway.

Federal regulations, such as HUD, FAA and the EPA require a maximum interior sound pressure level of 45 dBA. Some interior spaces (such as classrooms, hospital rooms, libraries, etc.) could require quieter environments.

6.2.7.5 Code and local requirements

New York City Acoustical Requirements

Most regulations (FAA, EPA (Table 2), HUD (Table 3), etc.) specify a maximum interior noise level of 45 dBA. For example, if the exterior noise level is 80 dBA and you need a maximum interior noise level of 45 dBA, then the building envelope needs to provide a minimum noise reduction of 35 dBA. New York City requires that all new or renovated buildings in “E” designated areas meet certain dBA noise reduction or OITC rating requirements. The new (2014) window/wall attenuation (dBA) or OITC rating requirements are usually 28, 31, 33, and 35 but they can increase in 1 dB increments (Table 1).

<table>
<thead>
<tr>
<th>Noise level with proposed project</th>
<th>Marginally Unacceptable</th>
<th>Clearly Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>70≤L_{10}≤73</td>
<td>(I) 28 dB(A)</td>
<td></td>
</tr>
<tr>
<td>73≤L_{10}≤76</td>
<td>(II) 31 dB(A)</td>
<td></td>
</tr>
<tr>
<td>76≤L_{10}≤78</td>
<td>(III) 33 dB(A)</td>
<td></td>
</tr>
<tr>
<td>78≤L_{10}≤80</td>
<td>(IV) 35 dB(A)</td>
<td></td>
</tr>
<tr>
<td>80≤L_{10}</td>
<td>36 + (L_{10} - 80) dB(A)</td>
<td></td>
</tr>
</tbody>
</table>

Note: A The above composite window-wall attenuation values are for residential dwellings and community facility development. Commercial office spaces and meeting rooms would be 5 dB(A) less in each category. All of the above categories require a closed window situation and hence an alternate means of ventilation.

* Required attenuation values increase by 1 dB(A) increments for L_{10} values greater than 80 dBA.

Source: New York City Department of Environmental Protections

TABLE 1: Table 19-3 from City Environmental Quality Review Technical Manual, 2014
TABLE 2: EPA Noise Guidelines from Section 6.2, AAMA TIR A1-15

<table>
<thead>
<tr>
<th>Effect</th>
<th>Sound Pressure Level</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing</td>
<td>≤ 70 dBA</td>
<td>All areas (at the ear)</td>
</tr>
<tr>
<td>Outdoor Activity</td>
<td>≤ 55 dB</td>
<td>Outdoors in residential areas and farms and other areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.</td>
</tr>
<tr>
<td></td>
<td>≤ 55 dBA</td>
<td>Outdoor areas where people spend limited amounts of time such as school yards, playgrounds, etc.</td>
</tr>
<tr>
<td>Indoor Activity</td>
<td>≤ 45 dB</td>
<td>Indoor residential areas</td>
</tr>
<tr>
<td></td>
<td>≤ 45 dBA</td>
<td>Other indoor areas with human activities such as schools, etc.</td>
</tr>
</tbody>
</table>

TABLE 3: HUD Requirements

ANSI S12.60 Standard Acoustical Performance Criteria, Design Requirements, & Guidelines for Schools

- ANSI S12.60 standard provides guidelines for noise in school classrooms. This noise can be generated by adjacent classrooms, music rooms, mechanical rooms, HVAC systems and/or outdoor noise sources.
- Areas of review in the commissioning process should include interior walls, doors and/or floor/ceiling assemblies, facades and/or facade elements (door, windows, unit ventilators, etc.), roof systems, skylights and heating, air conditioning and/or plumbing noise.
- Utilized in the LEED for Schools Rating System
Table 4 is a land usage chart that shows what types of buildings can be built in areas around airports based on the exterior noise levels.

### Table 1 - Land Use Compatibility with Yearly Day-Night Average Sound Levels

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Yearly day-night average sound level (Ldn) in decibels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Below 65</td>
</tr>
<tr>
<td>Residential, other than mobile homes and transient lodgings</td>
<td>Y</td>
</tr>
<tr>
<td>Mobile home parks</td>
<td>Y</td>
</tr>
<tr>
<td>Transient lodgings</td>
<td>Y</td>
</tr>
<tr>
<td>Public Use</td>
<td></td>
</tr>
<tr>
<td>Schools</td>
<td>Y</td>
</tr>
<tr>
<td>Hospitals and nursing homes</td>
<td>Y</td>
</tr>
<tr>
<td>Churches, auditoriums and concert halls</td>
<td>Y</td>
</tr>
<tr>
<td>Governmental services</td>
<td>Y</td>
</tr>
<tr>
<td>Transportation</td>
<td>Y</td>
</tr>
<tr>
<td>Parking</td>
<td>Y</td>
</tr>
<tr>
<td>Commercial Use</td>
<td></td>
</tr>
<tr>
<td>Offices, business and professional</td>
<td>Y</td>
</tr>
<tr>
<td>Wholesale and retail - building materials, hardware, and farm equipment</td>
<td>Y</td>
</tr>
<tr>
<td>Retail trade - general</td>
<td>Y</td>
</tr>
<tr>
<td>Utilities</td>
<td>Y</td>
</tr>
<tr>
<td>Communication</td>
<td>Y</td>
</tr>
<tr>
<td>Manufacturing and Production</td>
<td></td>
</tr>
<tr>
<td>Manufacturing, general</td>
<td>Y</td>
</tr>
<tr>
<td>Photographic and optical</td>
<td>Y</td>
</tr>
<tr>
<td>Agriculture (except livestock) and forestry</td>
<td>Y</td>
</tr>
<tr>
<td>Livestock farming and breeding</td>
<td>Y</td>
</tr>
<tr>
<td>Mining and fishing, resource production and extraction</td>
<td>Y</td>
</tr>
<tr>
<td>Recreational</td>
<td></td>
</tr>
<tr>
<td>Outdoor sports arenas &amp; spectator sports</td>
<td>Y</td>
</tr>
<tr>
<td>Outdoor Music shells, amphitheaters</td>
<td>Y</td>
</tr>
<tr>
<td>Nature exhibits and zoos</td>
<td>Y</td>
</tr>
<tr>
<td>Amusements, parks, resorts and camps</td>
<td>Y</td>
</tr>
<tr>
<td>Golf courses, riding stables and water</td>
<td>Y</td>
</tr>
<tr>
<td>recreation</td>
<td></td>
</tr>
</tbody>
</table>

**Key to Table 1**

Y (Yes) = Land use and related structures compatible without restrictions.

N (No) = Land use and related structures not compatible and should be prohibited.

(1) Where the community determines that residential or school uses must be allowed, measures to achieve an NLR of at least 25 dB must be incorporated into the building codes and be considered in individual approvals. Normal residential construction can be expected to provide an NLR of 20 dB, thus, the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of the NLR criteria will not eliminate outdoor noise problems.

(2) Measures to achieve NLR 25 dB must be incorporated into the designs and construction of portions of these buildings where the public is received, office areas, noise sensitive areas, or where the normal noise level is low.

(3) Measures to achieve NLR 30 dB must be incorporated into the designs and construction of portions of these buildings where the public is received, office areas, noise sensitive areas, or where the normal noise level is low.

(4) Measures to achieve NLR 35 dB must be incorporated into the designs and construction of portions of these buildings where the public is received, office areas, noise sensitive areas, or where the normal noise level is low.

(5) Land use compatible provided special sound reinforcement systems are installed.

(6) Residential buildings require an NLR of 25.

(7) Residential buildings require an NLR of 30.

(8) Residential buildings not permitted.

### TABLE 4: FAA 14 CFR Part 150 Land Use Compatibility Table

This table is a land usage chart that shows what types of buildings can be built in areas around airports based on the exterior noise levels.

6.2.7.6 Product design & practices for acoustic performance

In order to meet the more stringent acoustic performance applications there are a number of design options to be considered. Some of those basic options are as follows:
Adding additional glazing layers. Utilizing a triple glazed plastic dome assembly versus a double dome, adding multiwall plastic structured sheet, using triple glazed insulated glass all can enhance sound transmission performance.

Increasing the airgap between glazing layers will also help. It should be noted such recommended gaps of 2 inches becomes too large to contribute significantly to thermal performance so in this instance the heavy lifting thermally will be performed by other airspaces within the layered glazing assembly.

Inclusion of laminated glass enhances acoustic performance significantly relative to non-laminated glass layers.

Sound absorbing materials incorporated into the skylight framing elements can be helpful.

Skylight framing that includes multiple air chambers can also contribute to the overall product performance.

The roof curb which the skylight is mounted to should not be overlooked. Additional sound absorbing materials in the form of thermal insulation can further improve the total performance of the skylight/roof system.

The table below provides a general guideline of what performance affects can be achieved for various glazing options. Contact the skylight manufacturer for more specific information on the performance of their products.

### 6.2.7.7 Acoustical Performance of Window / Curtain Wall Systems with Different Glazing Options

The table below provides a range of sound transmission loss ratings that can be achieved on most types of window and curtain wall systems. Fixed and casement windows will generally perform at the upper end of the range since they usually have a lower amount of air leakage. An STC rating of 40 or OITC of 30 is difficult to achieve on a conventional window or curtain wall system with 25 mm (1 in) insulating glass.

<table>
<thead>
<tr>
<th>Window/Curtain Wall IG Glazing</th>
<th>OITC Rating</th>
<th>STC Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3 mm (3/32 in) annealed, 12 mm (1/2 in) air space, 2.3 mm (3/32 in) annealed</td>
<td>20-22</td>
<td>25-27</td>
</tr>
<tr>
<td>3 mm (1/8 in) annealed, 12 mm (1/2 in) air space, 3 mm (1/8 in) annealed</td>
<td>23-25</td>
<td>27-29</td>
</tr>
<tr>
<td>3 mm (1/8 in) annealed, 12 mm (1/2 in) air space, 4.8 mm (3/16 in) annealed</td>
<td>25-27</td>
<td>29-31</td>
</tr>
<tr>
<td>3 mm (1/8 in) annealed, 12 mm (1/2 in) air space, 4.8 mm (3/16 in) laminated</td>
<td>26-28</td>
<td>31-33</td>
</tr>
<tr>
<td>3 mm (1/8 in) annealed, 12 mm (1/2 in) air space, 6 mm (1/4 in) annealed</td>
<td>26-28</td>
<td>31-33</td>
</tr>
<tr>
<td>3 mm (1/8 in) annealed, 12 mm (1/2 in) air space, 6 mm (1/4 in) laminated</td>
<td>27-29</td>
<td>32-34</td>
</tr>
<tr>
<td>4.8 mm (3/16 in) annealed, 12 mm (1/2 in) air space, 4.8 mm (3/16 in) annealed</td>
<td>25-27</td>
<td>30-32</td>
</tr>
<tr>
<td>6 mm (1/4 in) annealed, 12 mm (1/2 in) air space, 6 mm (1/4 in) annealed</td>
<td>26-28</td>
<td>31-33</td>
</tr>
<tr>
<td>6 mm (1/4 in) annealed, 12 mm (1/2 in) air space, 6 mm (1/4 in) laminated</td>
<td>28-30</td>
<td>34-36</td>
</tr>
<tr>
<td>6 mm (1/4 in) laminated, 12 mm (1/2 in) air space, 6 mm (1/4 in) laminated</td>
<td>29-31</td>
<td>37-39</td>
</tr>
</tbody>
</table>

### TABLE 5: Range of Sound Transmission Loss Ratings

**NOTE 2:** The 3/16 inches" laminated glass consisted of two lites of 0.090 inches" thick, annealed glass with a 0.030 inches" standard PVB interlayer. The 44 4/₅ inches" laminated glass consisted of two lites of 0.118 inches" thick, annealed glass with a 0.030 inches" standard PVB interlayer. Laminated glass utilizing thinner glass lites will achieve lower acoustical performance than what is listed above in Table 5.
To achieve STC ratings of 40 or OITC ratings of 30 and above, a dual window configuration with two sets of sash or a prime window with an exterior or interior storm panel is generally required. Table 6.3.2 provides estimates of the sound transmission loss ratings for primary and secondary window systems.

<table>
<thead>
<tr>
<th>Prime Window/Curtain Wall IG Glazing</th>
<th>Prime to Secondary Air Space</th>
<th>Secondary Window/ Curtain Wall Glazing</th>
<th>OITC Rating</th>
<th>STC Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm (1/8 in) annealed, 12 mm (1/2 in) air space, 3 mm (1/8 in) annealed</td>
<td>50 mm (2 in)</td>
<td>3 mm (1/8 in) annealed</td>
<td>28-30</td>
<td>39-41</td>
</tr>
<tr>
<td>6 mm (1/4 in) annealed, 12 mm (1/2 in) air space, 3 mm (1/8 in) annealed</td>
<td>50 mm (2 in)</td>
<td>6 mm (1/4 in) annealed</td>
<td>32-35</td>
<td>42-44</td>
</tr>
<tr>
<td>6 mm (1/4 in) laminated, 12 mm (1/2 in) air space, 3 mm (1/8 in) annealed</td>
<td>50 mm (2 in)</td>
<td>6 mm (1/4 in) annealed</td>
<td>34-36</td>
<td>43-45</td>
</tr>
<tr>
<td>6 mm (1/4 in) laminated, 12 mm (1/2 in) air space, 3 mm (1/8 in) annealed</td>
<td>50 mm (2 in)</td>
<td>6 mm (1/4 in) laminated</td>
<td>35-37</td>
<td>44-46</td>
</tr>
</tbody>
</table>

TABLE 6: Sound Transmission Loss Ratings Estimates

The ratings listed above in Table 6 are not specific to any one type of frame material. These ratings may be lower if there is significant air leakage or if there are flanking problems between the primary and secondary sash. To accurately determine the acoustical performance of a window or curtain wall system, a sound transmission loss test is required.

6.3 Meeting Regulatory Requirements

6.3.1 Building and Energy Codes

The primary purpose of a building code is to protect the health and safety of the occupants of a building. Secondary is the protection of the building structure itself. Building codes are designed to prevent structural collapse, ensure fire safety, reduce energy usage and ensure safe means of egress. Codes are minimum standards to ensure safety.

Most states and municipalities adopt "model codes" and can adapt them to their local geographical needs. These can include building, fire, residential and energy codes. Publishers of model codes and standards include the International Code Council (ICC), the National Fire Protection Association (NFPA) and the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).

Codes of main interest to daylighting design and skylight selection are the International Building Code (IBC) and International Residential Code (IRC) for structural, flame, wind load and snow load requirements. Energy conservation code and Green building codes include the International Energy Conservation Code (IECC), ASHRAE 90.1, the International Green Construction Code (IGCC), and the Standard for the Design of High-Performance, Green Buildings (ASHRAE 189.1). The Florida Building Code and Miami-Dade County have additional requirements for High-Velocity Hurricane Zones and Windborne Debris resistance. The Texas Department of Insurance has requirements for Hail Resistance of roofing which also include Skylights. California bases their Title 24 building standards largely on the suite of model codes from the International Code Council with one exception being Part 6, the California Energy Code.

Most building codes define the local building official as the "Authority Having Jurisdiction" and the power that local building departments have should not be underestimated. Building Codes typically state the duties, responsibilities and the authority of a building department. These can include inspections, plan review and approval, product approvals, code amendment authority and building official interpretations.

Code requirements for a building can be dictated by local zoning ordinances, climate zones or occupancy types. These can include high-rise business districts, hurricane zones, wildfire-prone areas, hospitals and schools.
NOTE 3: It is vital to understand the jurisdiction a product would or could be used in as this can affect the product/code requirements a product must meet, may affect the laboratories where testing may be performed and may require the product be certified and approved by the jurisdiction.

6.4 Fostering Human Health and Performance

Daylighting improves performance, productivity, and general well-being through impacts on the visual system, circadian system, and perceptual systems. The visual system is what we see and reference through our eyes; circadian system is our body clock, rhythms of sleep and brain activity; and perceptual system is our biological computational system. Improved performance and productivity of those systems has a positive impact on school and work, as well as our health and happiness.

Daylighting proven to increase school and workplace performance.

Groundbreaking research by the Heschong Mahone Group and Rensselaer Polytechnic Institute found that attentiveness, and test scores and grade performance were improved with daylighting practices in schools. The studies were undertaken across all the range of grades and in different states in the USA; comparing academic performance before and after daylighting improvements. Other studies around benefits of daylighting have concluded there are a variety of positive impacts with daylighting while people are working. The catalog of improvements includes better attendance; improved job satisfaction; and productivity. Roughly said: a well daylit work-space equals employee happiness and in turn productivity and limits eye strain. Many studies that were focused on daylighting improvements have also been conducted in retail stores. Every one of us can imagine walking into a store and feeling like you were in a cave; this signal tells our visual and perceptual systems that cave/darkness you are not in a buying. Poorly lit retail spaces send a visual and perceptual signal that translates into a mood of not purchasing. We can also distinctly remember the stores that have been well daylit; with the balanced use of skylights and store lighting, Spaces with a balanced approach to store lighting and the use of skylights create a memorable experience. Creative daylighting design in retail spaces encourages shoppers to enter and increases potential sales; the use of skylights results in That old business adage about it is harder to keep a customer than to get a new one: cave-like stores mean losing customers and daylighting means keeping customers.

Switching to the benefit of daylighting on the personal side: health and happiness. The thought that the more natural light we have, the happier and healthier we are, is not new nor needs a lot of study. Ever hear of the wintertime blues or Seasonal Affective Disorder (SAD): having less daylight means we are less happy and more stressed out. There’s Aa cure for that : get outside in the sun or be in move to an interior space that has more daylight. The transformation happens quickly: daylight does equal happiness. There are profound implications with daylighting on health and well-being beyond SAD treatments. According to Joseph (2006), we can maintain and improve our physical and mental health with daylighting.

Summary:

There are a number of well publicized articles and anecdotal information on the benefits of daylighting, especially in building, with major categories: energy efficiency and physiological. The physiological effects are important and personal to all of us: it affects how we feel; how we sleep; how we work; how we learn; and how we live. Having sound strategies around daylighting design in buildings and understanding not only economic (energy savings) benefits but of more importance physiological ones translates into health and happiness. Our visual; perceptual; and circadian systems can all be positively impacted with the use of daylighting strategies such as skylights. Letting the daylight in has been a tried and true practice for centuries; one that needs continued efforts and focus to continue; our health and well-being is at stake.
6.56 Light Levels

The desired level of illuminance in a room will depend on the general function of the space and on the visual requirements of the task to be performed. Therefore, once a space’s visual tasks have been identified, the next step in the daylighting design process is to determine the desired illuminance light level that is required for the tasks to be performed by the occupants. Figures S4 and S5 depict different applications of non-diffused toplighting suitable for their unique spaces.

The IES produces numerous reference documents that are used by the lighting and daylighting professional. In particular, two key publications that are particularly helpful in informing the daylighting design process, are IES RP-5-13 and IES HB-10-11. These documents provide extensive information on lighting and daylighting design principles, practices, and ways of characterizing and evaluating design solutions. A fundamental part of the art and science of illumination, is determining the proper placement of light and the illumination levels that are recommended based upon many factors, including the type of visual task being performed and the age of the occupant performing the task. In order to guide this process, the IES has developed a procedure for selecting illuminance levels depending on the type of activity in the space. The procedure associates visual tasks with a specific illuminance category, which determines the associated range of recommended illuminance levels to be maintained, and even identifies tasks that are particularly suited to illumination through the use of daylighting/fenestration solutions. Table 7 provides a sampling of common visual tasks that are appropriate to daylight illumination, and it includes the associated IES illuminance recommendation for a specific type of activity (and its associated visual tasks) and viewer (assuming typical occupants aged 25-65). It is important to remember that Table 7 represents a sampling of illuminance values, and the daylighting practitioner should reference the appropriate IES publications and apply the IES illuminance selection process for determining the recommended illuminance levels that are required.
<table>
<thead>
<tr>
<th>Activity Areas Commonly Associated with Code-defined Toplighting Spaces</th>
<th>Candidate for Daylight Illumination</th>
<th>Recommended Maintained Illuminance Targets*</th>
<th>IES Reference**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Service – Casual Dining</td>
<td>○</td>
<td>10</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Food Service – Fast Food Dining</td>
<td>○</td>
<td>20</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Health Care - Patient Room, General</td>
<td>○</td>
<td>5</td>
<td>Table 27.2</td>
</tr>
<tr>
<td>Reading, VDT's with Antiglare</td>
<td>○</td>
<td>30</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Aviation Terminal – Concourse, seating</td>
<td>○</td>
<td>15</td>
<td>Table 36.2</td>
</tr>
<tr>
<td>1. Aviation Terminal – Gent Counter, Check-in</td>
<td>○</td>
<td>30</td>
<td>Table 36.2</td>
</tr>
<tr>
<td>2. Aviation Terminal – Security Screening, Public</td>
<td>○</td>
<td>20</td>
<td>Table 36.2</td>
</tr>
<tr>
<td>Aviation Terminal – Baggage Claim</td>
<td>○</td>
<td>20</td>
<td>Table 36.2</td>
</tr>
<tr>
<td>Library – Book Stacks, General</td>
<td>○</td>
<td>20</td>
<td>Table 29.2</td>
</tr>
<tr>
<td>Library – Lending Desk, Staffed</td>
<td>○</td>
<td>50</td>
<td>Table 29.2</td>
</tr>
<tr>
<td>Lobby – General, Daytime</td>
<td>○</td>
<td>10</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Lobby – Reception Desk</td>
<td>○</td>
<td>15</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Toilets/Locker Room - General</td>
<td>○</td>
<td>5</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Toilets/Locker Room – Vanities &amp; Fixtures</td>
<td>○</td>
<td>10</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Toilets/Locker Rooms - Showers</td>
<td>○</td>
<td>10</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Warehouse – Active, Bulky Items</td>
<td>○</td>
<td>30</td>
<td>Table 30.2</td>
</tr>
<tr>
<td>Warehouse – Active, Small Items</td>
<td>○</td>
<td>30</td>
<td>Table 30.2</td>
</tr>
<tr>
<td>Stairway, Corridor</td>
<td>○</td>
<td>5-10</td>
<td>Range for “typical” to “High Activity” (Table 22.2)</td>
</tr>
<tr>
<td>Circulation Corridor, Independent Passageways</td>
<td>○</td>
<td>5</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Administration – Filing</td>
<td>○</td>
<td>10-30</td>
<td>Range for “Seldom” to “Constant” Activity (Table 22.2)</td>
</tr>
<tr>
<td>Reading, Xerograph - Analog</td>
<td>○</td>
<td>30</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Reading, 8-10pt Font Printed Media</td>
<td>○</td>
<td>30</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Lounge – Reading/Work Areas</td>
<td>○</td>
<td>15</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Support Space, Storage, Equipment/Small Items</td>
<td>○</td>
<td>20</td>
<td>Table 23.2</td>
</tr>
<tr>
<td>Classrooms – General Reading/writing</td>
<td>○</td>
<td>40</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>Classroom/Workshop - Assembly</td>
<td>○</td>
<td>100</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>Classroom/Workshop - Machining</td>
<td>○</td>
<td>100</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>Classroom/Workshop - Machining</td>
<td>○</td>
<td>100</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>Classroom/Workshop - Woodworking</td>
<td>○</td>
<td>100</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>Auditoria – Exhibition / Testing</td>
<td>○</td>
<td>30</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>Conference &amp; Meeting Rooms - Discourse</td>
<td>○</td>
<td>30</td>
<td>Table 32.2</td>
</tr>
<tr>
<td>Courtroom – Attorney’s Tables</td>
<td>○</td>
<td>50</td>
<td>Table 23.2</td>
</tr>
<tr>
<td>Courtroom – Bench &amp; Clerks</td>
<td>○</td>
<td>50</td>
<td>Table 23.2</td>
</tr>
<tr>
<td>Courtroom – Jury Box</td>
<td>○</td>
<td>30</td>
<td>Table 23.2</td>
</tr>
<tr>
<td>Courtroom – Witness Stand</td>
<td>○</td>
<td>30</td>
<td>Table 23.2</td>
</tr>
<tr>
<td>Courtroom – Public Seating</td>
<td>○</td>
<td>10</td>
<td>Table 23.2</td>
</tr>
<tr>
<td>Bakeries – Mixing, Proofing, Ovens</td>
<td>○</td>
<td>30</td>
<td>Table 30.2</td>
</tr>
<tr>
<td>Health Care – General Medical Exam &amp; Treatment Room</td>
<td>○</td>
<td>50</td>
<td>Table 27.2</td>
</tr>
<tr>
<td>Art Facilities – Exhibit and Galleries Objects</td>
<td>○</td>
<td>20-100</td>
<td>Range for objects with low to no sensitivity to light (Table 21.2)</td>
</tr>
<tr>
<td>Food Service, Commercial Kitchen - Food Prep</td>
<td>○</td>
<td>50</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Administration - Mail Sorting</td>
<td>○</td>
<td>30</td>
<td>Table 22.2</td>
</tr>
<tr>
<td>Retail - Fitting Room</td>
<td>○</td>
<td>30</td>
<td>Table 34.2</td>
</tr>
<tr>
<td>Activity Areas Commonly Associated with Code-defined Topliting Spaces</td>
<td>Candidate for Daylight Illumination</td>
<td>Recommended Maintained Illuminance Targets*</td>
<td>IES Reference**</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Retail - Department Store, General</td>
<td></td>
<td>40</td>
<td>Table 34.2</td>
</tr>
<tr>
<td>Retail – Sales Transaction Areas</td>
<td></td>
<td>30</td>
<td>Table 34.2</td>
</tr>
<tr>
<td>Indoor Sports – Basketball, Class III Competition play with some Spectator Facilities</td>
<td></td>
<td>50</td>
<td>Table 35.3</td>
</tr>
<tr>
<td>Manufacturing – Rough, easy seeing</td>
<td></td>
<td>30</td>
<td>Table 30.1</td>
</tr>
<tr>
<td>Receiving/Shipping - Dock</td>
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<td>Table 31.2</td>
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<tr>
<td>Receiving/Shipping – Receiving/Staging</td>
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<td>Table 31.2</td>
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<tr>
<td>Automotive – Service Garages</td>
<td></td>
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<td>Table 30.1</td>
</tr>
<tr>
<td>Automotive – Bodyweld, Quality</td>
<td></td>
<td>50</td>
<td>Table 30.1</td>
</tr>
<tr>
<td>1. Gymnasia - Assembly</td>
<td></td>
<td>15</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>2. Gymnasia – General Activities</td>
<td></td>
<td>30</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>3. Gymnasia – Physical Education</td>
<td></td>
<td>50</td>
<td>Table 24.2</td>
</tr>
<tr>
<td>Municipal Fire Station – Apparatus Bay, General</td>
<td></td>
<td>30</td>
<td>Table 31.1</td>
</tr>
</tbody>
</table>

* Assumptions: Occupants aged 25-65, reflectances 30-70%, demand for accuracy important.
**This information came from the IES Lighting Handbook, 10th Edition, Chapters 21 through 36 for illuminance requirement recommendations for common lighting applications. The daylighting practitioner should refer to this publication, and to other IES Recommended Practice and Design Guideline Documents for more detailed recommendations on illuminance criteria for specific applications.

Tasks identified as being candidates for design strategies employing any combination of daylighting and electric lighting to achieve target illuminance values during daylight hours. Daylight may require unconventional approaches.

### TABLE 7: Common Lighting Applications Conducive to Daylighting and Representative Illuminance Requirements, information originates from IES Lighting Handbook.

**FIGURE S5:** Unit skylights used to maximize functional daylighting in a small residential space.
6.7.6 Moving Towards Sustainability

6.7.6.1 Environmental Impact

Expanding regulatory and standards activity has been in the arena of product transparency related to other environmental footprint parameters. A widening (some say “dizzying”) array of “green” or “sustainability” or “health” enhancement programs continues to emerge. Many of these are voluntary, but even building codes and standards organizations have carved out “above-code” provisions that are written in enforceable language – adoptable as mandatory by local and state jurisdictions. One major example is California’s Title 24, Part 11 “CalGREEN” code. Others are the ICC’s IgCC and ASHRAE’s 189.1 standard, which are in the process of merging their similar technical content into the 2018 IgCC.

U.S. Green Building Council’s LEED voluntary program has thus far been a major driver of demand for environmental impact transparency, by rewarding projects that use products which carry documented and verified impact potential. Others have followed suit, putting pressure on product manufacturers to show the requested documentation so the available rating points can be accumulated. Currently there are few generally accepted standards or organizations devoted to assessment and reporting of impacts, so there is a plethora of competing agencies trying to carve out some of the territory for themselves. Have a look at a few of them:

Of course, not all will survive, and most serve a limited niche of product types. Still, there will come a time that transparency of product make-up, health effects, and expected environmental impact performance in use (such as Environmental Product Declarations [EPDs] and Health Product Declarations [HPDs]) will be a requirement. For today, it is still a business decision whether to use resources to increase product transparency in a manner appropriate to their products.

AAMA has been instrumental in helping to develop a workable new business-to-business Product Category Rule (PCR) for windows. The evaluation of “cradle-to-gate” impacts (as prescribed largely by ISO standards) can also be used by skylight products using the “Window PCR” and format. Third-party verified partial EPDs are the communication outputs resulting from use of this tool. For true product performance evaluation over the full life cycle, however, the industry must go further and complete the first PCR intended for Business-to-Consumer use. Otherwise, the user will never be equipped to determine the natural daylight and ventilation option with the least impact.

6.6.7.2 Energy Efficiency

While skylights have always been desirable and aesthetically pleasing architectural elements, recent energy cost and supply concerns have caused their re-evaluation from the standpoint of energy efficiency. Meaningful analyses must go beyond simple heat conduction calculations.

Designs can take maximum advantage of passive solar heat gain in winter to supplement heating systems. Year-round skylights supply natural daylighting that can reduce the need for electric lighting. For air-conditioned buildings, this provides the added advantage of reduced lighting heat load on cooling systems in summer.

These effects can be fine-tuned through creative designing to offset the traditionally considered energy losses such as thermal transmittance, infiltration, etc., and provide net positive energy benefits.

Good daylighting design saves energy in many ways. The obvious one is lighting energy, which can represent a major portion of the total energy consumed by many buildings. Electric lights emit more heat than the same amount of natural daylight, so during the warmer months the air conditioning system has to work harder and needs to be sized for the added load. With daylight comes free heat, which can save energy during the cooler seasons. Some products used mainly for providing natural light can also significantly reduce the amount of heat lost when substituted for more traditional products.

7.0 GLAZING OPTIONS

Use of unit skylights and sloped glazing has grown into a prominent feature of modern architecture. Atrium enclosures, vaulted skylights covering shopping malls, canopies, and many similar uses of sloped glazing are now common. Sloped glazing systems have become important additions to building design.
Design criteria for skylights and sloped glazing are in a state of rapid and continuous creative development. The performance and selection of glazing have become major and critical factors. Changes in building code requirements, design practices, available glazing products and industry standards are a result of the growing use of complex and large sloped glazing systems. Emphasis is placed on the importance of meeting product requirements for performance, energy conservation, daylighting, and the safety of building occupants.

The selection of glazing for skylights or sloped glazing requires the judgment of a design professional. The architect, specifier, and professional engineer must be responsible for determining the building code requirements and choosing the appropriate glazing for the application. The design professional may consult with engineers along with code and standards organizations for technical guidance and also with the skylight manufacturers and glazing fabricators for performance data and product availability.

Today's glazing options include glass, monolithic plastic, multiwall polycarbonate, multiwall acrylic, and fiberglass reinforced panels. The following is a brief description of the characteristics of these glazing options.

7.1 Glass:
- Glass has an extremely broad range of thermal performance characteristics. Given the magnitude of available coatings, infill gases, and spacer types, glass can provide the broadest range of thermal performance. It is best to consult the skylight manufacturer and/or glass manufacturer for performance options that will deliver the desired results. For example, when designing a skylight to be used over a conditioned space in heating-dominated climates, the glazing should be double or even triple layer insulating units for optimal energy performance.
- Glass in skylights should generally be laminated for safety reasons. With additional provisions, the building code does allow for non-laminated glass to be used overhead, but the usage is extremely limited.
- Laminated glass provides fading protection by blocking approximately 99% of the UV spectrum. Ultraviolet light (the part of the light spectrum which is between 300 and 380 nanometers (nm)) is a major cause of fading of interior materials. For more information on other contributing factors of fading the architect should refer to the Ultraviolet Total Damage Weighted factor (UVTDW).
- Glass can be used to provide protection against extreme events such as hurricanes and bomb blasts.
- Glass provides optimal optical properties. The variety of available tints and coatings provide visible light transmittance over a very large range.
- Glass can also be provided with light diffusing capabilities by choosing frosted or fritted glass, or using a white laminate for the laminated glass.

For more information on the types of glass and their characteristics please refer to AAMA GDSG-1 Glass Design for Sloped Glazing.

7.2 Plastic:
- Plastics come in a variety of chemical compositions. Each material type has a range of formulations, additives, coatings and processing methods that can affect the strength and performance of the material.
  - Acrylic has good optical properties and is the more rigid of the plastic products covered here.
  - Impact Modified Acrylic (IMA) is formulated to provide the acrylic sheet with improved impact resistance.
  - Polycarbonate (monolithic and multiwall) has excellent impact resistance. This material is more vulnerable to UV light, therefore all polycarbonate used in skylight applications should be provided with UV protection.
  - Copolyester has excellent impact resistance. This material should also be protected from UV light.
- All of these materials, like glass (although not as broad a range), can be enhanced with coatings or formulations to improve their thermal performance and light diffusion.
- To be acceptable for use in skylights, these materials must meet specific fire and smoke resistance characteristics as mandated by the IBC. (See Chapter 26 of the IBC for requirements).
- Acrylics are inherently resistant to the effects of UV. However they must be specially formulated to provide UV protection to interior materials. Polycarbonate and Copolyester, by virtue of UV protective coatings, and can also block the transmission of damaging UV spectrum.
IMA, Polycarbonate, and Copolyester can also be used to provide protection against extreme events such as hurricanes and bomb blasts.

All of these materials are available in translucent, frosted or textured options with excellent light diffusing capabilities.

Maintaining optical clarity over time may require additional abrasion resistance. Abrasion resistant coatings are available for these products. Additives, coatings and coextruded layers can also be added to the plastic sheet materials to enhance weathering performance and retention of color or optical properties. Typically these abrasion resistant coatings are not thermoformable and must be used in flat applications only.

The vast majority of plastic used in dome skylights is IMA due to the ease of producing the dome shape, high static pressure resistance and relatively lower cost material. The softer, more impact resistance materials can be formed with structures (such as ribs) to increase the final dome shaped products static load resistance.

For more information on plastics and their characteristics please refer to AAMA PSSG-16 Selection and Application Guide for Plastic Glazed Skylights and Sloped Glazing.

7.3 Fiberglass Reinforced Panels:

- Reinforced, light-transmitting sandwich panels are constructed of an internal grid stiffener system with translucent fiberglass skins bonded to the interior stiffener system. Fiberglass, like Polycarbonate and Copolyester, must be protected by coatings or formulation to protect them from UV.

- Fiberglass panels are translucent by nature, providing diffused light, and do not provide clear views to the exterior.

- By nature of their panel thickness and the ability to provide insulation between the outer skins, these panels have good thermal properties.

- These products can be used to provide protection against extreme events such as hurricanes and bomb blasts.

- Fiberglass products, to be allowed for use in skylights, by code must meet specific fire characteristics. (See Chapter 26 of the IBC for requirements).

The designer should consult with the various fiberglass panel manufacturers for more in-depth structural and technical information.
8.0 DAYLIGHTING SOLUTION DEVELOPMENT

The guidelines outlined in this chapter are provided as a foundation relative to the use of skylights to optimize daylighting in commercial buildings, as a means for energy savings and to enhanced lighting/daylighting design. These fundamental guidelines apply primarily to unit skylights used in commercial applications which are typically rectangular or linear skylights, although with creative design they can be applied to nearly any design situation. Many of the basic design principles covered here are also applicable to residential buildings. For more detailed information regarding the principles and best practices associated with daylighting interior spaces using skylights, the reader is encouraged to refer to documents developed and maintained by the IES that are used by the lighting and daylighting professional. Two key publications that are particularly helpful in informing the daylighting design process, are the IES RP-5-13 and IES HB-10-11. These documents provide extensive information on lighting and daylighting design principles, practices, and ways of characterizing and evaluating integrated daylighting design solutions.

In general, the different forms of skylights can be applied to a wide range of building types in order to achieve many different design affects and design intents. The example scenarios which follow, can provide insights for using skylight technologies effectively in commercial buildings. There are two primary issues illustrated in these examples: the functional requirements for lighting (providing useful illumination through the controlled application of daylight), and the design intent of the skylight solution. The functional requirements determine how critical it is that the luminous environment meet such criteria as illuminance level, uniformity, light distribution, and glare control. The design intent determines the role to be played by daylight in the architectural expression of the space. From the utilitarian point-of-view, the daylight can be viewed simply as another light source intended to offer relatively uniform illumination throughout a space over the course of the occupied day and year. Alternatively, the daylight can be an integral part of the architectural experience, by throwing forms into relief, highlighting critical design and/or visual elements in the space (see Figure 16), and providing a sense of movement and change throughout the day. The following discussion is divided along these lines.

![Residential Application of Skylights for both Aesthetic and Daylighting Purposes](image-url)
8.1 Skylights for Architectural Emphasis

When skylights are used for architectural emphasis, there is a greater premium placed on the interaction of daylight with the other architectural elements of the building. The skylights are positioned and sized to enhance the architectural experience of surface and volume. There is a corresponding decrease in emphasis on uniformity or distribution of illuminance. As a result, toplighting with skylights for architectural emphasis is usually found in areas without critical task illuminance requirements, such as circulation areas, entries, and lobbies.

Architectural Emphasis Example – Premiere Retailer

In Figure 7, a high-ceilinged shopping space uses large pyramid skylights to define the shape and scale of the space, and to provide a bright, airy-feeling open space for browsing. Translucent, diffusing skylight glazing prevents strong, beam sunlight from entering. Instead, a softer, more even light quality is achieved. The central area becomes the focus of architectural attention because of its size and brightness. The surrounding areas are provided with supplemental electric lighting to reduce the brightness contrast between the daylight and non-daylight areas.
8.2 Skylighting for Uniform Illumination

When toplighting with skylights is provided to replace or supplement uniform electric lighting for critical task illuminance, the design approach is often quite different than when architectural emphasis is the goal. With this approach, the spacing of skylights, their size and glazing materials used, the operation of the lighting control system, as well as the other details of the skylight system, all become critical to success. Virtually all of these applications use simple roof penetrations, uniform spacing of skylights, and diffusing glazing or ceiling-mounted diffuser as would be used with tubular daylighting device materials. Section 6.0 of this document introduces and explains the technical terms associated with daylighting, and provides more detailed information on how to optimize skylight applications for uniform illumination.

Uniform Illumination Example – Big Box Retailer

In this store, uniformly spaced skylights provide daylight to supplement the standard, commercial lighting. An automatic lighting control system turns off (or dims) electrical lighting as daylighting availability increases. In the most basic (stepped) control of multi-lamp electric lighting fixtures—a typical first step in reducing electrical light output in response to increasing interior daylight illumination is to turn off 50% of the lamps in each fixture once a suitable level of daylight has been achieved (this cannot be seen in the photograph). In the second step, the remaining lamps are switched off in circulation areas. As a third step, all lamps would switch off. In practice, however, the owners seldom permit all the lights to turn off, because they do not want the store to appear unoccupied, unless the daylighting solution properly illuminates architectural surfaces to reinforce the appearance that the store is open and ready for business.

More sophisticated lighting control systems are available using continuous dimming daylighting controls. The controls permit imperceptible reductions in electric lighting as daylight availability increases; a very significant reduction in energy use and cost.

Compared to a similar building without skylights, the lighting energy consumption is significantly reduced, and savings are also typically seen in the HVAC system. Beyond energy savings, toplighting with skylights provide retailers with indoor spaces that have been proven to increase shopper activity and spending; and in general, a more pleasant shopping experience.

The same approach is widely utilized in other forms of commercial non-retail buildings; especially large ‘box buildings’ such as warehouses, distribution centers and industrial manufacturing facilities (see Figure 49). However, the same premise can be applied to nearly any building type that has a sun exposed roof area; is not shaded by surrounding construction - a growing trend in office spaces, school classrooms, and public spaces; and is required by the emerging green specifications/building guidelines.
8.3 Sizes and Shapes

Skylights are available in a wide variety of sizes, shapes, and component configurations to match nearly any building’s or architect’s need. They range from simple rectangles, to complex polygons, or tubular daylighting devices. They can be small to fit between rafters, or large enough to run the length of a building. To cover big spaces, the skylights can be in the form of long barrel vaults or smaller units combined on a space frame. In addition, custom skylights can be fabricated to meet nearly any requirement. For the purpose of this section, we will be focusing on unit skylights for uniform daylighting design. For more information on skylight products and glazing options, please refer to Chapter 6 of this document.

8.4 Layout

The layout and spacing of skylights in a roof will largely determine the light distribution characteristics of the skylight system, though some skylights use special lenses and optical diffusers to help diffuse the light into the space in unique ways. For special skylight applications, such as entry lobbies or small rooms, the skylight layout will be dictated by the design concept for the space. Careful layout becomes a different concern in large, daylit spaces where relatively uniform light distribution is desired. While maintaining a constant skylight area, the designer could choose to apply any daylighting solution ranging from a single large skylight in the center to many small skylights distributed uniformly across the roof.

This range of options provides some tradeoffs. Large, widely spaced skylights are usually the most economical to install, but may produce localized, bright conditions directly under or adjacent to the skylights, and relatively dark conditions between skylights. This results in uneven light distribution, poor illuminance uniformity, reduced energy savings, and possible glare issues for the space occupants. Conversely, small, closely spaced skylights, will provide more uniform lighting conditions, consistent illuminance uniformity, greater lighting-energy savings, but may be more costly to install.

Skylight spacing affects the uniformity of light distribution. The differences in illuminance level between locations directly under the skylight, compared to locations between skylights, will be greater as skylight spacing increases.

Ceiling height is a major determinant of skylight spacing. In general, it is preferred that light distribution should be uniform on the work/visual task plane. In most commercial settings, this plane is typically considered to be at a height of 30 inches above the finished floor. Too much distance between skylights results in dark areas occurring on this plane and should be avoided.
The most basic rule of thumb method for determining a daylighting design solution’s skylight layout uses basic spacing-criteria standards to achieve acceptable task plane illuminance uniformity. With this basic spacing criteria rule of thumb approach, illuminance uniformity dictates skylight spacing without consideration of the actual illuminance that is achieved. For general spacing criteria, the recommended maximum center-to-center spacing between two skylights should be no greater than the following equations reveal:

**Skylight Spacing ≤ (1.4 x ceiling height) + skylight width**

For ceilings with splayed skylight wells (recommended when possible):

**Skylight Spacing ≤ (1.4 x ceiling height) + (2 x splay width) + skylight width**

The splay width is how much a given side of the splay is offset horizontally from the edge of the skylight. Skylight spacing can be determined for different ceiling heights based on the rule of thumb given above previously. Figure 411 shows spacing for skylights with splay — and while Figure 310 shows spacing for skylights without splay. Note that skylights without splays need to be placed closer together than skylights with splays.

![FIGURE 310: Spacing for skylights without splay](image1)

![FIGURE 411: Spacing for skylights with splay](image2)

When using this basic uniformity rule of thumb to determine skylight spacing, the use of splayed ceiling geometries and/or applying skylight spacing that achieves an overlap of daylight areas from each skylight will result in improved illuminance level uniformity at the work plane and/or visual task. Conversely, increasing skylight spacing, and thereby reducing daylight
area overlap for each skylight, will result in darker areas of illumination between skylights, thereby causing decreased illumination uniformity. It is important to note that the use of uniformity-based rules of thumb, alone, cannot guarantee that desired task illumination levels are routinely achieved within the daylit space.

When strict target illuminance requirements are desired, a better, more rigorous approach to daylighting design is to use skylight photometry and local climate data to determine the optimal skylight placement and design for optimized annual performance in a space. When applying this approach to daylighting design, both uniformity and task illuminance objectives can be effectively achieved and will often result in superior energy-efficient daylighting solutions.

In addition to skylight placement, the surface reflectance of walls, floors, ceilings, and furnishings also have a significant impact on light distribution within the daylit space. Light colored surfaces, with high reflectance, will help to aid in distributing light throughout the space, and this, in turn, will reduce the potential for high brightness contrasts (relative ratios between light and dark areas/surfaces) that cause visual discomfort for occupants. It is especially important for ceilings to be highly reflective, so that they are as bright as possible. This reduces the glare potential from having bright skylights and/or diffusers adjacent to darker ceiling areas. High reflectance floors and furnishings will also help in this regard, because they help to brighten the ceiling by reflecting light from the floor surface to indirectly illuminate the ceiling area. In smaller rooms, or when skylights are adjacent to walls, wall reflectance is important; in larger rooms the wall effects are smaller. In general, however, maintaining even and consistent illumination of wall surfaces is desirable, and results in the occupants perceiving the daylit space to be well lit even under marginal daylighting conditions.

As a general rule, use highly reflective surfaces to distribute light, and use darker colors on surfaces where light distribution is not as important, such as the floor.

8.5 Light Wells for Unit Skylights

Architectural light wells are used extensively with unit skylights, since they allow designers to effectively transfer the harvested daytime through the roof structure and/or plenum spaces, and they provide a means for controlling the incoming daylight before it enters the main occupied spaces of the building. When properly designed, light wells can provide improved light distribution and visual comfort. In some buildings, light wells are optional design features, but in many buildings they are necessitated by the depth of the structural system or the existence of mechanical systems and equipment, which often separates the roof plane from the ceiling plane by several feet.

Architectural light wells are designed in a wide variety of shapes (see Figure 12). At the simplest, they are vertical-sided shafts, roughly the same size as the skylight. More elaborate wells have splayed or sloping sides that spread the light more broadly through the space.

The shape and size of the light well is often determined by the roof and ceiling structure. Wells can be made from conventional construction materials, or proprietary light well products can be used.

In designing architectural light wells for skylights, there are a number of factors that must be considered:

- **Solar geometry.** The altitude and azimuth of the sun’s position changes from hour to hour and season to season. The direct sunlight that enters a transparent skylight can be prevented from penetrating down to the task surface by effectively using light wells; conversely, the wells can reflect the sunlight to a particular destination. To block high sun angles, the light well must be deeper than for low-sun angles. To admit sunlight in the morning and block it in...
the afternoon, the well must be aimed toward the east. Sun path studies are used to design for direct sunlight control.

When transparent glazing is used, the design of the light well should consider sun angles that will occur throughout the hours of the year that the space is occupied. Light wells can provide a means of cutting off direct sun penetration for problematic solar positions. The photo Figure 13 on the left shows a shallow well. The deeper well on the right cuts off higher angle sunlight.

![Figure 13: Shading of Direct Sun by Light Well](image)

- **Surface reflectance.** Most architectural light wells reflect and diffuse daylight transmitted by the skylight glazing as it bounces from the skylight to the light well’s opening at the ceiling plane. Highly reflective, diffusing surfaces (e.g., white, flat paint) help provide a diffuse, broadly distributed light distribution pattern below the light well opening. On the other hand, a specular reflective surface, such as a mirror, will not diffuse the light, but will reflect an image of the sun and sky onto a limited area below the light well opening. Darker diffusing surfaces will distribute the light, but will reduce its intensity and may color it by selective absorption of the daylight, and This may negatively impact the efficacy of the skylight system. For applications where good light distribution is desired, a matte white surface is best; for other applications, a variety of effects can be created by altering the color, reflectance, and specular nature of the well surfaces.
Reflective Properties of Well Surface: Diffuse walls (e.g., flat or matte paints) reflect incident light in all directions, spreading the brightness. Specular walls (e.g., mirror surfaces) reflect a direct image of the sun or skylight to the space below. Semi-specular walls (e.g., gloss paints) exhibit qualities of both diffuse and specular reflection. Dark well surfaces reduce nearly all light scattering, and tend to admit only direct sunlight.

- Wall slope. The slope of light well walls helps to determine the distribution of light in the space. The broader the base of the well, the larger the task area in the space having a direct view of the skylight. This is an advantage under overcast sky conditions, but it can be a disadvantage when direct sunlight is present. Deep wells with vertical walls tend to keep the light concentrated in a smaller area, and tend not to provide very uniform light distribution. For this reason, splayed wells can help mitigate glare when diffusing glazing is used.

Splayed light well walls (Figure 14 right image) allow a larger area of the space to view the skylight surface. With diffusing glazing, this helps provide uniform illumination. With transparent glazing, this would allow greater penetration of beam sunlight; for transparent glazing, vertical walls with carefully designed shadow cut-off angles, or the use of additional shading elements within the splayed well, are usually preferred.

![FIGURE 714: Splayed Wall Effect](image)

Specular reflective surface: A surface characterized by the bright reflection of light rays striking and leaving the surface at equal angles.

It is important to use matte textures on major interior surfaces that are directly visible by occupants, so as to reduce the potential of unwanted glare from specular reflectance. Shiny surfaces tend to reflect images of the skylights, which can be visually uncomfortable if interior contrast ratios are not carefully controlled. Small, specular reflectors, however, can provide sparkle, which increases visual interest without discomfort.

When dark colors are desired, they should be limited to small, accent areas, rather than dominating the visual environment. In cases where dark colors predominate, the toplighting should be broken up and diffused as much as possible to reduce brightness contrasts. This could be accomplished with larger, low transmission skylights, or with broad skylight wells and dense interior shading.

In the case of tubular daylighting devices, the reflective tubing element that connects the roof-top daylight aperture to the interior/ceiling-mounted optical diffuser uses a highly-reflective specular surface to effectively transfer harvested daylight to the interior optical diffuser. The optical diffuser then delivers the daylight to the interior space in a controlled manner, and it is intended to reduce and/or illuminate the potential for glare that might be associated with an unshielded specular shaft/light well surface.

8.6 Glazing
Glazing is covered in previous chapters of this document; however glazing is one of the most important factors in good skylight design. There are many alternatives and choices to consider, and careful selection is important to a successful design. The two major types of skylight glazing for daylight design are: transparent and translucent. Either of these types can be: colorless, tinted, or reflective; as well as available in either plastic or glass material types. Glazing elements can also be incorporated which use refractive optics to selectively harvest and redirect available daylight into the building's interior spaces.

Transparent, colorless glazing materials transmit the most daylight, and provide the most natural view of the sky, which helps to satisfy the human need for contact with the outdoors. As a consequence, however, these materials admit the strong, direct beams of sunlight to the building. Beam sunlight may be blocked, redirected, scattered or diffused by interior objects (shades, banners, structural members, optical diffusers, etc.) if desired, to prevent possible discomfort for occupants.

In Figure 15, transparent glazing materials (left image) admit beam sunlight to the building, which can result in either harsh shadows or pleasant bright spots, depending upon the design intent. Diffusing glazing (right image) provides a more uniform, "spread out" light distribution.

Translucent glazing materials, frosty white in appearance, are widely used to diffuse and distribute sunlight entering through skylights. These glazing materials do not allow a direct view of the sky, although it is still possible to detect major differences in time-of-day and weather conditions. They provide a more uniform light quality, especially under direct sun conditions, and therefore, do not require as much supplementary control from shades or other shielding/diffusing objects or surfaces. There are differences in translucency with these materials. Highly diffusing materials tend to have lower overall light transmittance ratings. Those with higher transmittance are not as good at diffusing the light, and may exhibit interior “hot spots” (localized areas of high illuminance) under direct sun conditions.

Transparent, tinted glazing materials are widely used when a combination of direct sun control and sky view is desired. They behave much like sunglasses; the amount of skylight and sunlight is reduced, while maintaining a clear view of clouds and other exterior objects. This helps to control unwanted solar heat gains and glare, but also reduces the amount of useful heat and visible light admitted. Tinted materials are typically available in colors of gray or bronze, although greens, blues, and other colors are available. The color of the tint can affect the perceived color of objects in the space. For example, bronze tints create a warmer color appearance. This can be either attractive or disturbing, but it should be anticipated during glazing selection.
8.7 Visual Comfort

A primary objective in the design of any lighting system (daylight or electric light) is to provide the illuminance levels required for visual performance at the task, using a system that enhances visual comfort in the work environment through careful and thoughtful placement of light in the occupied spaces.

Both ceiling-mounted electric lights and skylights have the potential to cause visual discomfort, and the techniques for avoiding this are the same. There are two basic areas of concern:

- Avoiding excessively bright sources within the occupant’s field of view, and
- Avoiding reflections from bright sources on the work/visual task surface.

Bright light sources in the occupant’s field of view can cause discomforting glare. This is the result of a large brightness contrast between the light source and darker surfaces within the surrounding field of view. Contrast glare occurs when the eye has difficulty accommodating to the contrast differences. The basic solution, for both electric lighting and top-lighting, is to increase the brightness of the surroundings and to decrease the apparent brightness of the source by dimming, blocking/shielding or diffusing the light. With skylights, this is accomplished with lower transmittance glazing, light wells, diffusing shades, bright architectural surface reflectance, application of optical diffusers, and other design techniques that achieve improved light distribution.

These and related techniques for achieving visual comfort with electric lighting and top-lighting are explained in greater detail in most lighting design texts, and in particular, the Recommended Practice for Daylighting Buildings and The Lighting Handbook, Tenth Edition – Reference and Application.

9.0 CODES & REGULATORY CONSIDERATIONS

9.1 General

Requirements outlined in the model codes developed by the ICC related to the physical properties and weathering performance of plastic glazing materials are covered in the sections that follow.

Skylights are primarily covered in the IBC Sections 1505.1, 1709.6, 2405, 2606, and 2610, and the IRC Section R308.6, with ancillary provisions in other sections.

Skylights must meet the appropriate structural requirements of the roof including environmental loads per ASCE 7- such as wind loads, snow load, etc.

Building energy codes also contain extensive provisions that constrain the designer to certain performance limits of both the products and the buildings in which they are installed. The most influential ones in the US are:

- IECC – all building types
- ASHRAE 90.1 Standard – Non-residential and high-rise residential
- California Building Energy Standards, Title 24, Part 6 – all building types

The following review gives the user a basic understanding of the constraints they must consider in order to comply with the above previously noted documents. The latest versions published at the time this document was issued are the basis of this review.
Also note that an increasing number of projects are also being asked to conform to one of many available “sustainability” or “green” codes, programs, checklists, standards, etc. Since there is much diversity, fluidity, and variety in those additional “above code” requirements, this document will only concentrate on generally accepted constraints.

9.2 Review for Non-Residential Buildings and Residential Buildings Taller than Three Stories

Some relevant definitions in the 2018 IBC include:

- **SKYLIGHTS AND SLOPED GLAZING** - Glass or other transparent or translucent glazing material installed at a slope of 15 degrees (0.26 rad) or more from vertical. Glazing material in skylights, including unit skylights, tubular daylighting devices, solariums, sunrooms, roofs and sloped walls, are included in this definition.

- **SKYLIGHT, UNIT** - A factory-assembled, glazed fenestration unit, containing one panel of glazing material that allows for natural lighting through an opening in the roof assembly while preserving the weather-resistant barrier of the roof.

- **TUBULAR DAYLIGHTING DEVICE (TDD)** - A non-operable fenestration unit primarily designed to transmit daylight from a roof surface to an interior ceiling via a tubular conduit. The basic unit consists of an exterior glazed weathering surface, a light-transmitting tube with a reflective interior surface, and an interior-sealing device such as a translucent ceiling panel. The unit can be factory assembled, or field-assembled from a manufactured kit.

Some relevant sections in the code reviewed below in the following bullet points: (IBC 1503.5, IBC 1505.1, IBC 2405.4, IBC 2405.5, IBC 2606.4, IBC 2606.5, IBC 2606.6, IBC 2606.7.3, IBC 2610.2, IBC 2610.3, IBC 2610.4, IBC 2610.5, IBC 2610.6, IBC 2610.7, IBC 2610.8.)

- **Crickets and saddles** are needed for penetrations greater than 30 inches above the penetration with the exception of skylights that have such considerations included in the design of the product, installation method or flashing system.

- **Roof assemblies and roof covering performance classes** are divided up into A, B, and C tested in accordance with ASTM E108 or UL 790 with the exception of skylights and sloped glazing that comply with Chapter 24 or Section 2610 of the IBC.

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### NAFS-17 Excerpt

**10.2.5.5 Smoke density**

Plastic glazing materials shall be tested in accordance with ASTM E84 or ASTM D2843. When tested in accordance with ASTM E84, the maximum smoke developed index shall be not greater than 450. When tested in accordance with ASTM D2843, the maximum smoke density rating shall be not greater than 75.

**10.2.5.6 Self-ignition temperature**

Plastic glazing materials, when tested in accordance with ASTM D1929, shall have a minimum self-ignition temperature of 343 °C (650°F).

**10.2.5.7 Combustibility classification**

Plastic glazing materials, when tested in accordance with ASTM D635, shall meet one of the combustibility classes listed in Table 10.1.

<table>
<thead>
<tr>
<th>Combustibility class</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1</td>
<td>Maximum extent of burning shall be 25 mm (~1 in) or less</td>
</tr>
<tr>
<td>CC2</td>
<td>Average burning rate shall be 62 mm/minute (~2-1/2 in/minute) or less</td>
</tr>
</tbody>
</table>

**Note:** The IP equivalents identified are for approximate reference only and do not in any way imply accuracy of the measurement or the equipment. See Clause 4.1.1.
• Framing of skylights
  o Noncombustible materials
  o Approved pressure treated wood or other approved noncorrosive materials are permitted where fumes are
detrimental to metal.
  o Framing supporting sloped glazing and skylights must resist the tributary roof loads.
  o Skylights set at an angle of less than 45 degrees from the horizontal plane must be mounted at least 4 inches
  from roof plane.
  o Installation of a skylight without a curb is permitted on roofs with a minimum slope of 14 degrees (three units
  vertical in 12 units horizontal) in Group R-3 occupancies. However, all unit skylights installed in a roof with a
  pitch less than 14 degrees must be mounted at least 4 inches above the plane of the roof on a curb constructed
  as required for the frame unless otherwise specified in the manufacturer’s installation instructions.

• Unit skylights and tubular daylighting devices performance standard – “Unit skylights and tubular daylighting
devices shall be tested and labeled as complying with AAMA/WDMA/CSA 101/I.S.2/A440. ...” (IBC)

• Light-transmitting plastic glazing requirements - test in accordance with referenced standards for fire and smoke
  characteristics as specified in NAFS-17.
• Structural requirements- Light-transmitting plastic materials in their assembly must withstand the design loads.
• Fastening- Fastening must withstand the design loads.
• Skylight design- provide allowance for expansion and contraction of light-transmitting plastic materials.
• Size limitations- skylights must not exceed 10 feet in length nor 30 square feet in area.
• Plastic glazing fire considerations- Protect edges of light-transmitting plastic skylights or domes with metal or
  other approved noncombustible material. Alternatively, the light-transmitting plastic dome or skylight can be shown
to be able to resist ignition where exposed at the edge to a flame from a Class B brand as described in ASTM E108
  or UL 790, except that:
  o Curbs are not required for skylights used on roofs having a minimum slope of three units vertical in 12 units
  horizontal (25-percent slope) in residential occupancies and on buildings with a non-classified roof covering.
  o The metal or noncombustible edge material is not required where non-classified roof coverings are permitted.
• Application roof slope - Flat or corrugated light-transmitting plastic skylights must slope at least four units vertical
  in 12 units horizontal (4:12). Dome-shaped skylights shall rise above the mounting flange a minimum distance equal
to 10 percent of the maximum width of the dome but not less than 3, unless they pass the Class B Burning Brand
  Test specified in ASTM E108 or UL 790.
• Maximum area of skylights - 100 square feet except when the building is equipped with an automatic sprinkler
  system or the building is equipped with smoke and heat vents per the code.
• Aggregate area of skylights - The aggregate area of skylights must not exceed 33 percent of the floor area of the
  room where Class CC1 plastic glazing materials are used, and 25 percent for Class CC2 materials except if the
  building is equipped with an automatic sprinkler system per the code, in which case, the area limitation can be
doubled.
• Separation distance - Skylights must be separated from each other by a distance of not less than 4 feet except if
  the building is equipped with an automatic sprinkler system per the code or in Group R-3 with a combined area not
  exceeding the limits as already noted.
• Exterior wall opening that are required to be protected by the code - Skylights must not be installed within 6
  feet of such exterior walls.
• Combinations of light-transmitting plastic roof panels and skylights are subject to area and percentage
  limitations and separation requirements applicable to roof panel installations.
Balancing solar heat gain, thermal transmission, and good daylighting is more complex than the energy codes currently recognize in their prescriptive requirements. Energy codes typically establish simplistic, prescriptive limits on product ratings associated with heat loss or gain through the building envelope based upon climate zone. However, rigorous integrated design will require that aperture, SHGC, U-factor and VT ratings be carefully selected to meet the daylight harvesting design intent and actual space use for a building’s or space’s orientation and local climate. In many instances, a high-performance solution may be best accounted for using a performance-method’s whole-building annual energy and performance analysis. Designers must also be careful when applying the prescriptive requirements established within individual codes, since not all codes define design parameters in consistent ways. The following narratives are provided to assist the user in understanding fenestration-related performance metric nuances specific to different, commonly used code documents and code language.

NOTE X: The following code information reflects the model code at the time this document was written. An attempt has been made to provide the most critical and relevant elements of the model energy codes and as such this should be a very useful guide.

When using this information please keep the following considerations in mind:

- Local jurisdictions often deviate from the model codes since they may choose to not adopt a model code or adopt it in its entirety, partially or as an amended version.
- Local jurisdictions will vary in which version of the model codes they currently enforce. The model codes themselves are always in a process of being reviewed and changed under its normal cycles.
- Local code authorities vary in their interpretation of the code.
- The reader must be diligent to verify what the local jurisdiction requires for the project at hand.
- The recognition and use of the IECC & the ASHRAE Standards varies by location; one or the other and on occasion both are used and referenced.
- In California the California Energy Code (CEC) (Title 24, Part 6) is the only recognized code by law. Local jurisdictions can also apply to the CEC to approve more stringent requirements as part of their CalGreen adoption.

Energy code compliance can follow two paths, either prescriptive or performance. The prescriptive path can be met by either meeting the tabulated criteria for each product category with the area-weighted average ratings for all units in that product category, or by calculating the whole envelope "UA" for the actual design and comparing it to a minimally compliant UA based on the tabulated criteria.

The performance path is an annual whole building energy use analysis, where all building components are modeled. The energy use of the proposed building design and its systems is compared to a "budget" based on a reference design using minimally compliant components and systems. This path gives the most flexibility for trading off items of less efficiency against higher efficiency elements, and often is the only way some designs can meet the codes economically.

A variant that is rapidly gaining traction for residential buildings is the "ERI" (energy rating index) method, which is based on the ANSI/RESNET 301 whole building analysis standard and the resulting Home Energy Rating Systems (HERS) determinations.
9.2.12.1 A review of the International Energy Conservation Code (IECC)

**NOTE 4:** Like all model codes and standards, editions of the IECC are adopted, in whole or in part, at the local or state level. The most current version may or may not yet be adopted. The user is again advised to consult with the appropriate or applicable jurisdiction code.

**Below Following** are summaries of some relevant sections in the 2018 IECC: C202, C303.1.3, C402.1.5, C402.2.1.1, C402.4, C402.4.2, C402.4.2.2, C402.4.3, C402.4.3.1, C402.4.3.2, C402.4.3.3, C402.4.3.4, C402.5.2, C405.2.3, C405.2.3.3, C407.3, C502.2.2

- **Skylight definition.** Different from the IBC, the IECC (and ASHRAE 90.1) establishes the dividing line that distinguishes a skylight from vertical fenestration at 60 degrees above horizontal. (This line is at 75 degrees in the IBC.)
- **Fenestration product rating.** U-factors for skylights must be determined in accordance with ANSI/NFRC 100 by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacking a labeled U-factor must be assigned a default U-factor from a default table.
- **SHGC and VT.** The SHGC and VT of skylights must be determined in accordance with ANSI/NFRC 200 by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacking such a labeled SHGC or VT must be assigned default values with SHGC ranging from 0.6 to 0.7 and VT ranging from 0.3 to 0.6 for double dome skylights. However, currently there is no NFRC-approved procedure for obtaining VT ratings for non-planar plastic glazed skylights.
- **Annual VT.** A new annual VT performance rating has been developed, which provides for a functional annual-averaged visible light transmittance performance rating of optically-complex fenestrations (i.e. TDDs) accounting for annual sun path data. Specifiers should be aware of this new rating as it starts to be incorporated into new codes and standards since it has a very different meaning and performance implication than the traditional Normal Incidence VT rating values.
- **Component performance alternative.** Building envelope values and fenestration areas determined in accordance an total building envelop analysis with consideration given to wall, roof and fenestration area weighted performance must be permitted in lieu of compliance with the $U$, $F$, and $C$-factors in the prescribed tables
- **Skylight curb insulation.** Skylight curbs must be insulated to the level of roofs with insulation entirely above deck or R-5, whichever is less except when the skylight curbs are included as a component of a skylight listed and labeled in accordance with ANSI/NFRC 100
- **Skylights & daylight controls.** Fenestration by the prescriptive method must comply with the prescribed sections and include daylight responsive controls in compliance with code requirements
- **Maximum area.** The skylight area must not be greater than 3 percent of the gross roof area but can be increased to 6 percent with daylight responsive controls.
- **Minimum skylight fenestration area.** In an enclosed space greater than 2,500 square feet in floor area, directly under a roof with not less than 75 percent of the ceiling area with a ceiling height greater than 15 feet the total daylight zone under the skylights must be not less than half the floor area and must provide either a minimum skylight area to daylight zone under skylights of not less than 3 percent where all skylights have a VT of at least 0.40 or a minimum skylight effective aperture of at least 1 percent, determined in accordance with the following equation below:

$$\text{Skylight Effective Aperture} = \frac{0.85 \cdot (\text{Skylight Area}) \cdot (\text{Skylight VT}) \cdot (WF)}{\text{Top lit zone}}$$

Skylight area = Total fenestration area of skylights.

Skylight VT = Area weighted average visible transmittance of skylights.

WF = Area weighted average well factor, where well factor is 0.9 if light well depth is less than 2 feet (610 mm), or 0.7 if light well depth is 2 feet (610 mm) or greater.

Light well depth = Measure vertically from the underside of the lowest point of the skylight glazing to the ceiling plane under the skylight. (C402.4.2)
• **Lighting controls** in toplit daylight zones are required
• **Haze factor** of skylight plastic glazing must be greater than 90 percent when tested in accordance with ASTM D 1003 except for skylights designed to exclude direct sunlight entering the occupied space by the use of fixed or automated baffles or the geometry of skylight and light well. (This requirement is dependent upon usage of the space.)

**NOTE 6: For more discussion of haze measurement please refer to Section 7.0 of AAMA PSSG-16-“Selection and Application Guide for Plastic Glazed Skylights and Sloped Glazing.”**

Some exceptions apply to the minimum skylight area requirements, such as:

• Buildings in climate zones 6 through 8
• Spaces where the designed general lighting power densities are less than 0.5 W/ ft²
• Areas where it is documented that the existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed area for more than 1500 daytime hours per year between 8am and 4pm.
• Spaces where the daylight zone under the rooftop monitors is greater than 50% of the enclosed space floor area.
• Spaces where the total area minus the area of daylight zones adjacent to vertical fenestration is less than 2,500 square feet when code compliant lighting controls are utilized.
- **Maximum U-factor and SHGC.** The prescriptive maximum area-weighted average U-factor and solar heat gain coefficient (SHGC) for skylights are as follows:

<table>
<thead>
<tr>
<th>CLIMATE ZONE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4 EXCEPT MARINE</th>
<th>5 AND MARINE 4</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.75</td>
<td>0.65</td>
<td>0.55</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>SHGC</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>NR</td>
</tr>
</tbody>
</table>

NR = No Requirement

**TABLE 8: Building Envelope Fenestration**, table comes from the 2018 IECC Code

- **Increased skylight SHGC is permitted** - in Climate Zones 1 through 6, skylights are permitted a maximum area-weighted average SHGC of 0.60 where located above daylight zones provided with daylight responsive controls.

- **Increased skylight U-factor is permitted** - where skylights are installed above daylight zones provided with daylight responsive controls, a maximum area-weighted average U-factor of 0.9 is permitted in Climate Zones 1 through 3 and a maximum area-weighted average U-factor of 0.75 is permitted in Climate Zones 4 through 8.

- **Dynamic glazing** - When dynamic glazing is intended to satisfy the SHGC and VT requirements the ratio of the higher to lower labeled SHGC must be greater than or equal to 2.4, and the dynamic glazing must be automatically controlled to modulate the amount of solar gain into the space in multiple steps. Dynamic glazing must be considered separately from other fenestration, and area-weighted averaging with other fenestration that is not dynamic glazing is not permitted.

- **U-factor and SHGC.** An area weighted average are permitted to satisfy the U-factor and SHGC requirements for each fenestration product category. Individual fenestration products from different fenestration product categories must not be combined in calculating area-weighted average U-factor.

  "Area-weighted average” is:

  Sum of all individual units’ (rating x area), divided by the total area of all the units

  \[
  \left( \sum (A_1 \times \text{Rating}_1, \ldots, A_n \times \text{Rating}_n) / \sum (A_1, \ldots, A_n) \right)
  \]

- **Air leakage of fenestration.** The air leakage of skylights must not exceed 0.30 CFM/SQ-FT (skylights with condensation weeps) and 0.20 CFM/SQ-FT (All other skylights). Testing must be in accordance with AAMA.WDMA.CSA 101/I.S.2/A440 or NFRC 400 and performed by an accredited, independent testing laboratory and labeled by the manufacturer.

- **Daylight-responsive controls** - Code compliant daylight-responsive controls must be provided to control the electric lights within daylight zones in the following spaces:
  - Spaces with a total of more than 150 watts of general lighting within toplit daylight zones meeting all other relevant code requirements
  - Daylight responsive controls are not required for spaces in health care facilities where patient care is directly provided, dwelling units and sleeping units, lighting that is required to have specific application controls required by the code for other purposes

- **Daylight-responsive control function** - When required, daylight-responsive controls must be provided within each space for control of lights in that space and must comply with all of the following:
  - Lights in toplit daylight zones are controlled independently of lights in sidelit daylight zones
  - Daylight responsive controls within each space are configured so that they can be calibrated from within that space by authorized personnel.
  - Calibration mechanisms are readily accessible.
- Where located in offices, classrooms, laboratories and library reading rooms, daylight responsive controls are able to dim lights continuously from full light output to 15 percent of full light output or lower.
- Daylight responsive controls are configured to completely shut off all controlled lights.
**Toplit daylight zone** - The toplit daylight zone is the floor area underneath a roof fenestration assembly complying with all of the following:

- The toplit zone extends laterally and longitudinally beyond the edge of the roof fenestration assembly to the nearest obstruction that is taller than 0.7 times the ceiling height, or up to 0.7 times the ceiling height, whichever is less, see Figure 16 below:

![Diagram of Toplit Daylight Zone](image)

**FIGURE 416:0 Toplit Zone Figure courtesy of 2018 IECC**

- No building or geological formation blocks direct sunlight from hitting the roof *fenestration* assembly at the peak solar angle on the summer solstice.

- Where located in existing buildings, the product of the VT of the roof fenestration assembly and the area of the rough opening of the roof fenestration assembly divided by the area of the daylight zone is not less than 0.008.
The following is a review of the code for residential buildings (those covered by the scope of the IRC). The following review shows only the provisions that are different from those in the IBC and reflect the residential provisions of the IECC, for use in those jurisdictions that adopt both codes (or the IRC only):

9.33.1 International Residential Building Code (IRC)

Some relevant sections in the code reviewed below in the following bullet points: IRC R301.2.1, IRC R303.1, IRC R308.6, IRC R308.6.2, IRC R308.6.8, IRC R308.6.9

- Wind design criteria - Where not otherwise specified, the wind loads listed in Table R301.2(2) adjusted for height and exposure using Table R301.2(3) are used to determine design load performance requirements for skylights.

- Habitable rooms - Habitable rooms must have an aggregate glazing area of not less than 8 percent of the floor area of such rooms. Natural ventilation are through windows, skylights, doors, louvers or other approved openings to the outdoor air. Such openings are provided with ready access or must otherwise be readily controllable by the building occupants. The openable area to the outdoors is not less than 4 percent of the floor area being ventilated.

- Curbs for skylights - Unit skylights installed in a roof with a pitch less than three units vertical in 12 units horizontal (25-percent slope) are mounted on a curb extending not less than 4 inches above the plane of the roof unless otherwise specified in the manufacturer's installation instructions.

- Testing and labeling - Unit skylights and tubular daylighting devices are tested by an approved independent laboratory, and bear a label identifying manufacturer, performance grade rating and approved inspection agency to indicate compliance with the requirements of AAMA/WDMA/CSA 101/I.S.2/A440. Comparative analysis is allowed for glass-glazed skylights for sizes different from a tested size.

Some relevant sections in the code reviewed below in the following bullet points: IECC R303.1.3, IECC R402.3, IECC R402.3.1, IECC R402.3.2, IECC R402.3.3, IECC R402.4.3, IECC R402.5

- Fenestration product rating - U-factors of skylights are determined in accordance with ANSI/NFRC 100 by an accredited, independent laboratory, and third-party authorized label applied by the manufacturer. Products lacking such a labeled U-factor are assigned a value from a default table.

- The SHGC and VT of skylights are determined in accordance with ANSI/NFRC 200 by an accredited, independent laboratory, and third-party authorized label applied by the manufacturer. Products lacking such a labeled SHGC or VT are assigned values from default tables.

- Skylight U-factor – Per Table R402.1.2, the prescriptive maximum weighted average U-factor is 0.55, slightly higher in the southern two climate zones. The SHGC maximum applies to all glazed fenestration. Exception: Skylights in climate zones 1 through 3 where the weighted average SHGC for such skylights does not exceed 0.30. There are no SHGC requirements in the Marine Zone 4.

- Glazed fenestration exemption - Up to 15 square feet of glazed fenestration per dwelling unit are permitted to be exempt from U-factor and SHGC requirements, except when the U-factor alternative approach is used.

- Air leakage - Skylights must have an air infiltration rate of no more than 0.3 cfm per square foot when tested according to NFRC 400 or AAMA/WDMA/CSA 101/I.S.2/A440 by an accredited, independent laboratory and listed and labeled by the manufacturer.

- Maximum fenestration U-factor and SHGC - The area-weighted average maximum fenestration U-factor permitted using tradeoffs are 0.75 in Climate Zones 4 through 8 for skylights. The area-weighted average maximum fenestration SHGC permitted using tradeoffs in Climate Zones 1 through 3 are 0.50.*
10.0 SKYLIGHT FALL PROTECTION

There are more than a dozen trades in which workers are permitted regular access to flat or low-sloped roofs, including but not limited to roofing, building maintenance, HVAC, electrical, plumbing and telecommunications personnel.

According to the AAMA 2015/2016 U.S. Industry Market Study, there are nearly 275,000 commercial unit skylights sold annually. Nearly all commercial unit skylights installed on roofs accessed regularly by workers are aluminum framed and most use some form of plastic glazing (acrylic is most common).

It is difficult to determine how many workers are exposed to the fall hazards on a roof every day. According to the Bureau of Labor and Statistics, there are more than 120,000 roofers alone who are obviously at risk. Add in the other trades that frequently access flat or low-sloped roofs and MILLIONS of existing unit skylights on the roofs...the risk exposure is significant.

Periodically, fatalities attributed to skylights (which may include uncovered roof openings) are highlighted in industry publications and outside media. As illustrated in the graphics Figure 17 below, the actual number of fatalities associated with skylights and skylight openings is very small when compared to other workplace injuries and fatalities. It is important for all workers that have access the roof to be aware of all the hazards, including the potential to fall into a skylight, and how to prevent such incidents.

NOTE: A child should never have access to a roof where they could fall.

The risk exposure of falling through a skylight opening is SIGNIFICANT.
The actual number of fatalities attributed to skylights is comparatively MINIMAL.
BUT...every fall fatality is AVOIDABLE.

Currently, there is not a standardized method for testing a skylight for its ability to withstand an impact from a falling human. OSHA, and similar authorities, has established regulations – but the skylight industry generally agrees that these regulations are vague and open to different interpretations. ASTM has drafted a standard and test method to validate a skylight's (or related product's) ability to support the effect of the impact from a large male, and the extensive review process is underway.
Fall protection must be shared amongst the many parties involved with the design, construction and maintenance of roofs. The following established safety procedures for minimizing risk should be implemented and followed first as a strong foundation for mitigating the occurrence of all falls from roofs and roof openings. When the glazing is not proven to be sufficiently resistant to falls, the use of railings, security grids or safety screens (not to be confused with insect or glass retention screens) are recommended.

Only construction and building maintenance professionals should ever be on a roof, as there are a number of potential fall hazards present, including skylights. Access to a roof is the responsibility of the building owner and should be limited to such personnel by whatever reasonable means necessary.

Applicable OSHA safety regulations should be complied with at all times when it is necessary for individuals to be on a roof. This may include, but is not limited to, the use of guards, PFAS (personal fall arrest systems) and warning signs.

All individuals allowed to be on a roof as described above must be fully trained on roof safety by their employer and should have the competence and sense of personal responsibility and personal safety to follow all roof safety practices. The employer should have qualified personnel identify all potential roof hazards and ensure that all precautionary measures and practices are implemented. This may include, but is not limited to, the use of temporary barriers, PFAS (personal fall arrest systems) and warning signs. The potential hazards and safety measures implemented specific to the site must be communicated to and understood by all personnel working on the roof.

Signage should be posted by the building owners and managers at each access point on to the roof communicating roof safety and inherent dangers.

Skylights, and the roofs they are mounted in, are designed to resist the applicable environmental load requirements such as snow loads, wind loads, dead loads and, in some cases, hurricane-induced wind-borne debris impact loads. Standard design practices do not dictate that they are to be manufactured for human impact or point loads. Warning labels on skylights indicate this, as required by some evaluation entities (such as International Code Council-Evaluation Service) since 1986. In some cases, signage properly placed at roof access points has been employed to communicate this as well.

More information regarding the previous bullet points can be referenced from the National Institute of Safety and Health (NIOSH).

The AAMA Skylight/Sloped Glazing Council has worked diligently for over 30 years to establish technically solid performance standards and design guidelines in which safety has always been an important consideration. The issue of fall protection is not a new one. Manufacturer members of the AAMA Skylight/Sloped Glazing Council have been proactive in improving the safety performance of their products; as manufacturers of a product that is installed on a roof by customers, roof safety issues have been a consideration for some time.

As such, the Council’s mission is to look objectively at this issue and all its elements from which the data is derived. The AAMA Skylight/Sloped Glazing Council will continue its commitment to roof safety as presented here and will endeavor to pursue reasonable approaches in the future through the AAMA Fall Protection Task Group, along with continued participation in ASTM’s E06.51–25 Sub-committee developing Work Item WK17797. The draft document is entitled Standard Specification and Test Method for Human Impact and Fall-through Resistance of Unit Skylights and Related Products Used on Skylight Openings on Non-Residential Buildings.
11.0 SKYLIGHT SELECTION GUIDE

When determining a skylight type, the client’s needs must first be considered. Appearance, lighting requirements, energy performance, structural performance, ventilation capability, and egress requirements all play a role in selecting the most appropriate type of skylight for a project. Unit skylights and tubular daylighting devices are used for smaller rooms or to evenly distribute light over large open areas such as big box retail and warehouse spaces. Sloped glazing is typically associated with larger monumental applications and can provide an architectural feature as well as deliver natural light to a building. The following skylight categories are those most commonly used when designing a space. (briefly describe for when each is most commonly used for both residential and commercial applications and why) — Use definitions from the IBC and IECC.

11.1 Unit Skylights (Figures 18 thru 23)

A unit skylight (Figures 18-23) is a complete factory assembled glass or plastic-gazed fenestration unit consisting of not more than one panel of glass or plastic installed in a sloped or horizontal orientation that allows for natural daylighting. Unit skylights are either fixed (non-operable) or venting (operating). Operable skylight controls enable increased functionality, efficiency and occupant comfort, when they communicate with an automated indoor environment control system. Also, many operable and fixed skylights are available with pre-installed blinds and shades — motorized types of these also can be automated to respond to changes in ambient conditions.

In some cases plastic glazed roof top heat and smoke vents can be considered as unit skylights in the fact that they transmit light into the space as a secondary function to their primary purpose of venting smoke in a fire (unit definition comes from NAFS).

11.1.2 Types of Unit Skylights (or roof windows)

![Flat Unit Skylight](image1)
![Bubble Unit Skylight](image2)
![Pyramid Unit Skylight](image3)

![Parabolic Unit Skylights](image4)
![Circular Unit Skylight](image5)

FIGURE 148: Flat Unit Skylight
FIGURE 129: Bubble Unit Skylight
FIGURE 1320: Pyramid Unit Skylight

FIGURE 421: Parabolic Unit Skylights
FIGURE 22: Circular Unit Skylight
Operator Types

Operable skylights have either manual or motorized venting operation.

Manual Venting - Manual venting is performed by a hand crank, or a pole and loop adaptor and pole, when the unit is out of reach (see figures 1724 & 1825).

Motorized Venting - Motorized vents can be either operated electrically or solar powered (see Figure 1926).
11.2 Roof Windows

A roof window differs from a unit skylight in that roof windows are generally installed on a sloped roof for in-reach operation and in many cases can be used as a means of egress.

Note: Flat unit skylights and roof windows are often combined with tight-fitting interior shades that can assist with reducing peak transmission of heat and glare, and sometimes darkening the room. Electric, solar-powered operators are becoming prevalent, allowing either fixed or venting types to have remotely operated shading powered by the sun.

In addition, solar-powered venting unit operators, as well as shading, are now controllable automatically to maintain the desired indoor light, heat and air quality targets desired by the owner.

11.3 Tubular Daylight Devices

A non-operable fenestration unit primarily designed to transmit daylight from a roof surface to an interior ceiling via a tubular conduit. The basic unit consists of an exterior glazed weathering surface, a light-transmitting tube with a reflective interior surface, and an interior sealing device such as a translucent ceiling panel (see Figure 27). The unit is traditionally field assembled from a manufactured kit. (Figure 27)
11.4 Sloped Glazing

Glass and framing assembly (other than a unit skylight or tubular daylighting device) or other transparent or translucent glazing material installed at a slope of 15 degrees (0.26 rad) or more from vertical. ([Figures 28 through 33])

**FIGURE 1928**: Pyramid Skylight

**FIGURE 209**: Extended Pyramid/Hipped Ridge Skylight

**FIGURE 2130**: Ridge/Double Pitched Skylight

**FIGURE 2231**: Single Pitched Skylight

**FIGURE 2432**: Polygon Skylight

**FIGURE 2533**: Vaulted Skylight
12.0 EMERGING DAYLIGHTING / GLAZING TECHNOLOGIES

Emerging technologies are technical innovations which represent progressive developments within the daylighting industries. At the time this document was written there were several areas worth mentioning which are directed at increasing the use of natural daylight while reducing the carbon footprint on the planet.

- Dynamic glazing’s are products that change tint (or darken or shade) in response to temperature (thermochromic), sunlight (photochromic), or electric charge (electrochromic). These products can control the amount of light and heat entering a building thus having a large impact on solar heat gain within the building and personal comfort of its occupants.

- Advanced coatings are coatings comprised of organic or inorganic materials (metal and metal oxides/nitrides), that are deposited on the glazing surface, via sputtering or physical vapor deposition, that which improves the emissivity; adds electrochromic performance; and can provide for self-cleaning features.

- Optically enhanced glazing is the use of stacks and/or layers of a variety of sputtered metal and metal oxides on the glazing surface to improve SHGC; U-Factor; and light transmission or otherwise optically tuned to provide enhanced performance.

- Power generating glass such as Building Integrated Photovoltaics (BIPV) that have photovoltaic cells and panels integrated into the glazing panel have the benefit of producing renewable energy and providing additional shading to the glazing.

- Vacuum glass provides a vacuum space between two panes of glass. Heat is conducted by three modes: conduction, convection, and radiation. A vacuum prevents conduction and convection, and while a reflective coating serves to reflect radiated heat back where it came from.

- Solar tracking fiber optic daylight transmitting devices track and capture the sunlight using solar receivers on the outside of the building. Fiber optic cables then transfer the sunlight through the building structure and into the indoor environment to areas of a building not otherwise accessible to natural daylight by side-lighting or top-lighting.

- Solar intensifiers, usually found within the skylight, can track and/or simply increase the amount of sunlight from sunrise to sunset that is delivered into the building, thus improving the light transmission efficiency of the product.
APPENDIX A: SIMULATION AND DESIGN TOOLS

There is a difference between a calculation engine and the user interface. Many software tools make use of a common open source calculation engine (i.e. Radiance, or DOE 2.2) and apply their own unique graphical user interfaces (GUI) for input and output processing and reporting.

A1.0 Lighting / Daylighting (Hourly/Annualized) Software

LightStanza – A newcomer to the industry, created by Light Foundry, LLC, it is an innovative cloud-based, hourly daylighting design and analysis tool that allows for full, real-time, collaborative design and analysis for all members/disciplines in a building’s design team. ([http://lightstanza.com/](http://lightstanza.com/))

Radiance – Radiance is an open source synthetic imaging tool for UNIX computers, developed and produced by the Building Technologies Department of the Environmental Energy Technologies Division at DOE’s Lawrence Berkeley National Laboratory. RADIANCE is a highly accurate ray-tracing software system and uses a suite of programs for the analysis and visualization of lighting in design. ([http://radsite.lbl.gov/radiance/](http://radsite.lbl.gov/radiance/))


DAYSIM – DAYSIM is a Radiance-based daylighting simulation engine that allows users to evaluate the annual amount of daylight in and around buildings. It can be used to model dynamic facades systems including standard venetian blinds, state-of-the-art light redirecting elements, switchable glazing and combinations thereof. Users may further specify complex electric lighting systems and controls including manual light switches, occupancy sensors and photocell controlled dimming.

Simulation outputs include climate-based daylighting metrics such as daylight autonomy and useful daylight illuminance, annual glare indices and electric lighting energy use. DAYSIM can also be used to generate hourly schedules for occupancy, electric lighting loads and shading device status that can be directly coupled with thermal simulation engines such as EnergyPlus and eQUEST. Rhinoceros and SketchUp are Graphical User Interfaces which use DAYSIM, a Radiance-based daylight simulation engine. ([http://daysim.ning.com/](http://daysim.ning.com/))

AGi32 – AGi32 is a detailed lighting photometric design, analysis-, and visualization software tool produced by Lighting Analysts. AGi32 can be used calculate the amount of light that will be delivered in any space of varying shapes, interior or exterior, and supports the inclusion of surrounding objects, obstructions. The software tool aids lighting designers, engineers, and electrical contractors in the evaluation of lighting and traditional daylighting design solutions designs for projects through detailed interior illuminance calculations, glare metrics, and photo-realistic rendering. ([https://lightinganalysts.com/](https://lightinganalysts.com/))
A2.0 Energy Analysis Software

**DOE 2.2** – Serves as the calculation engine for eQUEST, or can be used as a standalone tool. (see [http://www.doe2.com/](http://www.doe2.com/)).

**EnergyPlus** – This is the primary whole building energy analysis engine that DOE still supports. It has much more capability than DOE 2.2, although it takes longer to run a model. Most modern user interfaces offered now use this engine. (see [https://energyplus.net/](https://energyplus.net/)).

**SkyCalc** – SkyCalc, developed by the Heschong Mahone Group, is a Microsoft Excel spreadsheet tool that allows building designers to determine the optimum skylighting strategy for optimal lighting and HVAC energy savings. SkyCalc is not an annual simulation tool, but rather a spreadsheet tool that allows user-defined parameters to scale annual building performance data developed for a “model” building developed using DOE-2 energy simulations. Since SkyCalc uses the Zonal Lumen Method for evaluating daylight harvesting benefits, the tool does not support the use of today’s optically complex fenestration systems. ([http://h-m-g.com/downloads/SkyCalc/sky30_download.htm](http://h-m-g.com/downloads/SkyCalc/sky30_download.htm))

**eQUEST** - eQUEST is a freeware tool designed to allow architects to perform detailed analysis building design technologies using sophisticated building energy use simulation techniques but without requiring extensive experience in the "art" of building performance modeling. eQUEST accomplishes this by combining a building creation wizard, an energy efficiency measure (EEM) wizard, and a graphical result display module with an enhanced DOE-2-derived building energy use simulation program. ([http://energydesignresources.com/resources/software-tools/equest.aspx](http://energydesignresources.com/resources/software-tools/equest.aspx))
B1.0 Residential Home

Zausner Residence, Waldoboro, Maine

**Challenge:**
The owner was looking for a new classic-revival style home with modern amenities that looked like it had a sense of history and had been around for a long time. The architects wanted to maximize the use of daylighting because of the cooler northern climate and wonderful quality of light in Maine. Additionally, the design needed to appear traditional from the exterior. Choosing the right daylighting system for this home was a key to the design. Daylighting exerts a profound effect on a person’s mood and productivity. Poorly designed skylights can be uncomfortable to be under. They’re sometimes hot, and the glare can be too intense if not designed properly.

**Solution:**
This innovative design featured “skylight dormers” which created dramatic lighting effects and allowed daylight to bathe the rooms from above while maintaining privacy in private areas such as bathrooms. In some areas, rooms to glowed from above and below due to glass blocks set into wood surrounds. The skylights are on the east and west sides of the roof. An extended pyramid skylight was used. The units are 4”-2” x 7”-9” (custom sizing). The sloped glazing was 1 1/16” I.G. – 1/4” Clear tempered over 5/16” clear, H.S. Laminated w/Low-E (3). The light wells themselves are 4”-2” wide x 7”-9” deep and x 4”-7” high (w, d, h). Some of the light wells use sloped walls to reflect the light down into the space. While the skylights themselves are not vented, there are operable windows in the light wells.
The sky view provided by the new skylight is stunning day or night. A light fixture hanging from the middle incorporates a new “cloud” designed to control sound and echoes. The new system was glazed in only 36 hours, is hail resistant and energy efficient.

POLYGON DOME
Private Residence

Challenge:
A 30 ft diameter, sixteen-sided, white, round skylight still had the original single layer acrylic glazing, no sky view and was damaged by hail. The skylight did not meet current energy codes and the structure was not strong enough to hold double glazing. Glass would reflect the new curb and the lighting that surrounded the opening, especially at night.

The client also wanted to hang a light fixture from the middle and incorporate a new “cloud” off the pole that held the fixture, designed to control sound and prevent echoes. Light quality and heat loss and gain were of the utmost importance.

Solution:
The new skylight retrofit was designed with the same amount of sides, but with more segments up the skylight and a slightly higher elevation for better aesthetics.

A new curb was engineered that could handle the thrust loads of the new skylight. To avoid reflections of the lights on the glass at night, the inside of the curb was finished with white aluminum cladding and a white acrylic lens was designed to cover the lights. A seven-foot-long chandelier and an eight foot sound-deadening “cloud” was suspended from the center of the new skylight retrofit—with the wiring hidden within the internal structure. Advanced glazing technology ensured daylighting and solar heat levels were corrected.
Urban Outfitters began a massive renovation of multiple dilapidated old buildings in Philadelphia’s abandoned Navy Yards as part of an ongoing plan to consolidate their operations into a single campus. Building 18 was a very ornate, wonderful piece of historical architecture, and the only Navy Yard building with a pre-existing open glazing system over the length of the building.

Challenge:
The goal was to provide a design that met the National Park Service’s stringent standards for historic renovation. Attaching the massive metal skylight structure to the curbing and integrating with the roof posed a special engineering challenge. The existing roof deck, with underlying concrete roof panels was restored to original historical specifications so proper attachment required precise engineering and manufacturing. Some were restored and the others replaced depending on the pre-existing condition. They also wanted to maximize the daylight opening but reduce glare and solar heat gain to make a comfortable working environment since natural light was extremely important for both morale, productivity and product development in this creative driven industry.

Solution:
A custom tinted glazing was developed utilizing a combination of Solarban 70 Low E bronze and clear laminated glass to provide all the positive benefits of natural daylight without suffering the undesirable effects such as excessive heat gain, glare and fading.
B2.1 Big Box Store

Hannaford Supermarket
Augusta, ME

Challenge:
The objective was to supply sufficient diffused natural light to key sections of the 50,000 square foot supermarket for both general and task lighting while significantly reducing energy costs.

Solution:
Architect Rick Ames, of Boston-based Next Phase Studios, chose unit skylights with aerogel. Fifty-four 4’x4’ unit skylights were installed for both general and task lighting in critical areas of the store. Most of the units were used to light the perimeter areas where Hannaford displays its own brand products, meat and produce. The diffuse quality of the light transmitted by aerogel skylights protects produce and meat products from harsh sunlight that could speed their deterioration.

Skylights were used to illuminate service and delivery corridors where there is limited need for artificial light. Skylights down the center of the store supplied sufficient general lighting with additional skylights installed to highlight specific displays. The aerogel-enhanced skylights provide a high insulating value and an excellent solar heat gain coefficient.
B2.2 Warehouse / Manufacturing

SIPCO - Jeddah Distribution Center, Kingdom of Saudi Arabia

Challenge:
Saudi Industrial Projects Company (SIPCO) makes, sells, and distributes some of the world’s most recognized consumer brands. Lack of natural light forced the use of an electrical lighting system that incurs operational and maintenance costs. The installed 400W Metal Halide lamps were operated at half strength to reduce power usage and heat build-up, thus creating lower illumination levels and a difficult environment for workers.

Solution:
SIPCO installed large tubular daylighting devices to meet the required illumination standards which subsequently reduced electricity consumption for lighting dramatically. The area was a high open ceiling distribution center where 185 daylighting systems were installed to achieve an average of 200 lux throughout the year. The installed units resulted in a savings of 648,240 KWH/year. One month after installation of the daylighting systems, SIPCO saw savings of SAR 17,011 ($4,530 USD) in the electrical bill. Reducing heat generated by electric, which reduces cooling loads, contributes to the overall savings. Thermographic imagery shows the difference between electric lights and tubular daylighting. Workers welcome the impact of natural light in daily work activity and management is satisfied by the results as it exceeds expectations. Similar projects are currently under study for different locations. The customer’s affiliated companies have installed tubular daylighting devices globally and consider them to be one of their main solutions towards green operations.
B2.3 Retrofit/Remodel

DPR Construction, Phoenix

**Challenge:**
The objective of DPR Construction was to renovate a current building into a Net-Zero office space for its Phoenix team. Incorporating its innovative mindset and goal for all employees to work in a sustainable, healthy environment, the company wanted to create a living laboratory for its work environment. DPR wanted to build a first-of-its-kind, revitalized building that serves as a statewide example of how sustainable design can be integrated into an efficient, effective, and environmentally responsible office space. The challenge was to take the remains of a circa-1972 boutique building and reconstruct it into a 16,533-square-foot building with innovative features to improve energy efficiency.

**Solution:**
Holistically designed with environment and comfort of its employees in mind, the new office integrated alternative ways to light the space; the expansive walls of windows and 82 strategically positioned tubular daylighting devices nearly eliminate the need for artificial daytime lighting 365 days a year. Studies were conducted to determine the appropriate height, location and size of the daylighting units, and to ensure that daylight was evenly distributed throughout the space. The daylighting systems directly helped the building attain Net-Zero Energy Building (NZEB) certification and LEED®-NC Platinum certification.
B2.4 Educational

Community College of Southern Nevada, Henderson, Nev.

Challenge:
Completed in September 2004, this was the first LEED-registered building in the State of Nevada; it has also achieved Energy Star Building status. The Morse Arberry Jr. Telecommunications Building, located at the South Campus Entrance, provides computer technology and associated electronic communications training for students, and it houses state-of-the-art classrooms, computer laboratories, a TV production studio, and telecommunications editing facilities. The challenge was to create an energy-efficient, high-technology structure that enables the fast-growing college to serve the educational needs of additional students while providing a stimulating learning environment.

Solution:
As part of the sustainable design strategy for the 85,000-square-foot building, 25 percent of the building was constructed from recycled materials and 75 percent of the rooms are daylit. All top floor classrooms are daylit with 68 tubular daylighting devices. Dimmers were added (to darken rooms for presentations and movies) to achieve optimum light levels. The new building serves as the home to the engineering, computing/information and media technology departments.
APPENDIX C.: Other Case Studies available online at time of publication:

http://eneref.org/report-details/lighting-project-brings-natural-daylight-into-karndean-warehouse/