SKYLIGHT PERFORMANCE SPECIFICATIONS

The following sections cover specification issues and technical concepts employed by Adaptive Energy Systems Corporation.

1. GLAZING MATERIALS

Glazing is one of the most important factors in good skylight design. We have eliminated the many alternatives and choices to consider. AES has developed a line of natural lighting fixtures that does not compromise optical performance that influence both daylight quality and potential energy savings. We have created a system that has virtually no impact on heating and cooling loads in its designed environment.

- **Glazing Efficacy** is the measure of how much light penetrates all the layers of glazing in relation to how much solar light gets through. We specifically refer to this as "light to solar gain ratio" or LSG. It is the ratio of visible transmittance (T_{vis}) to solar heat gain coefficient (SHGC) of the glazing. The relationship between LSG and SHGC determines how efficiently the glazing materials will perform.

1.1. GLAZING PERFORMANCE TRADITIONAL vs. ADVANCED SKYLUME

TYPE	LAYERS	COLOR	TVIS	SHGC	LSG	0-5 Yrs LLF	6-10 Yrs LLF
SkyLume	**Triple Glazed**	**Clear**	**.89**	**.24**	**3.71**	**2.5%**	**3%**
Traditional:							
Acrylic	Single Glazed	Clear	.92	.77	1.19	15%	25%
		Med White	.42	.33	1.27	25%	50%
		Bronze	.27	.46	.59	20%	35%
	Double Glazed	Clear	.86	.77	1.10	12%	22%
		Med White	.39	.30	1.28	18%	35%
		Bronze	.25	.37	.67	18%	27%
Fiberglass	Insulated	Crystal	.30	.30	1.01	30%	65%
	Translucent	White	.20	.23	.85	40%	70%
	U –0.24	Bronze	.10	.16	.64	30%	65%
Polycarbonate	Single Glazed	Clear	.85	.89	.96	20%	45%
		Bronze	.50	.69	.73	25%	50%
		Med White	.37	.50	.73	35%	55%
	Double Glazed	Clear	.73	.75	.97	20%	45%
		Med White	.43	.58	.73	25%	50%
		Bronze	.32	.43	.74	35%	55%
Glass	Single Glazed	Clear	.89	.82	1.09	5%	12%
		Med White	.55	.64	.87	15%	35%
		Bronze	.74	.59	1.25	12%	28%
	Double Glazed Low - e	Clear	.72	.57	1.25	5%	12%
		Bronze	.45	.39	1.15	15%	35%
		Green	.61	.39	1.56	15%	70%
	Triple Glazed Low – e	Clear	.70	.53	1.32	5%	12%
		Bronze	.42	.37	1.14	15%	35%
		Green	.61	.38	1.61	15%	70%

1.2. VISIBLE TRANSMITTANCE

The visible transmittance of a glazing material is the essential measurement for judging how much light will get through. It is reported as a ratio, and labeled either Tvis or VT for visible transmittance. The above listed Tvis numbers are generated from ASHRAE and IESNA handbooks.

Another issue with visible transmission is performance over time; some products may degrade over time, and have lower transmittance as they age. Fiberglass and Plexiglas is especially suspect in this area, as plasticisers and thermo-set resins used in manufacturing will change transmission characteristics under extended exposure to heat and ultraviolet light on the top surface. Please note typical LLF of each standard units.

1.3. SOLAR HEAT GAIN COEFFICIENT OR SHADING COEFFICIENT

While visible transmission measures the amount of the visible spectrum that will pass through a material, the heat gain coefficient (SHGC) measures the amount of solar spectrum that will pass through the material. Solar radiation contains a wide spectrum of wavelengths including ultraviolet, visible light, and infrared radiation. Eventually all energy is degraded to heat within the building.

The SHGC and shading coefficient (SC) are often used interchangeably, and are just as often confused. They both describe a ratio of how much of the overall solar radiation will penetrate the glazing materials and eventually be transformed into heat. However there is an important distinction between the two. The earlier less accurate SC assumes that all wavelengths of light are reflected or absorbed at the same rate. This has been traditional form of measurement in traditional skylights.

The SHGC is preferred measurement because it accurately accounts for variations in reflectance and absorption for different wavelengths and can handle a wider range of materials. The SHGC more accurately measures solar heat gain through multiple layers of glazing, materials with high reflectivity, low e coatings, or plastic materials that interact differently with various wavelengths of the solar spectrum.

The advanced Skylume systems use reflective coatings in the system that absorb wavelength specific solar rays and allow 100% visible light to reflect without distortion to light bounces. The ability to collimate natural daylight allows the system to create high Tvis properties while maintaining excellent thermal properties. As the table shows we perform much better than any low e coating system on the market today.

1.4. DIFFUSION

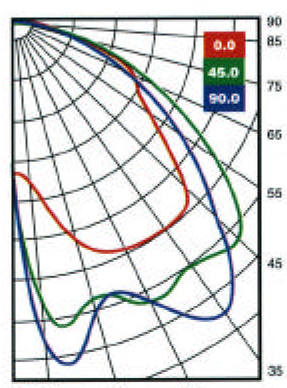
Merely specifying the visible transmittance and solar heat gain coefficient is not a sufficient description of a glazing product for skylights. Any specification should also include a description for diffusing properties. Traditional skylights rely on opaque lenses to distribute and diffuse light in the environment. By relying on collection lens to operate on the diffusing element uniform light relies completely on Sunlight and Skylight.
These two types of light are the most intense type of solar radiation and are non-polarized light, which generally cause glare in the environment.

Adaptive Energy Systems, Inc. realizes that there are no current standards for measuring diffusion properties of skylights. We have generated an IES file for skylight that was intended to describe the diffusion qualities of the skylight then factor in light intensity with a program developed by DOE called Skycalc for light level descriptions. This will aid in quantitative measures needed for commission light systems within the environment.

SkyLume Series 4’x4’ Distribution Data

Photometric Data

Solar Source (Lumens)	140,000
Luminaire Width	3.78'
Length	3.78'
Height	4.0'
Photometry Type	C
Total Opacity Efficiency	88.1%
Test Distance	20"
Space to Mtg. (S/M H)	2.82



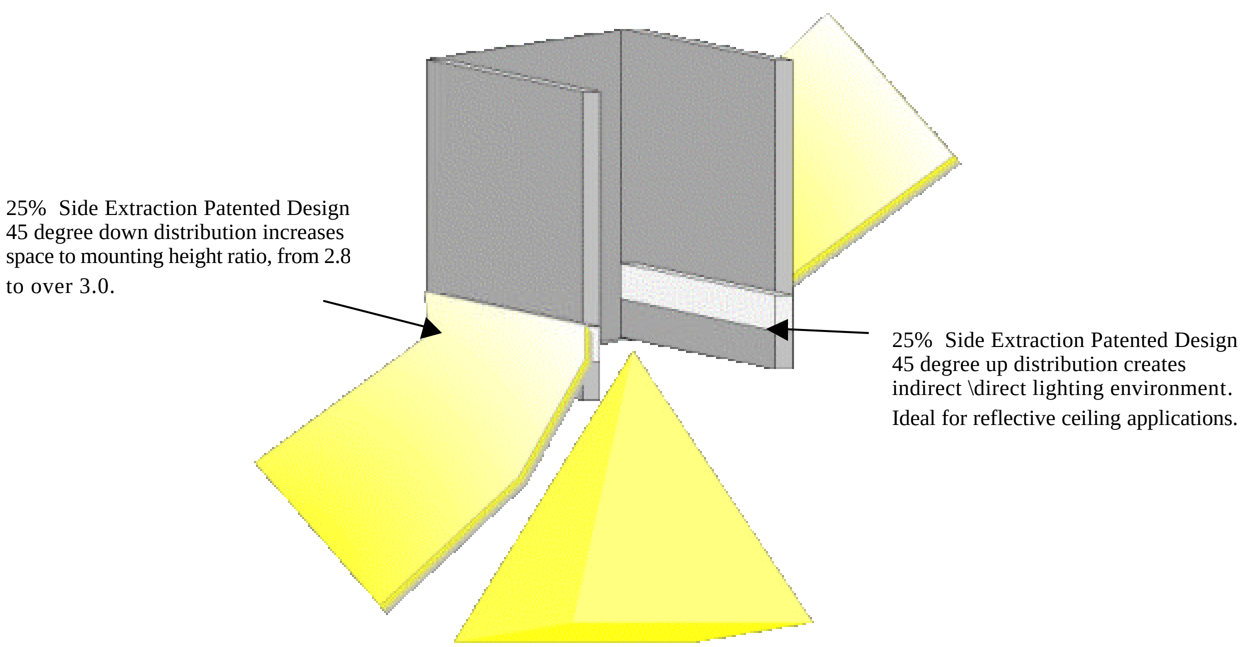
1.5. GLAZING U-VALUE

The U-value of a skylight measures its heat transfer capabilities when placed between two spaces of different temperatures. The U-value is simply the inverse of the R-value, which measures the materials resistance to heat transfer. The overall U-value of a skylight is a function of its glazing materials and its frame. This is often referred to as the "unit U-value" and is discussed further in section 3 below. Here we will only address the U-value of the glazing assembly.

Most traditional skylight manufacturers offer units with double, and some even triple, glazing. Increasing the number of glazing layers produces higher insulating qualities (lower U-values), but will also lower the SHGC and Tvis of the skylight. Thus, for diffusing skylights, generally one layer is of diffusing material and other layers are of a clear, transparent material. Typically skylights are constructed to deliver light through the top domes and are limited within the top domes to create better insulating properties. Some efforts include using very thin polyester film layer to provide additional insulating value with little loss in Tvis.

The Advanced SkyLume system incorporates a variety of glazing materials that both enhance Tvis while lowering the U-value of the system. This system is comprised of the following glazing components:

- **Top Dome** is pure cast acrylic with non-glare coating that has a Tvis of >.97. This outer shell is designed to transmit all solar radiation. Because there is virtually no absorption of solar radiation the outer shell will continue to maintain high Tvis without any cleaning or maintenance.
- **Collimation Lens** is also produced of pure cast acrylic. Prisms are designed to collimate daylight and ensure specular light bounces on the reflective panels. This patented lens design ensures that there is perfect light distribution within the light wells eliminating up to 95% of the direct light generated by sunlight and skylight. By creating daylight collimation we are producing 100% full spectrum visible light that is polarized eliminating any glare in the environment.
- **Light Wells** are designed to ensure specular reflectivity is maintained without light loss. Reflective sheets are also designed to absorb 98% UV and 100% IR wavelengths this ensures 100% full spectrum visible light delivered to the environment. The absorption of the IR and UV radiation that occurs on the panels are insulated through 4lb insulating foam creating a R-22 insulation with glazing materials. 99% of all solar radiation is reflected off the panels eliminating any radiant solar rays through the bottom diffuser. These panels are produced with 99.9999% silver chemically etched with UV epoxies onto virgin aluminum substrates. The metal will never oxidize or delaminate under any solar conditions.
- **Bottom Diffusing Lenses** There are a variety of lenses developed for applications that height and task specific.
  - **Side Extraction** allows proportional light to be extracted at various angles from the light well sides.



- **Prismatic Lens** optically correct lens design allows specular non glare distribution in the environment ideal for application 15' – 20' ceilings
- **Sun Dial Lens** design is true batwing distribution eliminates hot spotting were visual task is critical, designed for 10' –15' ceilings.
- **P35 Lens** brings more down light punch designed for high ceiling applications.

1.6. OTHER PROPERTIES

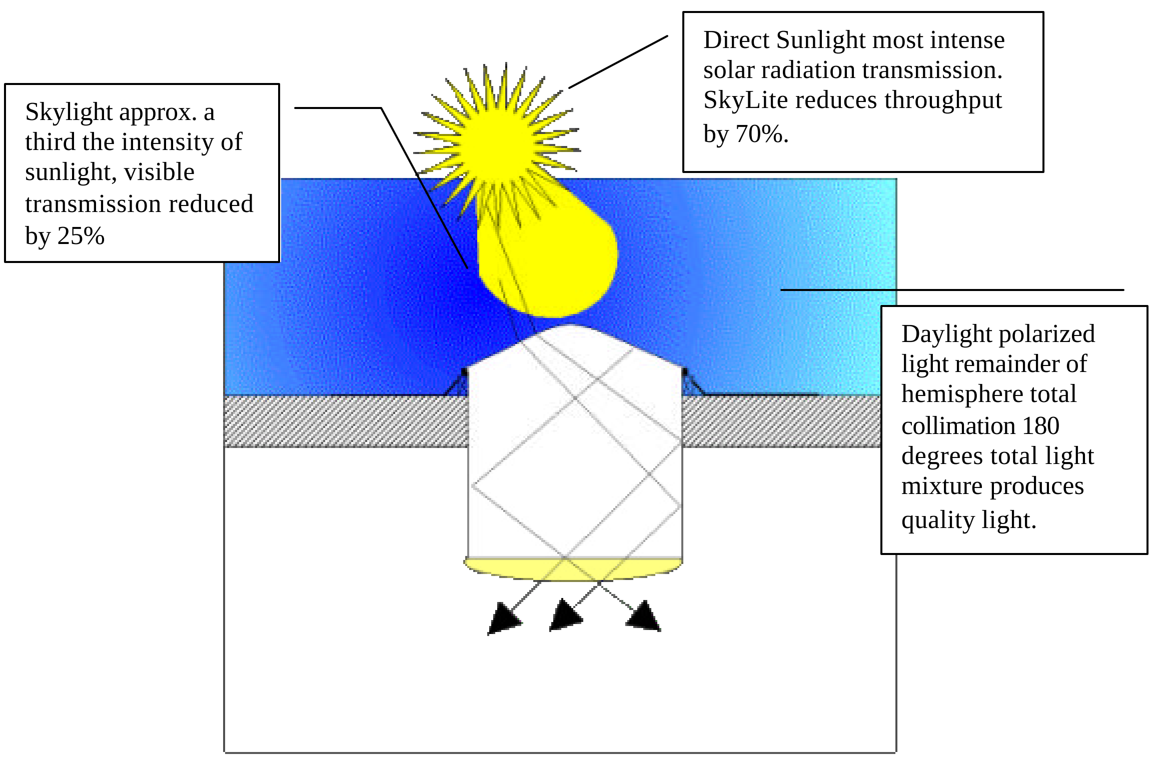
Other physical properties of glazing materials that should be considered include:

- **Strength:** The ability to withstand applied forces, such as wind, snow, and gravity.
- **Weatherability:** The ability of the material to resist surface erosion due to dust and other airborne abrasives, and ultraviolet or thermal degradation resulting in yellowing or hazing, which will reduce light transmission and desired performance.
- **Thermal expansion:** The length of expansion per degree of temperature difference. This determines the amount of movement that must be accommodated by the glazing frame.
- **SKYLUME SERIES TOP DOME SPECIFICATIONS**
  - Thermal expansion: 3.9×10^{-5} in/in/^{o}F (7×10^{-5} cm/cm/^{o}C)
  - Weatherability: cast acrylic sheet continuous-cast, cross linked acrylic sheet meets or exceeds the quality control provisions of ASTM Specification D4802-88, Category C-2, Type UVA material having ultraviolet light-absorbing properties. Manufactured with outstanding optical quality 86% TRANSMISSION
  - Lightweight... Half the weight of glass
  - Four times stronger than glass
  - Tensile Strength, Rupture, and Elongation D638
    (Specimen Type 1, 0.2"/min) 9.0M-10.OM psi (62-69 MPa)
    4-5%.

2. LIGHT WELLS

The light well is as important to the efficiency of the skylight as is the glazing material. A specifier should realize that there is not much point in trying to specify the most efficient glazing material if the light well is inefficient. Paying attention to the details of the light well configuration and surface materials have been considered by ADAPTIVE ENERGY SYSTEMS. The ability to fill the wells with natural light then reflect up to 97% of the light in specular light bounces without losing any visible colors have been achieved AES at a practical cost.

Understanding how the light well shape and reflectance affect the efficiency has helped AES understand how to maximize the well efficacy in the environment. Figure below illustrates how the glazing materials allow light wells to properly diffuse and efficiently combine Sunlight, Skylight, and Daylight to eliminate any harmful solar rays to the environment.



2.1. WELL FACTOR

The well factor (WF) describes the fraction of the light entering the light well that penetrates into the room below. This factor is determined by the geometry of the light well and the reflectance of the surfaces of the light well. To calculate a WF first you need to determine the well cavity ratio. And the reflectance's of the well surfaces.

The WCR is a single value that describes the proportions of the light well. It is the ratio of the wall area to opening area, similar to the room cavity ratio used in lighting calculations. The well widths and lengths and lengths used here are those at the bottom of the light well.

$$WCR = \frac{5 \text{ X WELL HEIGHT X (WELL WIDTH + WELL LENGTH)}}{\text{WELL WIDTH X WELL LENGTH}}$$

Traditional Skylights typically will have a WCR of two or three, Advanced SkyLite Fixtures have an WCR of 10. Translated most typical skylight applications will maintain WF of 26 where the Advanced SkyLite Fixtures have WF's of 87.

2.2. SKYLIGHT EFFICACY

The efficacy of a skylight design is described as the skylight efficacy (SE), which is a ratio of the light transmitted, to the solar heat gain of the entire skylight assembly. It is defined as a function of the light-to-solar gain ratio of the glazing material times the WF. Skylight efficacy, SE, can be expressed the following equations:

$SE = \frac{\text{Tvis x WF}}{\text{SHGC}}$
TRADITIONAL SKYLIGHT SINGLE GLAZED MED WHITE
$SE(.33) = \frac{.42 \text{ x } .26}{.33}$
ADVANCED SKYLUME FIXTURE
$SE(3.19) = \frac{.89 \text{ x } .86}{.24}$

3. FRAMES AND UNIT U-VALUE

The most basic function of any skylight frame is to provide a rigid frame for the glazing material and a secure method of attachment to the roof. However, there are many possible secondary functions that can add complexity to the design of a frame, such as:

- raising the skylight above any ponding water on the roof
- venting the building
- dispersing internal condensation
- securing multiple layers of glazing
- resisting heat flow
- resisting vandalism
- supporting internal shading systems
- venting smoke automatically

Unit skylights are typically fabricated with glazing material and frame bonded together with a gasketing material and all sealants at the factory, and shipped as a ready to install unit. The attachment of glazing material to frame must accommodate potential expansion and contraction of the materials, natural building flux and vibrations, and aging due to exposure to weather and ultraviolet light. The method of attachment of glazing material to frame may largely determine its long-term weather resistance.

Skylight frames can be made out of a variety of materials. Most common are metal-clad wood, metals reinforced vinyl, and insulated frames. Thus the design of the skylight frame is a very important criterion in the budgeting of the skylight. Because of our concern with energy performance of skylights, we will concentrate on the thermal performance of frames. The U-value of a unit skylight is a function of both its glazing material and the thermal resistance of its frames.

3.1. FRAME THERMAL PERFORMANCE

Metal is highly conductive of heat, thus a metal skylight frame can contribute a lot of heat to the light well on hot days, and allow even more heat to conduct to the outside at night and during cold weather. The larger the surface area of metal exposed to the weather, the larger the magnitude of heat flow will be. A very cold frame will cause moisture from the interior of the building to condense on its surface. This condensed moisture is likely to drip down the light well and cause water stains on the ceiling.

The Advanced SkyLume Series Fixtures uses the most energy efficient frames in the industry today, thermalized frames that either use thermal breaks or insulating layers. These frames are application dependant ranging from refrigerated applications to office environments. Metal frames with thermal breaks have become a standard in the window industry in order to improve thermal performance. They are rarely seen in the traditional skylight industry due to application limitations.

A frame can also be insulated to reduce heat flow. This is applied by foam insulation or a site installed insulation inside the frame. Wood frames are naturally much more insulating than metal. Hollow vinyl will perform similar to wood. A vinyl frame insulated with foam is the most energy efficient of them all. A frame can be rated with its own R-value or U-value. An even better indication is an overall unit U-value that integrates the performance of both glazing material and frame.

3.2. CONDENSATION

In addition to thermal breaks or insulation, condensation problems are typically handled with condensation gutters or weep holes. The system typically works to eliminate any drip issues related to condensation but will pass dust and bugs during windy days. The Advanced SkyLite Fixtures are completely sealed units and will not condensate due to its high overall R-value.

3.3. MOUNTING TYPES

There are three major mounting types for skylight frames:

- Curb mounted frames: The frame attaches to the top of a separate curb. The curb is the structural connection to the roof, most commonly site built of wood 2x10s or 2x12s. The curb also creates the transition form roofing material to skylight flashing to ensure a watertight seal around the skylight opening.
- Integral curb: The curb is pre-manufactured as of the skylight frame, typically of the same materials of the frame.
- Flush mount: The skylight if flush with the surface of the roof. This can be appropriate with tilted roof surfaces.

An integral frame skylight, if it is not insulated, will lose more heat than a similar curb mounted skylight, because there is a larger surface area of the frame exposed to the outdoors. The insulated frames and curbs produced by the Adaptive Energy Systems, inc. offer equal or better U-values than surface mounted frames, which are the least reliable units of them all.

3.4. UNIT U-VALUE

The heat losses or gains due to temperature differences between the outside and inside air result from the product of the U-value (thermal transmittance) skylight area and the temperature difference. An accepted way of describing U-value is in terms of Btu per hour of heat loss per square foot of skylight opening, per degree Fahrenheit of temperature difference between the outside and inside air temperatures. The heat loss through the glazing, frame, and curb all contribute to the overall unit U-value.

When specifying a product unit U-value, you should make sure that you are comparing similarly defined values. U-values can be made to look better by considering the loss only through the glazing or by defining the area as the total surface area of the skylight, including sides, instead of the skylight opening. There is room for confusion here since for a window, the rough opening is larger than the nominal size of a window, whereas with skylights, the rough opening is smaller the nominal size. Ultimately, heat loss calculations are concerned with the heat loss through the opening in the insulated roof.

Representative U-values are shown below for standard low profile installations. Barrel or vaulted are not included because variations in surface areas. When discussing U-value, we are mainly concerned with the heat losses in the winter or refrigerated applications. Typically the difference between outside winter temperatures and normal inside temperatures are so much greater than those in the summer. Considering U-value only to estimate summer thermal transmittance will overestimate this component of heat gain because in the summer, the stratified air rises and is trapped in the light well. This stratified air acts like a blanket, insulating somewhat against heat transfer.

UNIT U-VALUE IN BTU/H DEGREE F- SF							
	Curb Type	Integral Frame			Flush/Site Assembled		
Glazing type	Glazing Layers	Metal w/thermal break	Metal clad wood	Wood or Vinyl	Metal	Metal w/thermal break	Structural glazing
SkyLite	Triple Glazed	.540	.410	.310	.210	.110	.110
Plexiglas	Single-glazed	1.730	1.600	1.310	1.210	1.100	1.100
	Double-glazed	1.100	1.040	.840	.810	.690	.650
	Triple-glazed	.870	.810	.610	.620	.510	.450
Fiberglass	Ins. Panel U-o.24	.483	.494	.368	.460	.363	.295
Glass	Single-glazed	1.890	1.750	1.470	1.360	1.250	1.250
	Double-glazed	1.100	1.040	.840	.810	.690	.650
	Double low-e	.990	.920	.720	.700	.580	.540
	Triple-glazed	.870	.810	.610	.620	.510	.450
	Triple low-e	.760	.710	.510	.520	.410	.360
	Four layer low-e	.710	.660	.460	.470	.360	.300

4. BUILDING CODES AND STANDARDS

Skylight are regulated by a variety of building codes to assure that their application does not compromise the energy efficiency, structural integrity, or safety of the building. Building codes as they apply to skylights may vary from municipality to municipality. Therefore the codes for the municipality where the skylights are to be used should be reviewed prior to initial design.

In spite of the variations, however, some general comments can be made about more widely used codes. These apply primarily to energy efficiency, the load bearing capabilities of the skylight, and the area and spacing for combustible skylight materials (principally plastic glazing).

4.1. ENERGY CODES

Many of the key energy codes enforced in the United States recognize that appropriately sized skylights, when used with daylighting controls, save energy. The California Standards and the national ASHRAE/IESNA 90.1 Code are reviewed below.

- **CALIFORNIA**
  The perspective path of the California Nonresidential Building Energy Efficiency Standards (Title 24) allows up to five percent of roof area to be covered with skylights. This area is exempted from the calculation of the roof overall U-value. There is also an exception for atriums that allows up to ten percent of the roof area to be covered with skylights (if atriums is more than 55' tall).
  - **ADAPTIVE** ENERGY SYSTEMS exceeds light levels needed for 99% of industrial and manufacturing needs currently with an average two percent of roof area covered with skylights and deliver min to max ratios under 3:1. We also can maitain energy free 80% of annual daylighting hours in a majority of cases.

  Along with limitations on skylight area, the standards have a maximum climate specific U-value for the skylight units and SC requirements. The skylight unit U-values vary from U-0.85 to U-1.31. The shading coeffecient requirement is lower for translucent materials. Daylighting controls are not required, but if daylighting controls are used, control credits are allotted which gives the designer flexability to add more electric lighting.

  There is a second approach, the "prespective overall approach," which allows the designer to calculate an overall heat loss for the entire building. This approach does not limit the skylight area. Because of the performance of the Advanced SkyLume Fixture thermal properties and the ability to turn off electrical lighting during peak deamnd rates hours the overall system can provide lucrative paybacks with controlled environments.

  California has a third, highly flexible compliance approach called the "performance approach" which uses whole building energy budgets. This allows a broad usage of skylights ina variety of application from production floor to office environments, as long as an approved building simulation program demonstrates that their design uses less energy than a similar building that meets perspective energy standards.

- **NATIONAL**
  The ASHRAE/IESNA 90.1 Energy Code for Commercial and High Rise Residential Buildings is becoming the basis for many for many other states nonresidential energy codes and the federal building standards. It is adopted by reference in the 1995 Model Energy Code. The ASHRAE/IESNA 90.1 prescriptive requirements for skylights are markedly different that California's. The code has an overall U-value requirement for roofs, including the skylights. But it exempts some skylight area contingent on the insallation of daylighting controls in the daylit zone. The maximum exempt area is dependent on climate zone, lighting power density of the area under skylights (higher LPD results in more allowable area), and visible transmittance of skylights (lower Tvis results in more allowable area).

  There is also a requirement in ASHREA / IESNA 90.1 that the "exempt" skylights have a minimum curb U-value of 0.21 Btu/Hr./sf.

  States and local jurisdictions are free to modify parts or all of the ASHRAE/IESNA 90.1 Code or develop their own. Therefore, it is essential to check local requirements.

- **LIGHTING**
  Both California's Title 24 and the ASHRAE/IESNA Code define the "daylit zone" as an area within 45 degrees of the bottom of a skylight well. Thus the daylit zone becomes a rectangular or square area with the dimension that are two times the ceiling height, plus the length and width of the well. These formulas do not account for the shape of the well.

  California allows lighting credits based on control type, visible light transmittance, and the skylight to roof area ratio. There is also a threshold "effective skylight apeture" below which daylight credits are not allowed.

  Both codes also limit the connected lighting load in commercial buildings, variously termed the "lighting power density" (LPD) or "unit power density" (UPD), both of which are measured in watts per square foot (W/sf). It is not directly related to skylights, but is directly related to the amount of electrical energy that can be saved and to their load management. potential. In general, buildings with high LPD's present opportunities for greater energy saving with daylighting, both through lighting savings and reduction in cooling loads from internal heat gain.

COMPARISON OF CODE LIGHTING POWER DENSITIES		
LIGHTING POWER DENSITIES IN Watts/SF	***CALIFORNIA TITLE 24 1998***	***ASHRAE / IESNA 90.1 (UP TO 50,000sq.ft.)***
Classroom, K-12	1.40	1.65-1.83
Class, University	1.40	2.01
Grocery	1.50	2.50
Office	1.20	1.65
Restaurant	1.20	2.50
Retail	1.70	2.50
Warehouse	1.00-1.20	.48

4.2. FIRE CODES

Plastic glazing materials are combustible and their use is allowed with area limitations and spacing requirements. The use of automated fire suppression equipment affects these parameters, as does the type of plastic used. Approved are separated into two types, based on small-scale flammability test: CC-1 and CC-2. The Uniform Building Code places the following limitations of plastic skylights:

- The plastic glazing must be mounted at least four inches from the plane of the roof.
- Skylights with CC-1 glazing may be no larger than 200sf per skylight
- Skylights with CC-2 glazing may be no larger than 100sf per skylight
- The total area of skylights containing CC-1 materials is limitted to 33% floor to roof area
- The total area of skylights containing CC-2 materials is limitted to 25% floor to roof area
  - The use of sprinklers relax some of these limitations.

The Uniform Building Code (UBC) requires smoke vents for one percent of the roof area in Business, Factory, Mercantile, and Storage occupancy single story building with over 50,000 square feet of undivided space. Office and retail spaces are exempt from this smoke vent requirement if storage height does not exceed 12 feet. The UBC also requires that Hazardous occupancy building with more than 15,000 square feet have two percent of the roof area in smoke vents.

Theses smoke vents typically have a metal or plastic covers and can double as skylights. Though the SFR of one or two percent matches amount needed to properly illuminate a facilty Advanced SkyLite Fixtures, the smoke vents can be interspersed with traditional or smoke hatches to reduce cost. Smoke vents are usually Factory Mutal rated. The fusable links on mechanical smoke are also typically Factory Mutual approved.