Value of Skylights

- Provide excellent lighting conditions to the interior of buildings.
- Reduce the use of electric lighting, to save energy and reduce peak electric loads when combined with photo controls.
- Satisfy human needs for contact with the outdoors.
- Increase safety and security with highly reliable daytime lighting.
- Provide emergency smoke vents.
Skylighting Guidelines and SkyCalc® Energy Design Resources

- Study Sponsored By:
  - Southern California Edison
  - Pacific Gas and Electric Company
  - AAMA
  - NYSERDA
  - DesignLights Consortium
  - Northwest Energy Efficiency Alliance
  - Heschong Mahone Group

- Study Conducted By:
  - Lisa Heschong, Jon McHugh, Douglas Mahone, Francis Rubinstein (consultant)
The Guidelines

- Apply primarily to skylight applications designed to provide uniform lighting for commercial or industrial buildings.
- They refer to manufactured, off-the-shelf skylight components used in commercial applications, commonly referred to as “unit skylights.”
- Typically simple, rectangular, or linear skylights, although with creativity they can be applied to nearly any design situation.
- Many of the lighting principles covered here are also applicable to residential buildings, although the energy impacts are entirely different in homes and should not be extrapolated from the information in the handbook.
- Similarly, atrium skylights and other large, custom-designed skylights involve many other issues that are not addressed in the publication (but are acknowledged in this presentation).

Skylighting Guidelines: www.energydesignresources.com
Considerations

- Visual and thermal comfort.
- Seasonal and daily shifts in daylight availability.
- Heat loss and heat gain.
- Integration with the electric lighting system.
- Choice of daylighting control strategy.
- Integration with the roofing system.
- Integration with the HVAC design.
- Utility costs and peak electric demand.
- Structural and safety concerns.
Application

- Skylighting as a lighting strategy is most obviously applicable to single-story buildings which have large open areas.
- Include retail stores and shopping malls, grocery stores, schools, single-story office buildings, manufacturing and agricultural buildings, and warehouses and distribution centers.
Points about Solar Geometry

- Most skylights are installed on flat roofs, where the skylight can “see” almost the full hemisphere of the sky.
- Typically, there are also few obstructions to block sunlight from reaching the skylight.
- A skylight on a sloped roof cannot see the full sky hemisphere, but only a partial view determined by the slope of the roof.
Points about Solar Geometry

- Depending upon the angle and orientation of the sloped roof, the sun may not reach the skylight during certain times of the day or year.

- Example: a skylight on an east-facing roof with a 45° slope will only receive direct sun during the morning and midday hours.
  - In the afternoon it will receive skylight, but only from three-fourths of the sky.
  - As a result, in the afternoon it will deliver substantially less light to the space below than an identical skylight located on a flat roof.
Skylight Shape

- *Flat-glazed* skylights on a flat roof will intercept very little sunlight when the sun is very low in the early morning and at the end of the day.

- Skylights with *angled sides*, whether a bubble, pyramid, or other raised shape, can intercept substantially more sunlight at these critical low angles, increasing the illumination delivered below by *five to 10 percent* at the start and end of the day.
Skylight Spacing

- The general rule of thumb is to space skylights at 1.0 to 1.5 times ceiling height (center-to-center in both directions).
- This assumes a highly diffusing glazing and a modest depth for light wells.
- Actual designs can vary considerably from this rule of thumb.
Choice of Glazing Material

- How much light is transmitted through the glazing—measured by the visible transmittance (Tvis).
- How much of the direct beam sunlight is diffused—measured by the transparency of the material.
- How much of the sun’s radiant heat is transmitted through the glazing—measured by the solar heat gain coefficient (SHGC) or the less precise shading coefficient (SC).
- How much heat from the air will pass through the glazing—measured by the R-value of the material or the U-value of the skylight unit assembly.
Light Wells

- Light wells are a primary component of skylighting systems. They bring the light through the roof and ceiling structure, and they simultaneously provide a means for controlling the incoming daylight before it enters the main space.

- A light well is similar to the housing of an electric light fixture.

- Both are designed to distribute the light and to shield the viewer from an overly bright light source.
Light Wells – Solar Geometry

- The height and orientation of the sun change both daily and seasonally.
- The direct sunlight that enters a transparent skylight can be prevented from penetrating down to the task surface by 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.
Light Wells – Surface Reflectance

- Light wells reflect and diffuse sunlight as it bounces from the skylight to the task surface.
- A highly reflective, diffusing surface (such as flat white paint) will help to provide a diffuse, broadly distributed light pattern below the skylight.
- A specular reflective surface, such as reflective foil, will not diffuse the light, but will reflect an image of the sun and sky onto a limited area below the skylight.
Light Wells – Surface Reflectance

- Colored surfaces will distribute the light evenly, but will reduce its intensity and can dramatically shift the appearance of colors in the room below.
- For applications where uniform light distribution is desired, a matte white surface is best.
Light Wells – 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.
Light Wells – Wall Slope

- A broad base is an advantage under *overcast sky conditions* or with a diffusing skylight, but it can be a serious disadvantage with a transparent skylight when *direct sunlight* is present.

- **Deep wells with vertical walls** prevent direct view of the skylight and block low angle beam sunlight, but tend to keep the light concentrated in a smaller area and provide less uniform light distribution.
Glazing Efficacy

- The measure of how much light penetrates all the layers of glazing in relation to how much solar heat gets through.
- It is more specifically referred to as the “light-to-solar gain ratio” or LSG.
- It is a ratio of the visible transmittance (Tvis) to the solar heat gain coefficient (SHGC) of the glazing.
- Important to understand that it is not just one property or the other that is important, but the relationship between the two that determines how efficiently the glazing material will perform.
## Glazing Efficacy

<table>
<thead>
<tr>
<th>Type</th>
<th>Layers</th>
<th>Color</th>
<th>Tvis</th>
<th>SHGC</th>
<th>LSG</th>
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</table>
Skylight Efficacy

- Combines LSG with the effects of the light well. The well factor (WF) describes how much of the light that enters the well is actually transmitted down to the room, after reflectances and absorption.

- Thus, skylight efficacy is a measurement of how efficiently the overall skylight assembly can deliver light to the room below without causing an undue burden of additional heat.
Light Wells

- The shallower a light well is relative to its width, the less light is transmitted.
- Splaying the light well, so the bottom of the light well is wider than the top, transmits more light than a light well with vertical sides.
- For a given geometry, a light well which is painted white will have the highest efficiency.
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, you need to first determine the well cavity ratio (WCR) and the reflectances of the well surfaces.
Well Factor (WF)

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

\[ WCR = \frac{5 \times \text{Well Height} \times (\text{Well Width} + \text{Well Length})}{\text{Well Width} \times \text{Well Length}} \]

- A cube shape has a WCR of 10. An extremely narrow, tall well might have a WCR of 20.
- A very shallow well might have a WCR of two or three.
Skylight Efficacy (SE)

- The efficiency 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)

\[ SE = LSG \times WF \]

\[ Tvis \times WF \]

\[ SHGC \]

- It can be seen from this simple equation that doubling the WF will directly double the SE.
- For a cube-shaped light well, cutting the reflectance of the surfaces in half (by changing the paint color from white to goldenrod, for example), will also reduce the SE by half.
Skylight Frames

- 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.
- Secondary functions that can add complexity to the design of a frame:
  - 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 devices
  - supporting internal screens or safety grills
  - venting smoke automatically
Safety Issues

- Maintenance of roof structure integrity.
- Resistance of the skylight itself to weather loads and abuse.
- Prevention of accidental breakage or entry.
Finally …. (for this part)

- Make sure you check and conform to all codes and standards!
  - State energy codes
  - ASHRAE/IESNA 90.1 or current
  - ASTM
  - ANSI
  - Fire Codes
  - AAMA
Apple Store Soho

- Bohlin, Cywinski, Jackson, Architects

Images: www.bcj.com
SkyCalc®, as a simple daylight and building simulation spreadsheet, considers the following effects that skylights have on building energy consumption:

- Reduced electricity consumption by electric lighting (when daylighting controls are used).
- Reduced internal heat gains by electric lighting (when daylighting controls are used).
- Increased solar gains.
- Increased thermal transmittance of roof.
SkyCalc® Assumptions

- You will be using diffusing skylights positioned to provide uniform lighting over your space.
- You are modeling a single-story building, or just the top floor of a multi-story building.
- The average energy prices you specify will give reasonable estimates of cost savings.
- The weather data you select is representative of average weather conditions for your site.
- You have correctly described your building and lighting systems in the inputs.
Key Points

- use SkyCalc® early in your building design process to develop a preliminary design and estimate of savings.
- Thus .... A preliminary design tool!
SkyCalc® Climate Data

- The climate data for SkyCalc® is actually an hourly output file from a DOE-2 simulation of a “reference” building.
- These outputs are modified to represent the building with the skylighting design and a “base” building similar to the skylit building in all ways but one—the base building doesn’t have skylights.
SkyCalc® Components for Calculations

- Simple user *inputs*.
- A *database* of default schedules, skylight performance characteristics, and material properties.
- *Hourly climate data* generated by the DOE-2.1E building energy simulation program containing interior illuminances, sensible heat gains, solar heat gains, and outdoor dry bulb temperatures for a reference building.
- Calculation *algorithms* embedded in cell equations, user defined functions, and subroutines.
The DOE-2 Reference Building Characteristics

- 100’ by 100’ building with a 20 foot ceiling, task height is 2.5 feet above the floor.
- 4% skylight-to-floor ratio, shading coefficient = 1.0, effective aperture = 2% (overall $T_{vis} = 0.5$)
- Roof $U$-Value = 0.057, Skylight overall $U$-Value = 1.0 Btu/hr•°F•ft$^2$, adiabatic walls (no heat lost or gained).
- Both lighting and equipment power density are 1.5 W/ft$^2$
- Occupant density is 1 person per 100 ft$^2$.
- Set points: Cooling 72°, Heating 68°.
- All schedules (lighting, occupancy, process loads) are set at 100% for 24 hr/day and 7 day/wk.
- Daylighting controls are disabled.
Key Points about Calculations

- Simple ratios are used to relate the illuminances in a skylight design to the reference building.
- The two factors to be compared are the effective apertures and coefficients of utilization.
- The *effective aperture* describes what fraction of the light impinging upon the roof penetrates the skylight and light well.
- The *coefficient of utilization* describes what *fraction of light* exiting from the bottom of the light well reaches the task.
- The lumen method algorithm as published in Chapter 9 of the 8th Edition of *IES Lighting Handbook* is used to calculate the coefficient from skylights.
Key Assumptions of this Method

- The skylights are completely diffusing (Lambertian distribution) and uniformly spaced.
- Each surface in the room is diffusely reflecting.
- Each major surface of the room is uniformly illuminated.
Limitation!!

- This method will not accurately model clear skylights, non-uniform spacing, or high partitions.
Energy Savings Calculations

- Savings are calculated by subtracting the energy consumption of the daylit building by component (lighting, cooling, and heating) from the base building without skylights.
- These savings are recorded in the results table and graphs.
Examples with SkyCalc®

- Our next class (week after next since case studies are presented next week) will be:
  - SkyCalc® examples and hands-on
  - Field trip to Sahara West Library
Resources

- A copy of the Skylighting Guidelines can be downloaded at www.energydesignresources.com.
- SkyCalc® can be downloaded at www.h-m-g.com or at: www.energydesignresources.com.
- www.bcj.com (Apple Store Soho)
- All info for this lecture from above materials!
- Some images are from on-line resulting from a google image search.