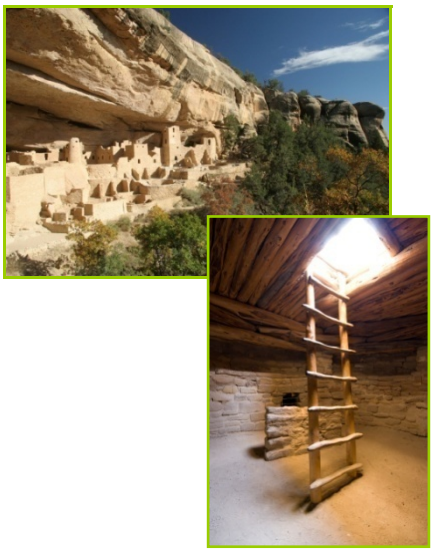
Greenpaper©

May 2009

Daylighting

Prepared For:
The Los Angeles Community College District

Parthenon



Mesa Verde, Four Corners, Colorado

DESCRIPTION OF STRATEGY

Daylighting is the controlled admission of natural light into a space through windows to reduce or eliminate electric lighting. By providing a direct link to the dynamic and perpetually evolving patterns of outdoor illumination, daylighting helps create a visually stimulating and productive environment for building occupants, while reducing as much as 1/3 of total building energy costs.

Proper daylighting design is not so much how to provide enough daylight to an occupied space, but how to do so without any undesirable side effects. It involves more than just adding windows or skylights to a space. It is the careful balancing of heat gain and loss, glare control, and variations in daylight availability. For example, successful daylighting designs will invariably pay close attention to the use of shading devices to reduce glare and excess contrast in the building. Additionally, window size and spacing, glass selection, the reflectance of interior finishes and the location of any interior partitions must all be evaluated.

It is important to appreciate that the daylighting design process involves the integration of many disciplines including architectural, mechanical, electrical, and lighting. These design team members need to be brought into the process early to ensure that daylighting concepts and ideas are carried throughout the project.

HISTORY

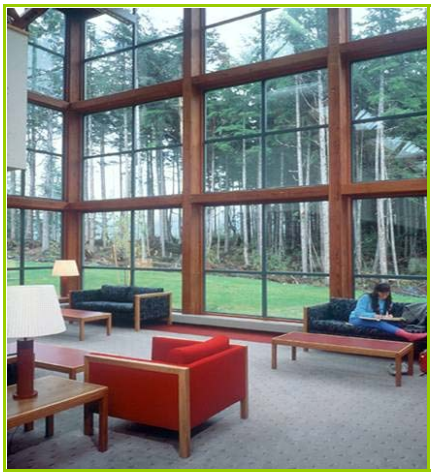
Man functioned for years without electric light. For thousands of years we constructed our built environment to capture and harness daylight. The Anasazi people who occupied Mesa Verde understood seasonal sun light and built the cliff dwellings to welcome the winter sun and avoid the summer sun.

Then along came electricity and we forgot all we learned over the millennia. We became lazy and as a result loose that connection with nature.

> *Without a glass palace*
> *Life becomes a burden*
> *Glass opens up a new age*
> *Brick building only does harm*
> ***Paul Karl Wilhelm Scheerbart***

Much of today's interest in daylighting is driven by energy savings potential. Equally important, or perhaps even more important, is man's connection with daylight. We need daylight for more than just sight.

BuildLACCD



WHY DAYLIGHT?

There are many benefits to a daylit space. These include:

Physiologically benefits

- Responsible for the body's production of vitamin D
- UV causes dilation of blood vessels, which reduces blood pressure
- Creates an overall feeling of well being
- Quickens the pulse and increases appetite.

Psychological benefits

- Reduces monotony
- Satisfies our "need for a view"
- Provides orientation
- Sets our biological clock

Energy benefits

Electric lighting represents between 40 and 50% of the total energy for buildings, depending upon occupancy type. Include the effect of the heat generated by the lighting and the percentages go even higher. Through the use of daylight, reliance on electric lighting can be reduced. Obviously, during hours without daylight, the electric lighting system will be required. However, depending upon orientation and space use, savings in the neighborhood of 50% can be seen in electricity use for lighting.

Performance benefits

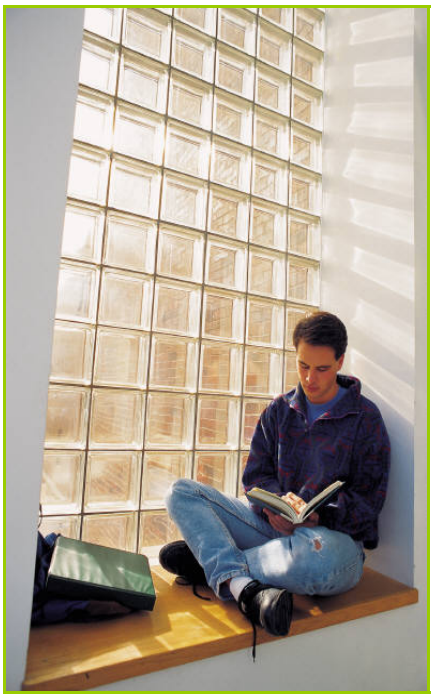
Far outweighing the savings in energy reduction, improved performance by the occupants can provide significant savings through:

- Improved learning
- Increased productivity
- Reduced absenteeism
- Reduced sick leave
- Staff retention

Results are well documented of studies showing improved learning within daylit buildings. Schools in Capistrano, CA; Seattle, WA and Fort Collins, CO were studied in 1999. Math and reading scores increased from 7% to 26%. See http://h-m-g.com/Projects/daylighting/projects-PIER.htm.

A daylighting and productivity study by Pacific Gas and Electric examines the correlation between occupant productivity and exposure to daylight within school buildings and demonstrated better school test performance (typically 20%) when occupants are exposed to daylight.

Increased productivity has also been reported. While not as easily benchmarked as test scores Lockheed Martin reports that after daylighting its facility in Sunnyvale, Calif., the company achieved 15% higher worker productivity. See: The non-profit Center for Energy & Climate Solutions' Cool Companies website, www.cool-companies.org, 2002.



Additionally, studies have shown that buildings with abundant daylight see reduced absenteeism and sick leave. The University of Oregon discovered that those with excellent daylighting recorded 30% fewer sick days, and those with views to the outdoors experienced 20% fewer sick days. In fact, these statistics are additive…those with great view and excellent daylighting recorded upwards of 50% less sick time.
See http://www.lrc.rpi.edu/programs/daylighting/reports_publications.asp.

Staff retention is also affected by daylighting. Per Ebb Ebbesen, a Senior Vice President of construction at the Navy Federal Credit Union, the Navy FCU is attributing its 'green' corporate campus for helping to reduce employee turnover from 60% annually to 17%.

Given the cost of human capital, payback for daylight harvesting systems can be reduced to months rather than years.

OPPORTUNITY

The sun provides a plentiful source of illumination. A clear noon sky approaches 10,000 fc.

Clear sky
Horizon brightness is greater than zenith brightness.
Illumination levels can range from 5,000 to 12,000 fc

Overcast sky
Zenith brightness is 3x horizon brightness

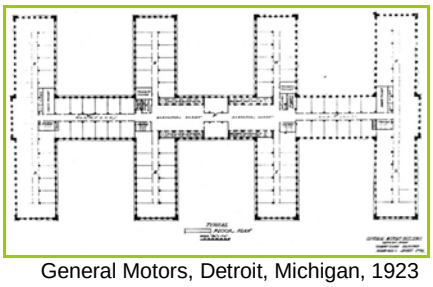
Partly Cloudy sky
Brightness varies depending upon extent of cloud cover

Interior illuminance levels typically range from 10 footcandles (or lower) to 70 to 100 footcandles for most commercial buildings. With such an abundant source of illumination, good design and control of sunlight should be able to achieve much of our 70 to 100 fc task requirements.

DAYLIGHTING STRATEGIES

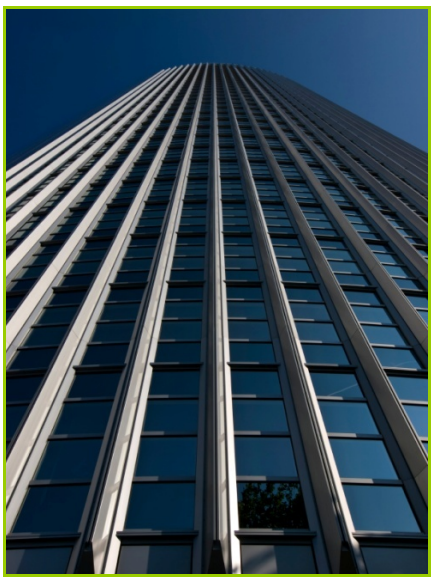
Delivery of daylight into the building is accomplished via apertures in the building skin. Various methods can be used, including:

- Side Lighting
- Top Lighting
- Atria
- Innovative Technologies



General Motors, Detroit, Michigan, 1923

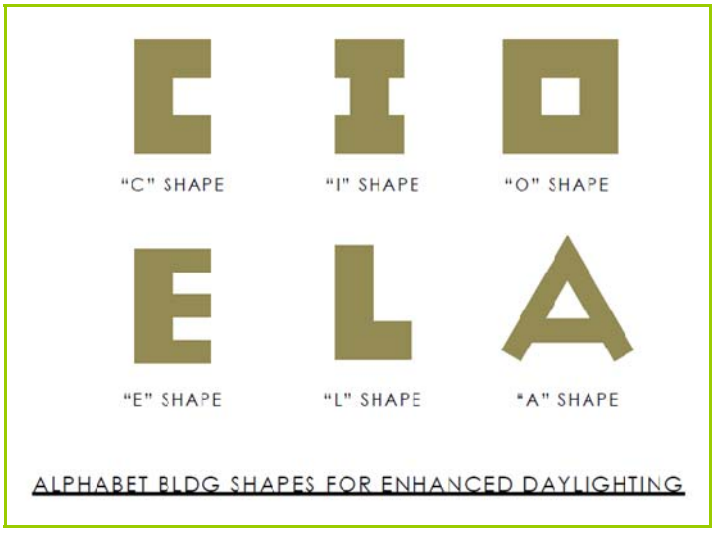
Overhangs for south façades



Vertical fins for east and west façades

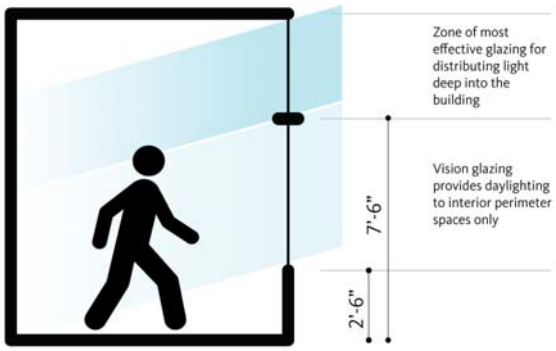
Side Lighting

For side lighting, daylighting within a space is typically limited to a distance approximately 2.5 times the height of the top of the aperture above the finished floor. Given a 9' – 10' ceiling with the top of the glazing at 8' – 9' would result in penetration of 20 to 22 feet. For this reason, many daylit buildings are configured in an "alphabet" shape, to reduce the floor plan depth.



The ideal building orientation is north/south facing to avoid excessive solar gains from east and west sun, especially during the summer and fall. High summer sun on the south side can be controlled by simple shading devices (e.g. overhang or light shelves) while solar gains from low winter sun help to reduce heating requirements. East and west exposures can be somewhat shaded by vertical fins. Natural light from the north side is virtually glare-free but still sufficient for adequate daylighting. The relation of floor to ceiling height, window height and plan depth is crucial for effective daylighting.

A common indicator of daylight availability within a building is the daylight factor. Daylight factor is the proportion of available external illuminance which occurs within the internal space expressed as a percentage. Daylight factor calculations take into account the physical geometry of a building and its surroundings, the transmission of glazing, the effects of any shading devices and the reflectance of all surfaces in and around the study space.



$$\text{Daylight Factor} = \frac{\text{Window Area (sf)}}{\text{Floor Area (sf)}} \times \text{Window Geometry} \times \frac{\text{Visible Light Transmittence of Glass Used}}{\text{Minimum Visible Light Transmittence}} \times \text{Window Height Factor}$$


Skylight

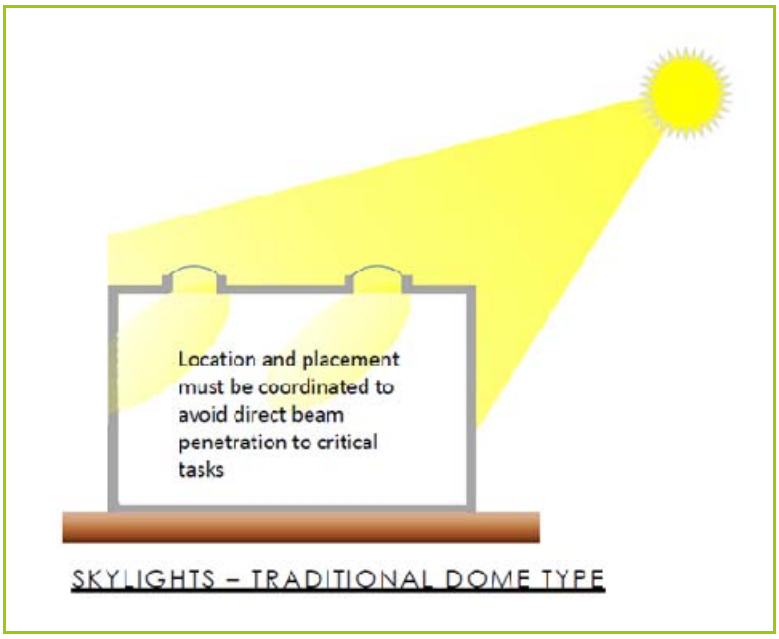

Skylight with Fabric Baffles to Reduce Glare


Skylight

Top Lighting and Atria

In lieu of side lighting, and particularly for single story buildings or the top story of a multi-level building, top lighting can be an effective strategy. For uniform top lighting, the skylight area should be roughly 3.5 – 7.5% of the floor area (depending upon transmission of the skylight) and spaced approximately 1.5 times the ceiling height.

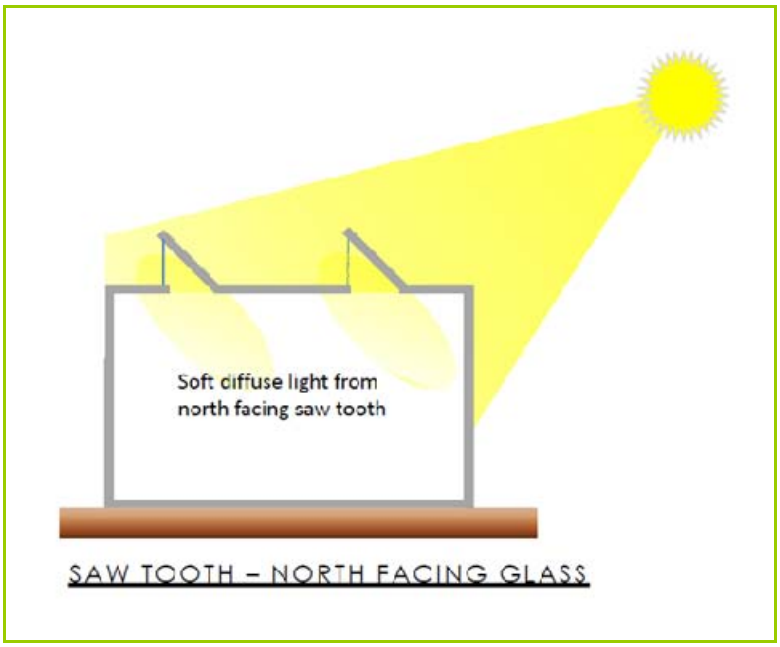
Daylighting in an atrium allows sunlight penetration to multiple floors within a building interior. The following diagrams illustrate top lighting and atrium concepts.

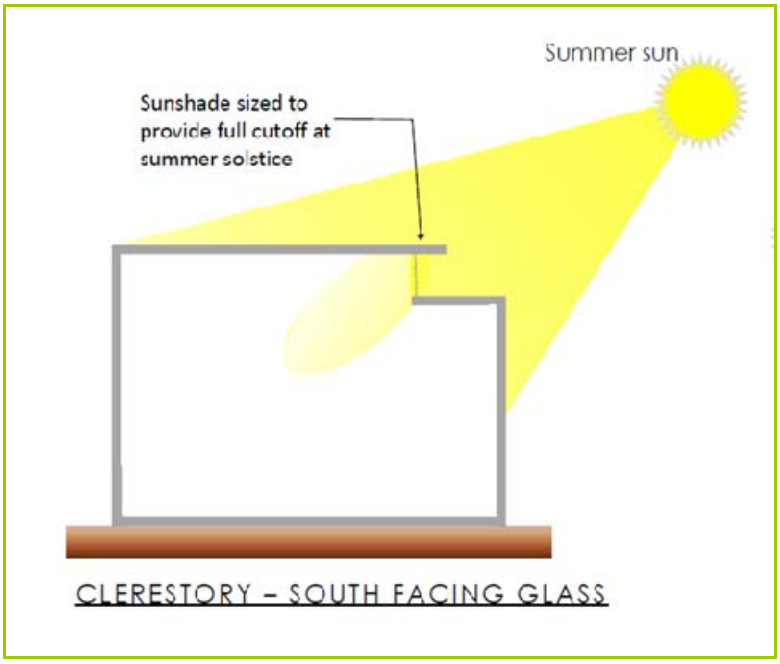


Clerestory

Clerestory

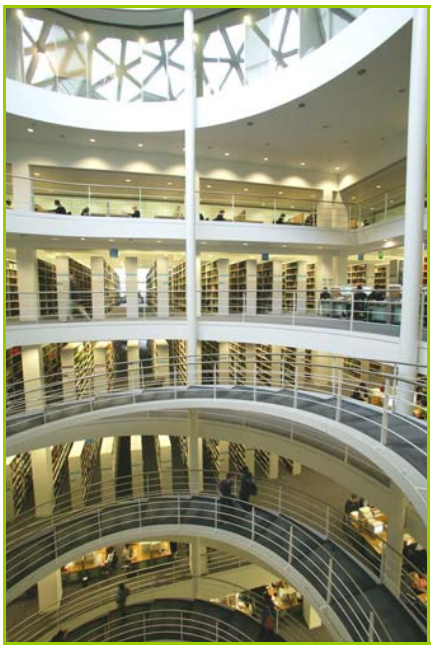
Clerestory





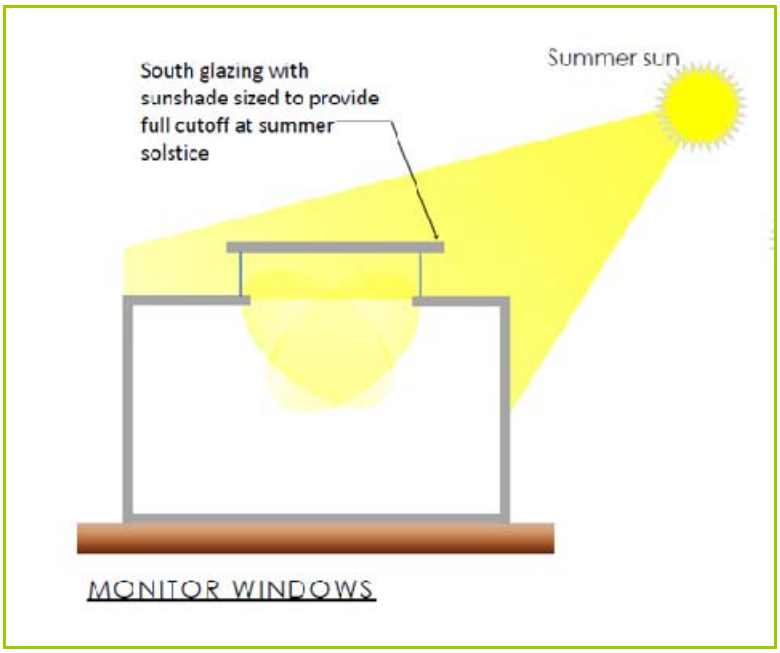
A north facing orientation for a clerestory or sawtooth is preferred wherever possible. For other orientations, care must be taken to eliminate unwanted direct solar radiation during all times of the year.

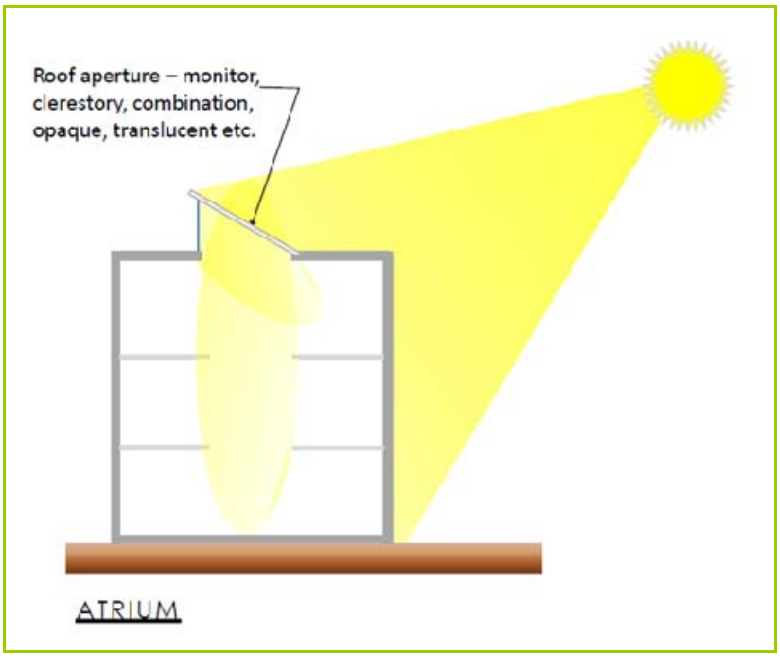
Architectural Roof Monitor



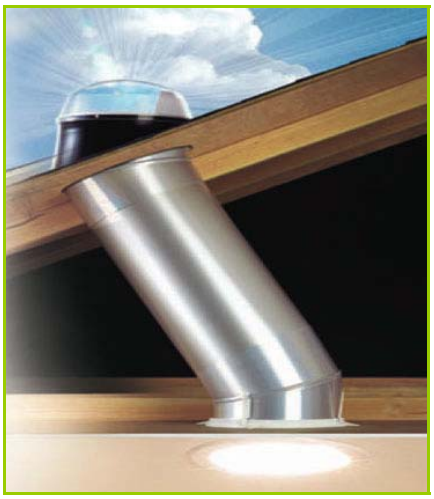
Atrium Daylighting

Atrium Daylighting






Light Pipes (Solar Tubes)


Light Pipes (Solar Tubes)

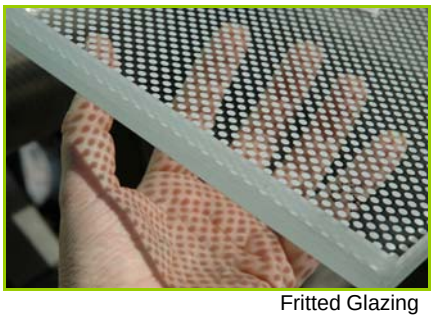

Light Pipes (Solar Tubes)

Innovative Technologies

Light Pipes. Light pipes (or solar tubes) can work over long distances. In principle, sunlight can be channeled into any area of a building. A heliostat on the roof tracks and collects sunlight, then beams it through a lens to a working space, which can even be underground. Unless the light pipe is very short and wide, a heliostat is needed to collect and concentrate the sun's rays. Beamed sunlight can also be used for decorative purposes. Light pipes have no running costs, are weatherproof and maintenance free, and increase visual comfort.

Fiber Optics. Sunlight is brought into the building through optical cables. The optical cable is made of several thin optical strands. The cable is flexible and can efficiently reach many locations into a building. This can also work over long distances and integrate with the building services. This is achieved by solar panels mounted on the roof or facades of the building. The solar panels employ an array of optical lenses to collect and concentrate incoming sunlight. The lenses can also track the sun. The sunlight is emitted through specifically designed luminaires that recreate the feeling of sunlight.


Fiber Optic Daylighting System


Fritted Glazing


Overhangs for south façades


Exterior fins for east and west façades

SHADING AND GLARE CONTROL

A challenge in any daylighting scheme is to reduce unwanted heat gain and control glare. There are several strategies to achieve these goals.

Glazing Materials

The simplest method to maximize daylight within a space is to increase the glazing area. However, three glass characteristics need to be understood in order to optimize a fenestration system: U-value, Shading Coefficient, and Visible Transmittance.

- U-value represents the rate of heat transfer due to temperature difference through a particular glazing material.
- Shading Coefficient (SC) is a ratio of solar heat gain of a given glazing assembly compared to double-strength, single glazing. Note that Solar Heat Gain Coefficient (SHGC) is a related term that is similar, although the values are different.
- Visible Transmittance (Tvis) is a measure of how much visible light is transmitted through a given glazing material.

Glazing can be easily and inexpensively altered to increase both thermal and optical performance. Glazing manufacturers have a wide variety of tints, metallic and low-emissivity coatings, and frits available. Multi-paned lites of glass are also readily available with inert-gas fills, such as argon or krypton, which improve U-values.

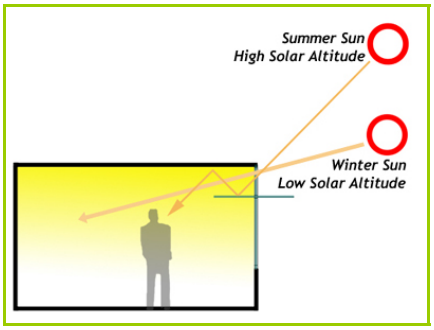
Spectral Selectivity refers to the ability of a glazing material to respond differently to different wavelengths of solar energy – in other words, to admit visible light while rejecting unwanted invisible infrared heat. A glazing with a relatively high visible transmittance and a low solar heat gain coefficient indicates that a glazing is selective. Spectrally selective glazing uses special absorbing tints or coatings, and are typically either neutral in color or have a blue or blue/green appearance.

Fritted glazing is an important product in terms of shading sunlight, reducing thermal gains, and responding to glare. Standard or custom frit patterns can be applied to a variety of glazing assemblies, including additional selective films, insulation, air gaps and inert gas infills. The advantages of this technology are the simplicity of an integrated shading device with low maintenance.

Exterior Shading

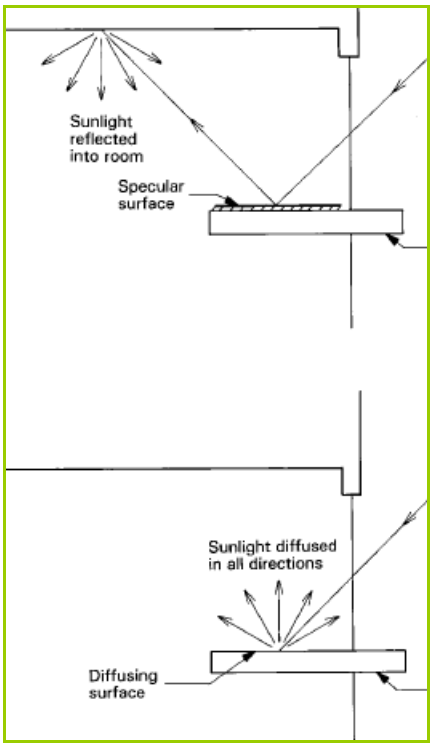
Use exterior shading, such as overhangs and vertical fins, to keep out unwanted solar heat and glare. Another option is to design the building geometry to shade itself. Exterior systems are typically more effective than interior systems in blocking solar heat gain.

Movable devices allow more efficient use of daylight and occupant adjustment, but they add another level of complexity to the building, which impacts first costs and maintenance costs. Movable devices that are automatically controlled via a sun sensor yield the best energy savings. Reliable systems have been in use around the world for years and have only recently become available as cost-effective options in the United States.



Light shelf concept


Light Shelves
Photo courtesy of University of Oregon



Using a specular surface on top of a light shelf will enhance daylight penetration, versus a diffusing surface

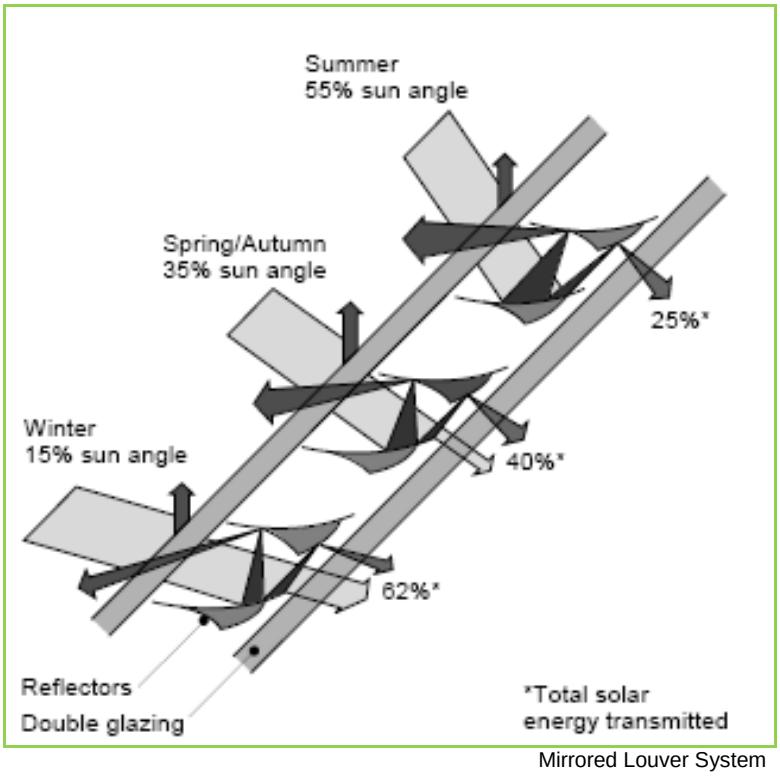
Light Shelves

In the summer, when the sun is high in the sky, light shelves block direct sun at both the upper and lower windows. Sunlight enters the upper window and is reflected to the ceiling, allowing it to penetrate deep into the space. Using a specular surface on top of a light shelf will enhance daylight penetration, versus a diffusing surface

In the winter, low sun can penetrate directly into the space through the clerestory. If glare control is needed, an integrated solar louver system may be considered for the clerestory glazing. Tinted glazing can be used at the lower view window for glare and heat control, while clear glazing can be used at the clerestory to increase daylight admission.

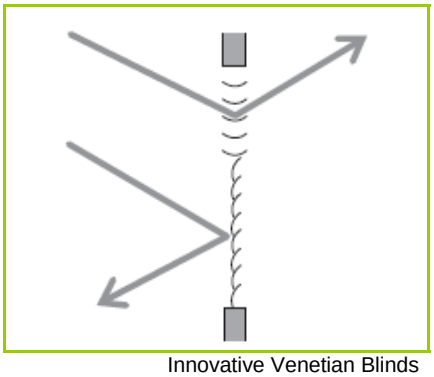
Mirrored Louver Systems

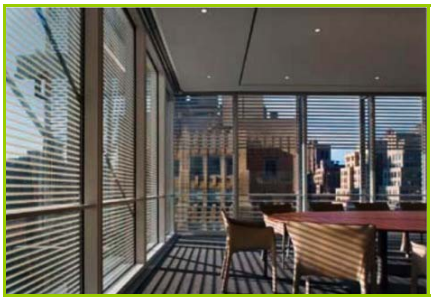
More sophisticated fixed louver systems have curved slat profiles and can be installed inside double glazing to reduce maintenance. The system has a seasonally-varying shading performance. In the winter, more daylight is admitted into the building than during the summer due to the varying sun angle.



Mirrored Louver System


Bottom-Up Shades


Innovative Venetian Blinds


Innovative Venetian Blinds


Sage Glass


Ceiling mounted photosensor

Bottom-Up Shades

Bottom-up mechoshades allow occupants to block unwanted glare at the lower section of the windows while allowing in daylight at the upper portion. As compared to traditional shades, bottom-up shades are slightly more expensive, but they may have significant energy and practical benefits, particularly where computer monitors are located near windows.

Innovative Venetian Blinds

When closed, typical venetian blinds block nearly all of the incoming daylight. To increase daylighting utilization, blinds with two independent sets of slats can be provided. The top portion redirects incoming light onto the ceiling, while the bottom set provides shading in the same way as a normal venetian blind. The angle of all the slats can be adjusted manually and the whole blind can be retracted.

Sage Glass

SageGlass is an electronically tintable glazing that provides glare control on demand. The window tint can be controlled either manually or automatically based on solar intensity. SageGlass is a multi-layer, thin-film tungsten-oxide coating that is as durable as low-emissivity coatings. The glazing uses 0.28 W/ft2 to switch the glass from clear to tinted state, a process that takes several minutes, and 0.1 W/ft2 to maintain that tinted state. Used with typical clear glass in an insulated glazing unit, SageGlass reduces the visible transmittance from 62% to 3.5% while reducing the solar heat gain coefficient from 0.48 to 0.09.

CONTROLS

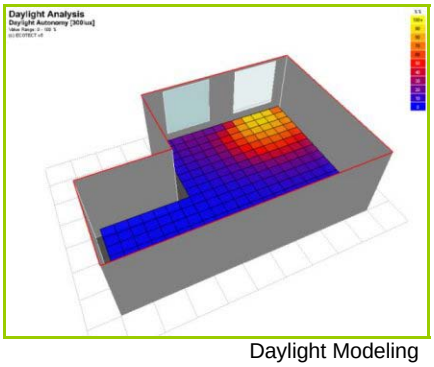
A successful daylighting design not only optimizes architectural features, but is also integrated with the electric lighting system. With advanced lighting controls, it is now possible to adjust the level of electric light when sufficient daylight is available. Three types of controls are commercially available:

- Switching controls—on/off controls simply turn the electric lights off when there is ample daylight.
- Stepped controls—provide intermediate levels of electric lighting by controlling individual lamps within a luminaire.
- Dimming controls—continuously adjust electric lighting by modulating the power input to lamps to complement the illumination level provided by daylight.

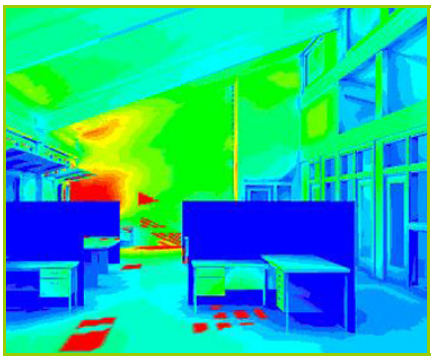
To take full advantage of available daylight and avoid dark zones, it is critical that the lighting designer plan lighting circuits and switching schemes in relation to fenestration.

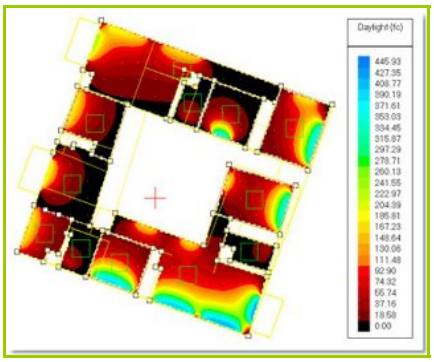
Different sensors are appropriate for different applications. For example, in a classroom, the sensor should have an expanded cone of view to control a large area. The California Energy Commission's Public Interest Energy Research (PIER) program has researched how to improve the efficiency of classroom daylighting controls. For additional information, refer to www.archenergy.com/lrp/demandresp_lighting/project_3_3.htm.


Ceiling Design to Maximize Daylighting



Daylight Modeling


Daylight Modeling



Daylight Modeling

INTERIORS DESIGN

With all daylighting schemes, whether side lighting or top lighting, the geometry and surface characteristics of the interiors design plays an important role in the effectiveness of the daylighting system. Ceiling geometry can allow taller windows and deeper light penetration into the space.

Reflectance values for room surfaces will significantly impact daylight performance and should be kept as high as possible. It is desirable to keep ceiling reflectances over 80%, walls over 50%, and floors around 20%. Of the various room surfaces, floor reflectance has the least impact on daylighting penetration.

DAYLIGHT MODELING

Sophisticated daylight software programs are commercially available. These programs can be used by many professional lighting designers to calculate lighting levels for various glazing and shading options on a project.

In addition to these commercial programs, the California Energy Commission's Public Interest Energy Research (PIER) program has developed free software called Sensor Placement and Optimization Tool (SPOT). The SPOT program is able to analyze daylighting schemes to optimize the energy and lighting performance of the system. The SPOT software is now on version 4 and available for free download at www.archenergy.com/SPOT.

ADDITIONAL RESOURCES

The following websites contain additional information on daylighting.

Government websites
- windows.lbl.gov
- www.energy.ca.gov
- www.energy.gov

Industry websites
- www.aboutlightingcontrols.org
- www.betterbricks.com
- www.cie.co.at
- www.daylighting.org
- www.iesna.org
- www.lrc.rpi.edu/programs/daylighting/index.asp
- www.ncsc.ncsu.edu/programs/north_carolina_daylighting_consortium.cfm
- www.nwalliance.org

Manufacturer websites
- www.ledalite.com
- www.leviton.com
- www.lightolier.com
- www.lutron.com
- www.wattstopper.com