elements of
DAYLIGHTING

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architecture + engineering

AKNOWLEDGEMENTS

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STUDY SECTIONS

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INTRODUCTION

Scope of Exploration

This publication aims to help steer designers on a path towards more daylight-conscious design and provide the tools to do so in today's increasingly eco-conscious environment

The study sections consist of the follwoing:

The **Introduction** outlines some benefits of daylighting and general parameters for consideration in any daylighting system.

The **Element Studies** section provides guidelines for designing particular architectural elements that enhance or mediate daylight.

The **Case Studies** section provides brief examples of each element's successful implementation. An annotation in each element will refer the reader to applicable case studies, and each case study will list those elements which it employs.

Following are the reference sections:

First is a brief overview of the **LEED Daylighting Standards**.

A **Glossary of Daylighting Term**s features some common daylighting terminology you may encounter throughout the book.

Finally, one will find the **Additional Resources** section, which provides publications and websites for further investigation, as well as manufacturers of the previously evaluated elements.

Daylighting Basics

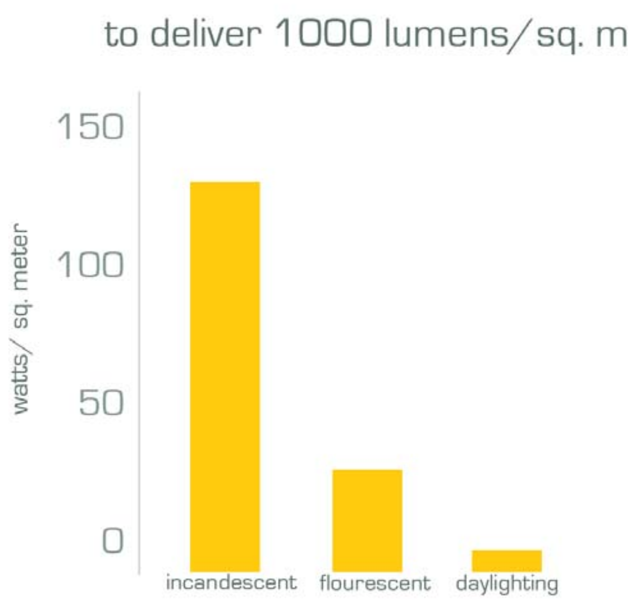
WHY DAYLIGHTING?

Benefits of natural daylighting include energy savings, improvement of heath and well-being, and natural color rendering. With these benefits, daylighting has the potential to diminish costs by downsizing mechanical systems, reducing electricity used for lighting, and increasing productivity by improving both physical and mental health.

- "In terms of 1997 dollars, initial costs are increased $0.50 to $0.75 per square foot of occupied space for dimmable ballasts, fixtures, and controls; daylighting has been shown to save from $0.05 to $0.20 per square foot annually." [Ander http://www.wbdg.org/resources/daylighting.php]

every 5 minutes of increased productivity results in an annual savings of $650

[Kats 7]



[McCluney 4]

PSYCHOLOGICAL & PHYSIOLOGICAL BENEFITS

Human well-being encompasses both physiological and psychological areas.

Some such behaviors affected include:

Intellectual task performance
styles of conflict resolution
hormone secretions
mood + stress

Studies demonstrate the psychological and physiological benefits derived from daylighting in office, school, health care, and retail settings.

Benefits of Daylighting in **OFFICE** environments

{the amount that physical environment accounts towards worker productivity}

- "Workers in call centers were found to process calls 6% to 12% faster when they had the best possible view versus those with no view." [Heschong: Windows and Offices vii]
- "Office workers were found to perform 10% to 25% better on tests of mental function and memory recall when they had the best possible view versus those with no view." [vii]
- "Reports of increased fatigue were most strongly associated with a lack of view." [vii]
- "The greater the glare potential from primary view windows, the worse the office worker performance, decreasing by 15% to 21%." [vii]
- "Reduced absenteeism and increased perceived productivity result from daylighting." [Kats 6]

An increase in daylight illumination levels from 1 to 20 footcandles results in a 13% improvement in performance in the ability to instantly recall and mentally reverse strings of numbers.

[Heschong: Windows and Offices vii and137]

- "Attracting and retaining the best employees can be linked to the benefits offered to workers, including the quality of the physical, environmental, and technological workplace." [7]

Benefits of Daylighting in **HOSPITALS**

- In brightly-lit rooms, patients have a shorter length of stay.
- "Patients with a view of nature went home a day earlier, had $550 lower costs-per-case, used fewer heavy medications, had fewer complications, and displayed better emotional well-being." [Lewis 1]
- "A study of heart surgery patients found that patients whose window overlooked a field edged with trees healed faster and required less pain medication than those with a view of a brick wall." [Heschong Windows and Offices 25]

Patients exposed to increased intensity of sunlight experience less perceived stress and have decreased pain medication costs by 20%.

[Lewis 1]

Benefits of Daylighting in **RETAIL** Environments

- "An average non-skylit store in a chain would be likely to have 40% higher sales with the addition of skylights, with a probable range somewhere between 31% to 49%." [Heschong: Skylighting 2]
- "If a typical non-skylit store were averaging sales of $2 per square foot, then its sales might be

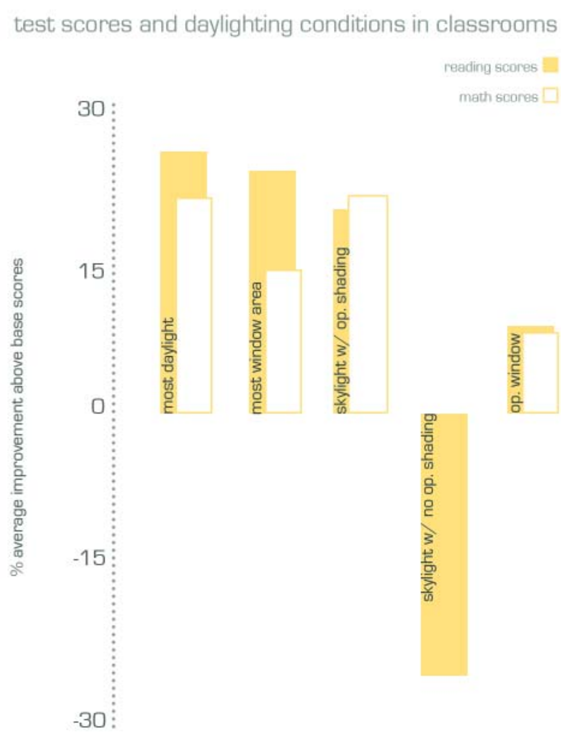
expected to increase to somewhere between $2.61 to $2.98 with the addition of a skylighting system." [2]

- "Were the chain to add the skylighting system to the remaining 33% of their stores, their yearly gross sales are predicted to increase by 11%." [2]
- "The retailer reported that the primary motivation for the inclusion of daylight was to save on energy costs by having photocontrols turn off electric lights when sufficient daylight was detected. The retailer has been very pleased with the resulting reduction in operating costs. Based on current energy prices we estimated average whole building energy savings for the daylit stores at $0.24 per square foot for the current design, with a potential for up to $0.66 per square foot with a state-of-the art design." [Heschong: Retail and Daylighting vi]
- "The value of the energy savings from the daylighting is far overshadowed by the value of the predicted increase in sales due to daylighting." [vi]
- "The profit from increased sales associated with daylight is worth at least 19 times more than the energy savings, and more likely, may be worth 45-100 times more than the energy savings." [vi]

[Heschong: Skylighting 2]

Benefits of Daylighting in **SCHOOLS**

- "Students in classrooms with the most window area or daylighting achieve 7% to 18% higher scores on standardized tests than those with the least window area or daylighting." [Heschong: Windows in Classrooms vii]
- Daylighting can also have a positive on effect student health and attendance rates.



[Heschong: Daylighting and Human Performance 66]

CLIMATIC CONCERNS

Several climatic variables must be taken into account in order to achieve optimal daylighting benefits.

- Latitude

  A site's particular latitude determines the angle at which the sun's rays hit the ground and building surfaces. These angles should be accounted for when designing shading systems.

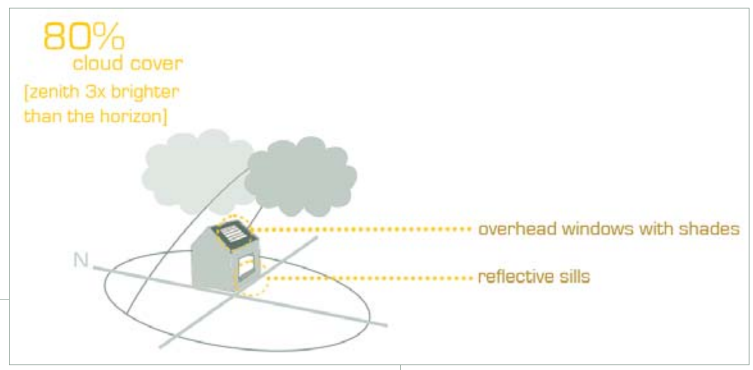
- Degree Days

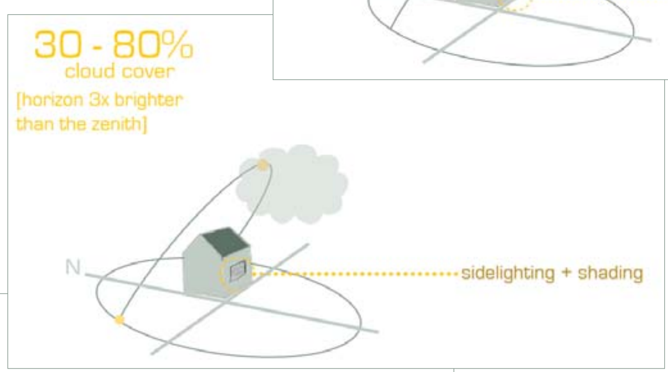
  A location's climate and sub-climate will determine the number of heating and cooling degree days it experiences on average annually. These numbers should be considered when designing for acceptable levels of solar gain. In a hot climate, shading should be present year-round; in a cold climate, one may instead wish to permit direct sun rays into a building throughout the year.

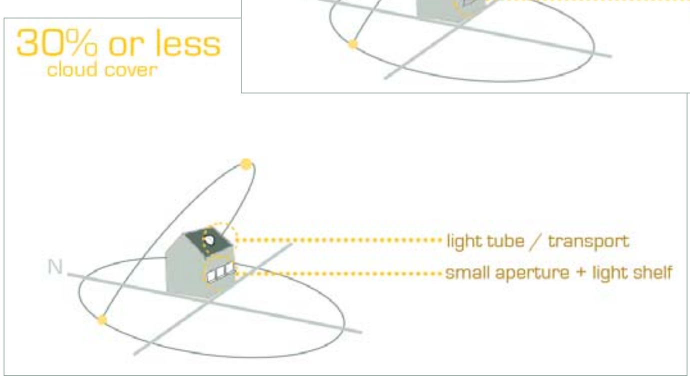
- Local Weather Patterns

  The amount of cloud cover affects the amount of daylight entering a building. Overcast skies are three times brighter at the zenith than the horizon. For this reason, in locations where it is often overcast, toplighting will be better for daylighting than sidelighting.

  - Overcast sky: 80% cloudy
  - Cloudy sky: 30-80% cloudy
  - Clear sky: less than 30% cloudy



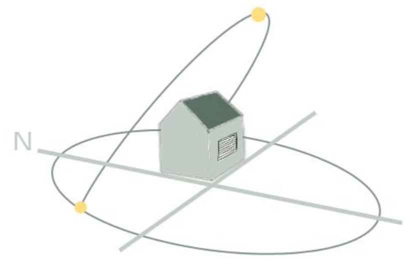




Modeling Methods

Both physical and computer modeling provide modes through which to analyze climatic factors including:

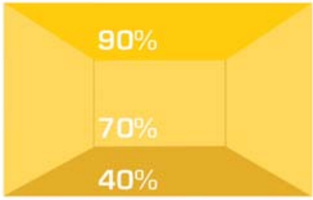
- Sun modeling
- Incident daylight computation
- Shadow projection



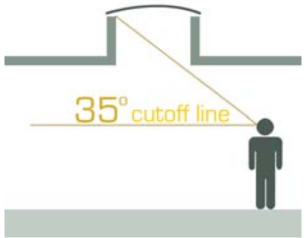
GENERAL GUIDELINES

Following are some rules of thumb and troubleshooting methods to consider when designing daylighting systems.

- The depth that light will enter a room roughly equals twice the height of the window head.
- Walls should be light-colored to promote brightness.
- Avoid dark paint colors; avoid dark-colored window frames in a sunny window to reduce contrast inexpensively.
- Avoid small windows in large walls.
- Place windows on the long rather than short wall of a narrow room for better light distribution.
- Avoid whiteboards or blackboards in direct view of a window/roof light to avoid glare.
- Consider plantings/screens for inexpensive shading.
- Avoid bad veiling reflections.
- Maintain a 35° cutoff line for toplighting to prevent glare.



optimal reflectance levels for ceilings, walls, and floors



Techniques for controlling **solar gain**:

- Shading

  Shading devices can be used to prevent direct solar rays from hitting glass and entering a space while allowing diffuse light to enter. This category includes louvers, exterior light shelves, overhangs, etc.

- Double Skin Facade

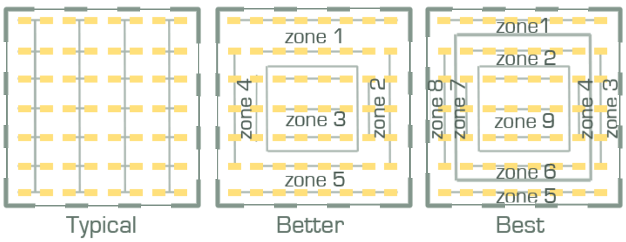
  This type of facade creates a buffer space that allows for light transmittance while mediating heat gain.

AUTOMATED INTEGRATION

A fully integrated natural and electric lighting system is key to achieving the energy savings associated with daylighting. This coupling takes advantage of natural light without suffering from a lack of sufficient light during periods of poor natural light quality. Integrated systems usually involve sensors that adjust electric light levels automatically with manual controls that can override the system when needed. The following are some key components of integrated lighting controls:

- **Switching circuits** for electric lighting should be arranged in a manner that places all lights near windows on different switches than those further away from windows or facing different cardinal directions. This allows one to only use fixtures in areas that are receiving insufficient natural light. Separate task lighting can be used for desk work so that entire rooms are not illuminated to an unnecessarily high level.

circuits and switching schemes in relation to fenestration



- **Photoelectric controls** dim or turn off electrical lights depending on natural light levels. Most are equipped with a time delay to allow for slight fluctuations caused by clouds or other brief light level changes. Systems which moderate lighting levels are beneficial because people often turn lights on even when they are not needed. There are two primary types of photoelectric controls:
    - Photosensors

      These units sense available daylight levels and regulate electric lighting levels. They can read and regulate a constant balance between natural light and electric light sources. These are best for smaller spaces where the unit responds to the individual space's needs.
    - Photoswitches

      This sensor turns lights on and off based on light levels and is generally used in outdoor lighting and large spaces such as factories. These sensors must be located away from the light source they are controlling to prevent incorrect readings.
- **Occupancy sensors** can be coupled with photosensors to further reduce electric lighting needs when a space is unoccupied. There are three primary types and combinations of these sensors:
    - Passive infrared (PIR)

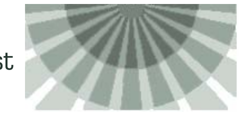
      This technology detects heat from a body in motion in reference to ambient heat. This detector requires a direct line of sight with the occupants, so this is not practical in offices with partitions or other spatial interruptions.

      
    - Ultrasonic (ULT)

      In this system, sensors send out a high frequency ultrasound. If there is motion, the sensor detects a shift between the emitted and reflected signal. This system can detect occupants that are out of direct line of sight and is

good at detecting minor motion; however, things such as high air movement can trigger false reads.



- Dual-technology (PIR/ULT)

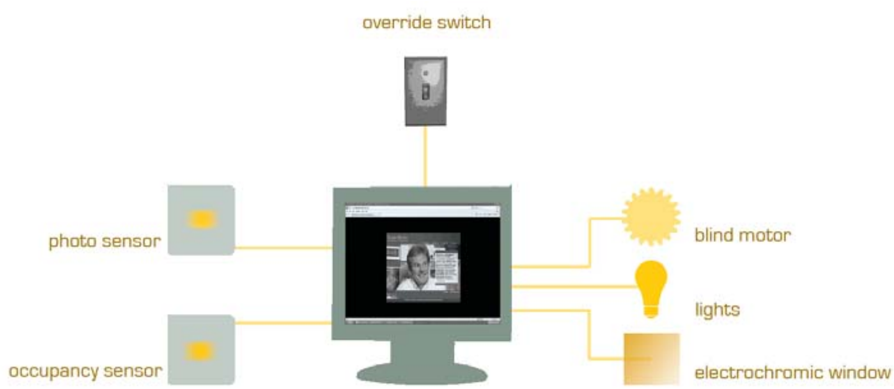
  This sensor combines the two systems just mentioned and is the best performing sensor.

- Audible (microphonic)

  This devise detects noise that is louder than back ground noise; this is a cheaper technology but sensitive to false reads.

- Timers & time clocks

  Timers are simple manual devices that turn off lights after a set time has elapsed (usually set by a dial). Time clocks are similar but turn the lights on and off on set periods during the day. This is not an automated occupancy sensor, but can serve the same function of making sure lights are only on when people are in the room.



The most effient integrated lighting systems implement both photo and occupancy sensors.

GLASS TYPES

The type of glass in a building has a considerable impact on daylight levels and heat gain. Following are a selection of enhanced glazing options.

- BIPV (building integrated photovoltaic)

  A laminated layer of silicon PV cells between layers of glass that provide limited day lighting (roughly 10%) and generate electricity (during peak hours, 3.9 watts per sq ft). Acts as a light diffuser and also generates energy.

- Electrochromic glazing

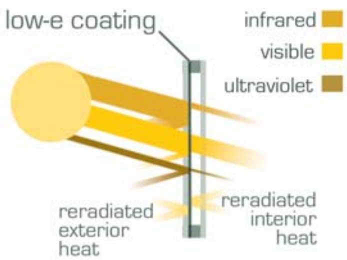
  Glass that features a chemical composition that has the ability to change color when a charge of electricity is applied, allowing a person to control when a window is tinted or translucent. This feature allows for optimal daylighting with the option of controlling glare or harsh direct light.

- Fritted/Patterned Glass

  A pattern or texture applied to glass used for solar reflectance, as a light diffuser, and for aesthetic value. There are even cases where this type of glass has been cited as a bird friendly material. (Swarthmore College received a LEED innovation point for this). The fritted glass can be produced through sand blasting, acid etching, and ceramic applications, each resulting in a slightly different aesthetic appearance.

- Glass Block

  A glass block is typically is 8"x8". The block is thick enough to provide more insulation than single plane glass. It also provides privacy and security while still admitting natural light.



- Low-E (Low Emissive) Glazing

  Glass with a microscopically thin metal or metallic oxide coating that reduces heat radiation, reflecting it back towards the incident side. This glazing allows for low heat gain and loss while maintaining high translucence.

- Tinted Window Film

  Dyed film retrofit that lowers light admittance and heat gain. Spectrally specific dyes rely on reflection and emissivity rather than absorption, which helps reflect the infrared light.

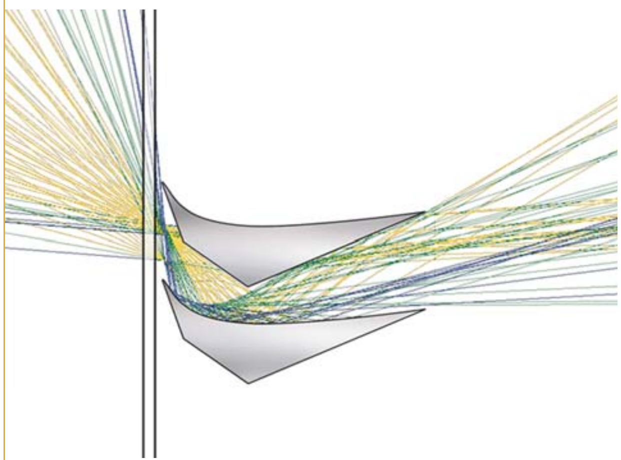
- Vacuum Glass

  Glass with a space vacuum between two panels of glass that often has a low-e coating. The vacuum eliminates the transference of heat through conduction and convection, and the low-e coating combats readiant heat.

ELEMENT STUDIES

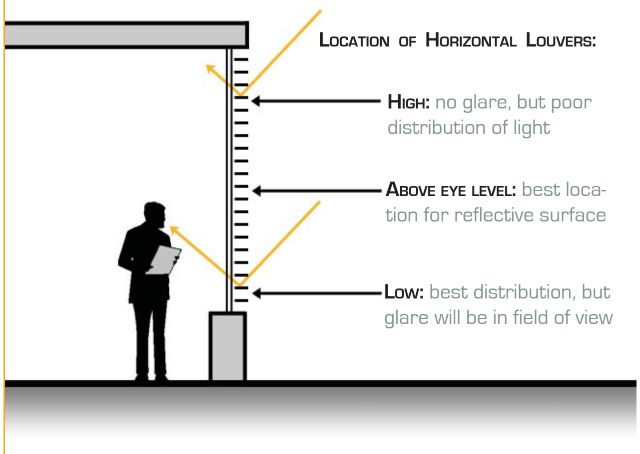
LOUVERS

Louvers



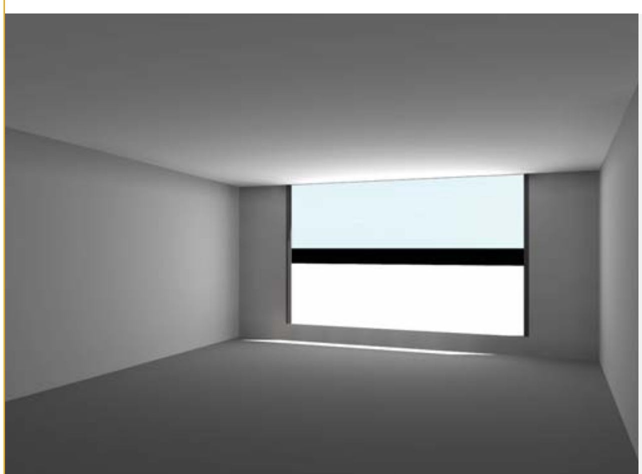
Louvers reduce heat gain, glare, and energy costs within a building. There are four main orientation categories of louvers: horizontal louvers, vertical louvers, cantilevered louvers, and overhead louvers. Each addresses a different situation, sun orientation, or a specific desired affect.

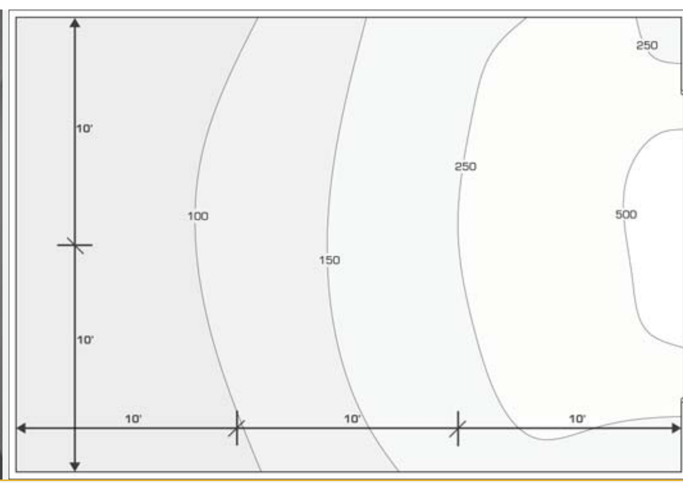
Horizontal louvers are most effective in a southern oriented façade. They both block and diffuse sunlight, and they allow light to penetrate deeper into the building than cantilevered louvers. If they are perpendicular to the window surface and have enough depth, they can diffuse daylight while still preserving views.



Cantilevered louvers, like horizontal, are most effective in a southern oriented façade to block the sun, but it is possible to have them oriented and angled correctly on the northern side of a building to catch the sunlight and reflect it back into the building. Cantilevered suspended facades can be easily adapted to existing buildings and can be manufactured with a variety of fascias, outriggers, and blades.

Vertical louvers should be used on east or west facing facades to stop harsh light low on the horizon and to help diffuse the sunlight rather than having harsh





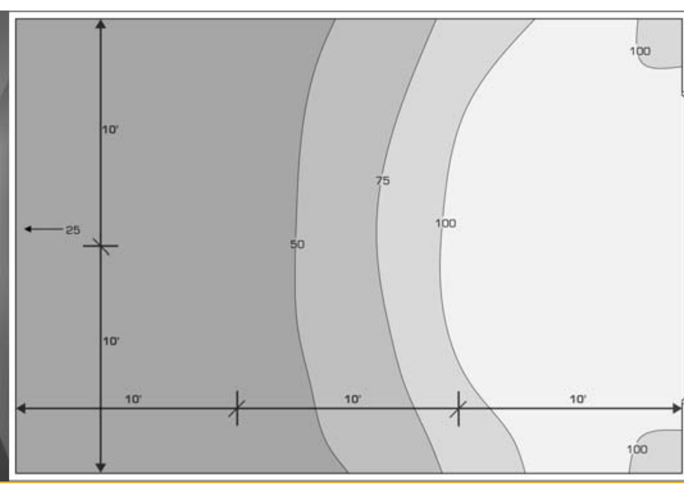
plain window

Units: Foot-candles

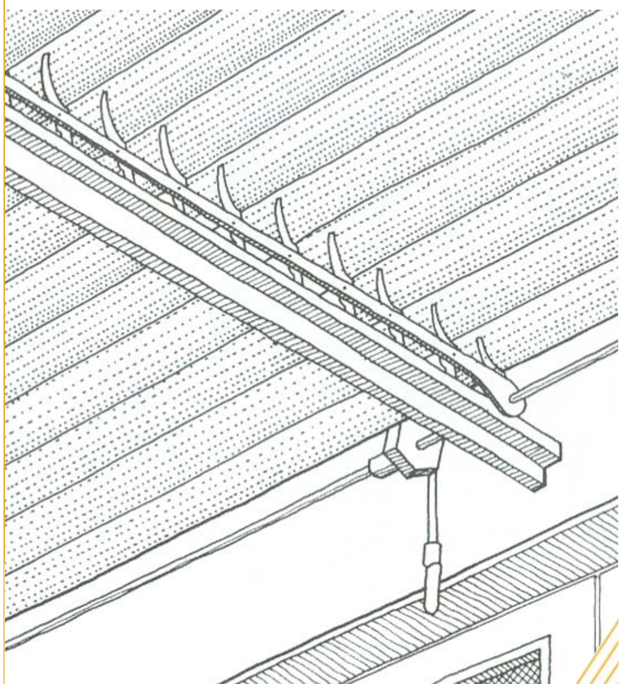
changing shadows as the sun moves across the horizon. Vertical louvers can also be angled to project light further into the space.

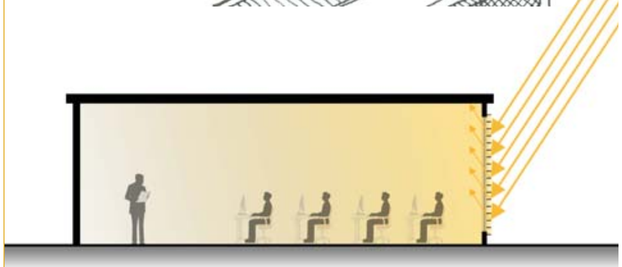
Overhead louvers/baffles are used to diffuse light through an overhead skylight and to prevent unwanted heat gain, if placed outside the window.

angled louvers



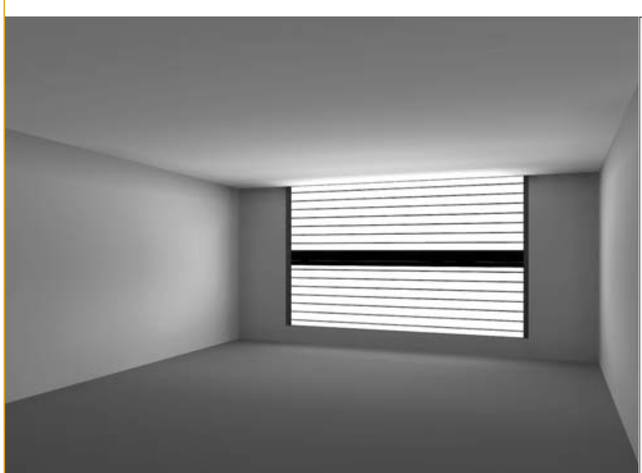
Louvers

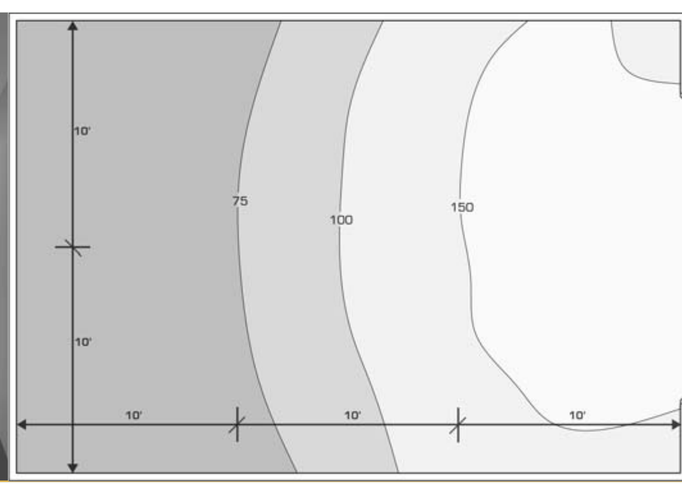




The shape, size, angle and material of louvers significantly impacts the efficiency of their design. The shape of an individual louver can be adjusted to fit an aesthetic or to perform a specific desired function. **The size of louvers can vary widely and still achieve the same shading characteristics, as long as the ratio between the depth and the spacing between the louvers remain constant.** The angle at which louvers are fixed has a large affect on both performance and views. If angled correctly, louvers can block the high summer sun and permit the low winter sun to enter and help heat a building.

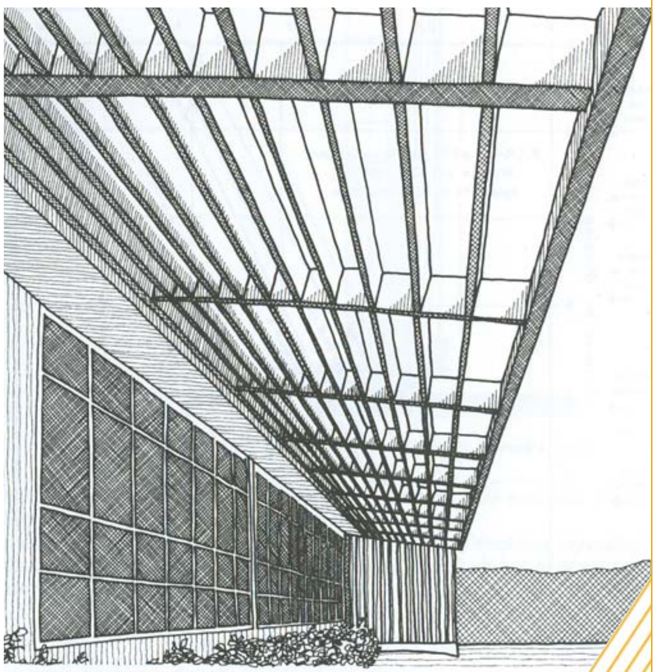
A lighter-color material can be used to reflect more daylight into a space; remember, however, that reflected light from a shading device creates potential for glare. Therefore, in order to prevent unwanted glare, they should be carefully located away from the occupants' field of view. The shaded side of an opaque louver in direct sunlight will appear much darker than the well lit surfaces. This stark contrast will give the perception of glare and should be avoided by making the shaded side of louvers light in color. A perforated louver also reduces the perception of glare by allowing a minute amount of light through while still blocking the majority of the solar radiation.

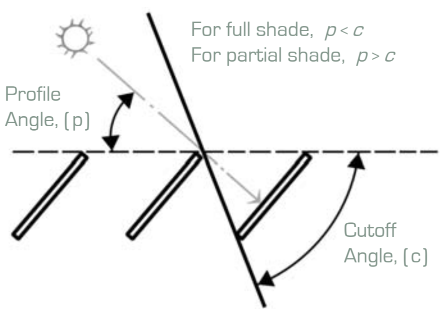




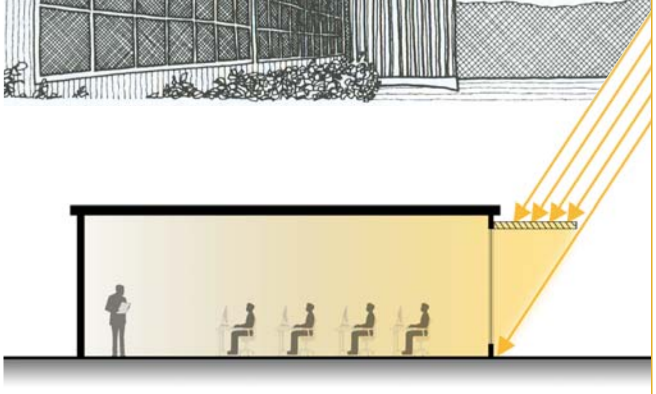
horizontal louvers **Units:** Foot-candles

Materiality affects heat gain; when selecting finishes and materials, it is important to consider their properties and distinguish which materials reflect both light and heat and which materials only reflect light. Materials such as polished metals can reflect UV rays meaning both light and heat will be mirrored into the space, while a white paint finish will only reflect light. The installation of louvers on the interior or exterior of the building greatly influences heat gain; so it is important to consider climatic situations. Mechanical louvers are an effective way of maintaining the best balance between light and shading for both daily and seasonal conditions.

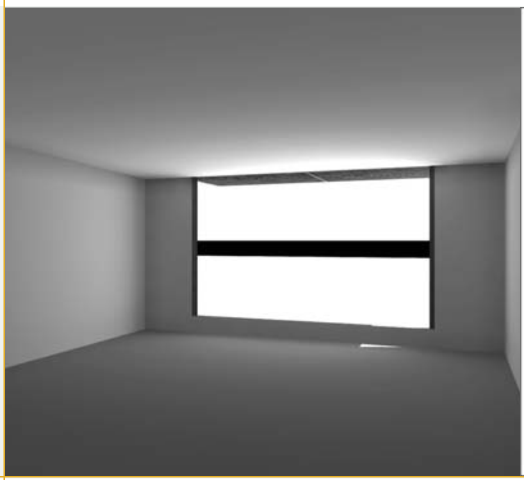


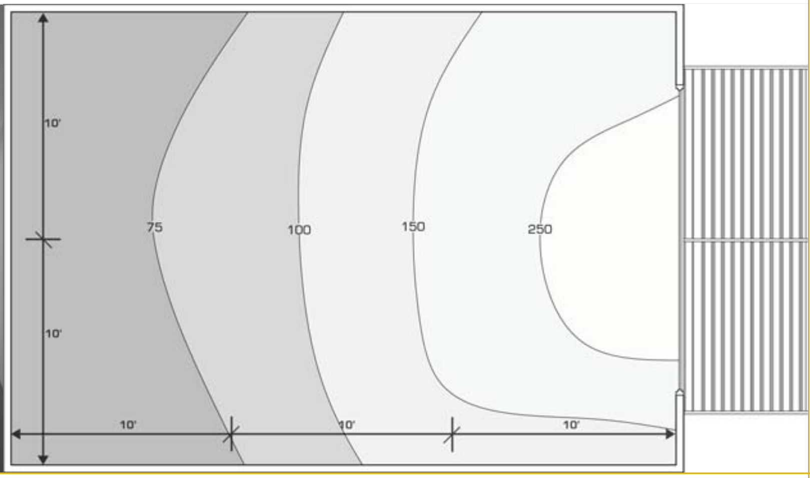


Geometry of Overhead Louvered Sunshades



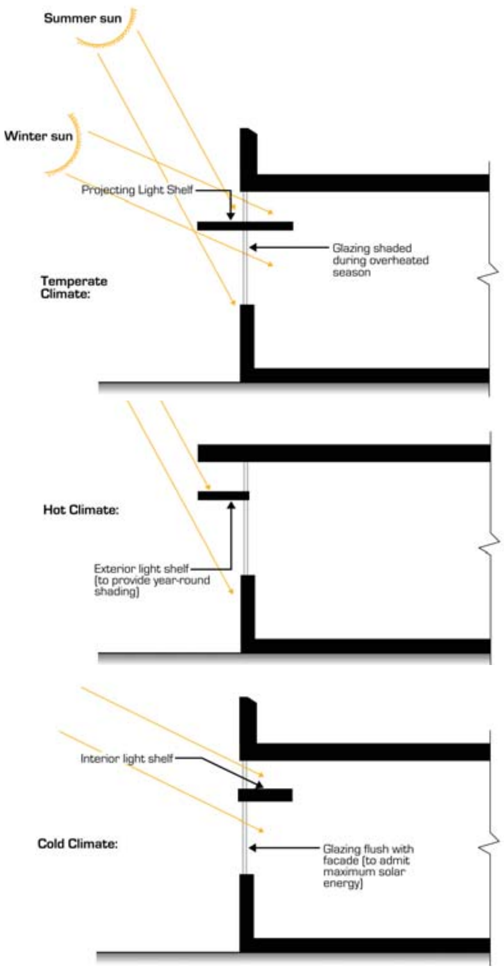
cantilevered louvers





LIGHT SHELVES

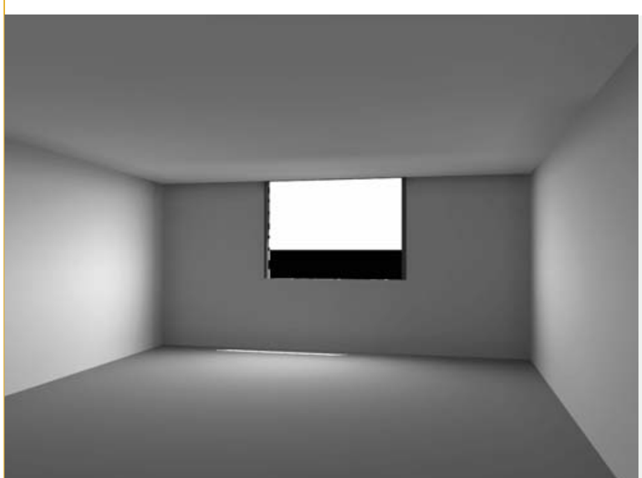
Light Shelves

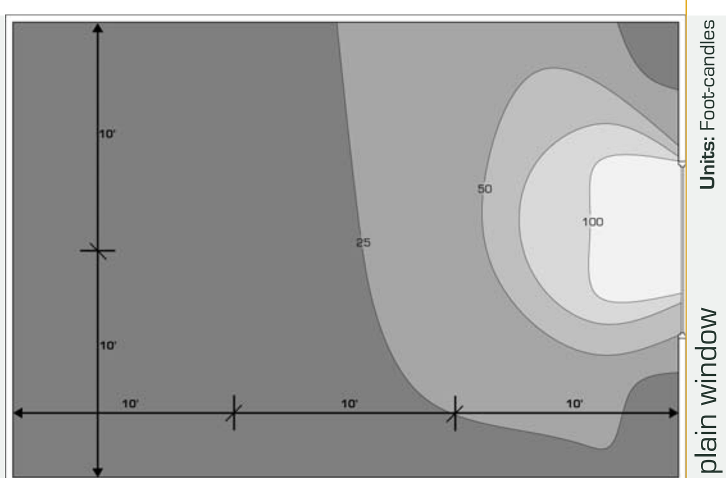


Light shelves are increasing in popularity as a design strategy used to distribute daylight. They reflect daylight deep into a space while blocking excessive amounts of light and heat gain around the perimeter. By reducing the levels of direct light near the window and redirecting light deep into the space, light shelves greatly improve the uniformity of natural light. **They can increase the day lit zone from 15-20 ft. to about 30 - 35 ft. and up to 45 ft.** When paired with a photosensor-controlled lighting system, they can significantly reduce the use of electric lighting, thus reducing the cooling load of a building.

Many conditions influence the optimum size and position of light shelves. They should be oriented as low as possible without interfering with the view through the lower window, and they should be above eye level in order to prevent glare. **A typical height is around seven feet.** Occupants should never see the top surface of the light shelf, as this surface creates glare. If heat gain is not an issue, the top surface of the light shelf can be mirrored; otherwise, the upper surface should be white.

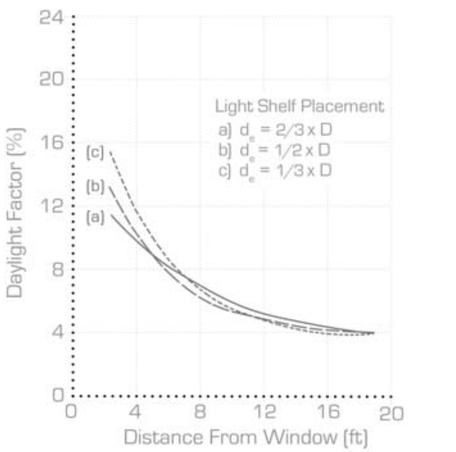
You can increase the amount of light reflected onto the ceiling by tilting the external part of the light shelf





above the horizontal plane. The optimum tilt is less for shallow rooms than for deep rooms, and the rear wall reflectance should be increased with higher tilt. **One should lengthen or thicken a tilted light shelf to maintain proper shading levels.**

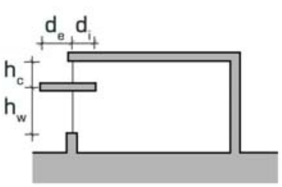
You can further improve the lighting in the space by sloping the ceiling up from the window. The ceiling should be a highly reflective white color with a relatively matte finish. A glossy or mirrored ceiling leads to a higher potential for glare.

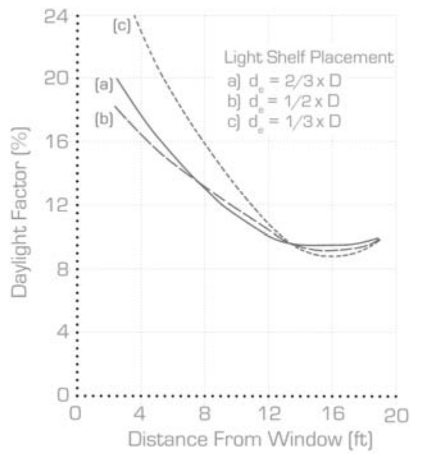


Overcast Sky Daylight Distribution From Light Shelf, h_c = 1/3 H

$d_e + d_i = D$

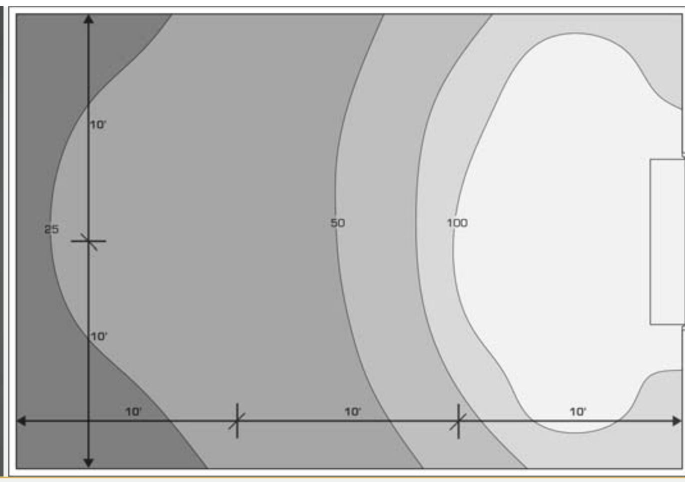
$h_c + h_w = H$





Clear Sky Daylight Distribution From Light Shelf, h_c = 1/3H

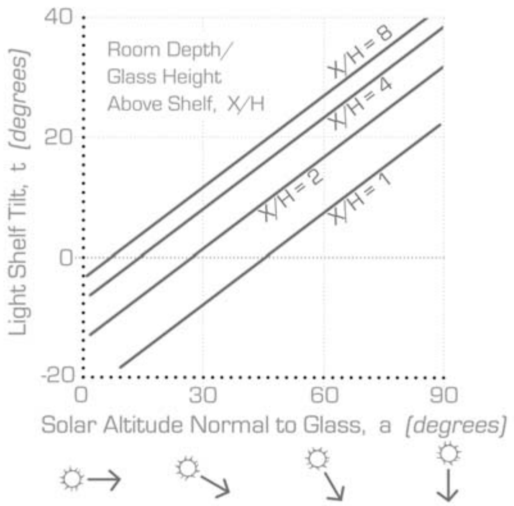
window + light shelf



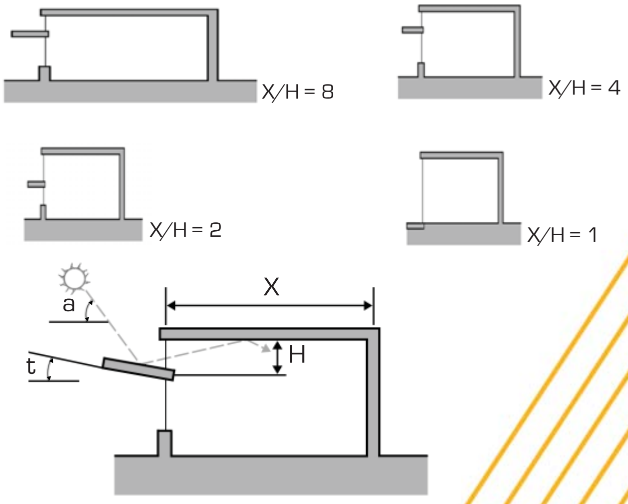
Light Shelves

Case Studies: Sidwell Friends MS 48
Manufacturers 82

- **Cost:** between \$25 and \$35/ft²
- **Interior light shelf size:**
  Generally 2-3 inches thick and 1-3 feet long
- **External light shelf length:**
  20° of South: 1.25 – 1.5 times the height of the upper window
  Beyond 20° East or West of South: 1.5 – 2 times the height of the upper glass
- **For white shelves facing south:**
  Make shelf tilt equal 40° – (0.5 x latitude°)
- **For shelves facing east, west, and north:**
  Make shelf tilt equal 15°



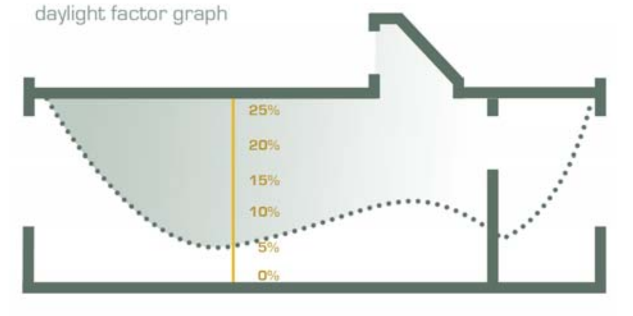
Optimum Tilt of Light Shelves, Clear Sky



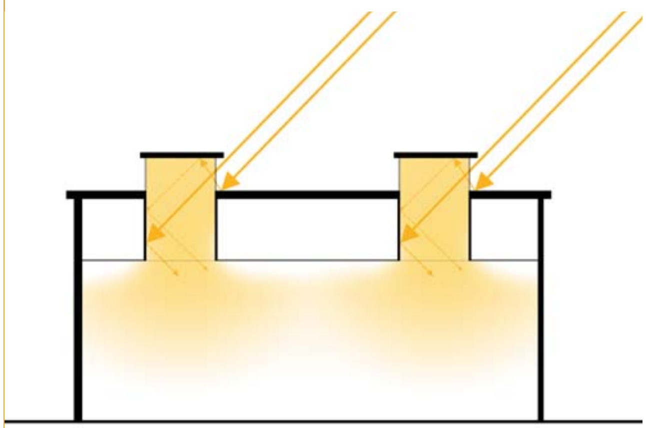
LIGHT MONITORS

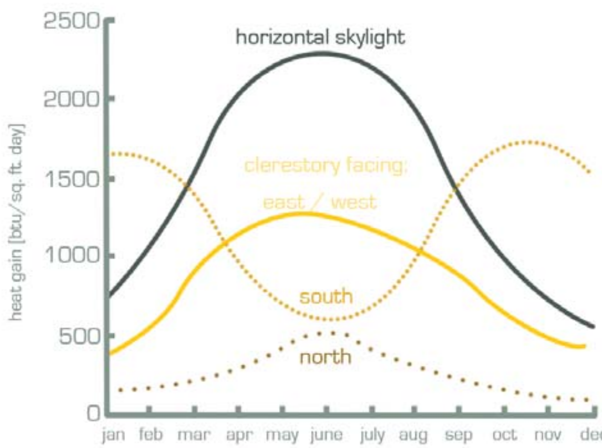
Light Monitors

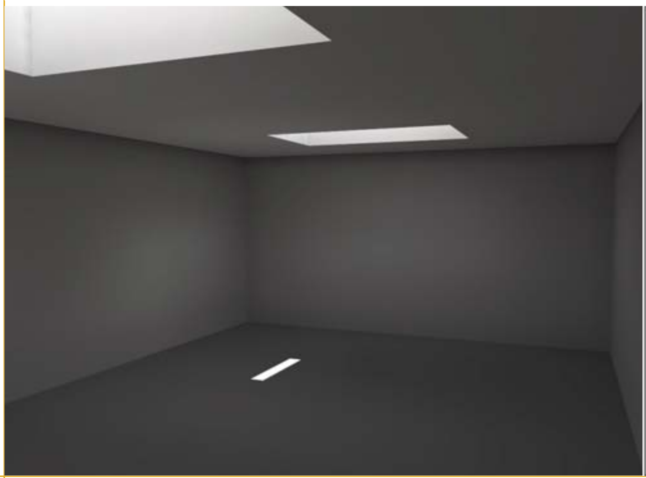
Toplighting, including skylights and light monitors, allows deeper penetration and greater distribution of sunlight than sidelighting if used correctly. In fact, roof openings can provide three times the light level of sidelighting openings the identical size.

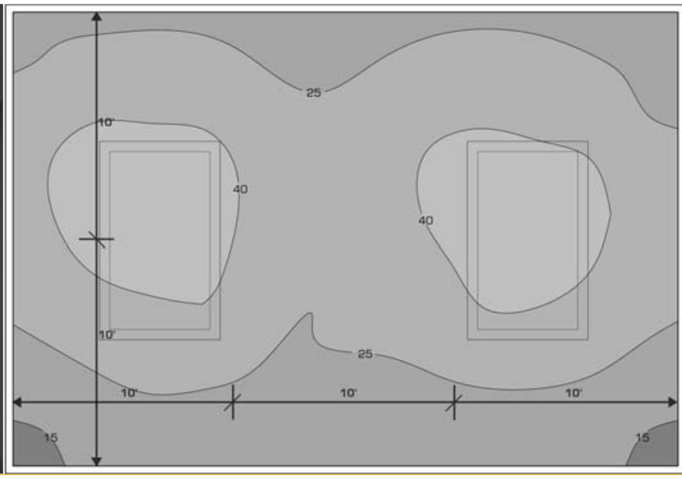


Although counter intuitive, the amount of heat admitted by toplighting is significantly less than that admitted by sidelighting. For example, **a south-facing horizontal window admits almost 2,500 btu/sq. ft. per day in June while a south-facing clerestory of the same size only admits 500 btu/sq. ft. per day in June**. An added





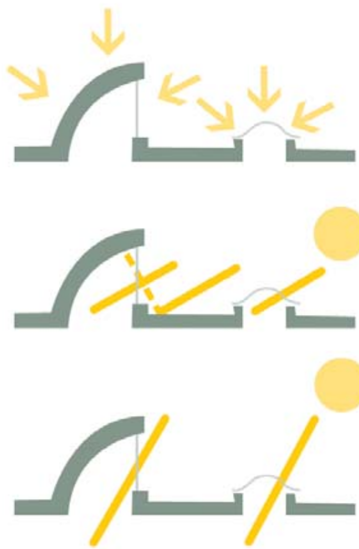




straight well **Units:** Foot-candles

benefit: the clerestory admits over 1500 btu/sq. ft. per day into the building during the winter months. Refer to the following design guidelines to achieve maximum skylighting benefits:

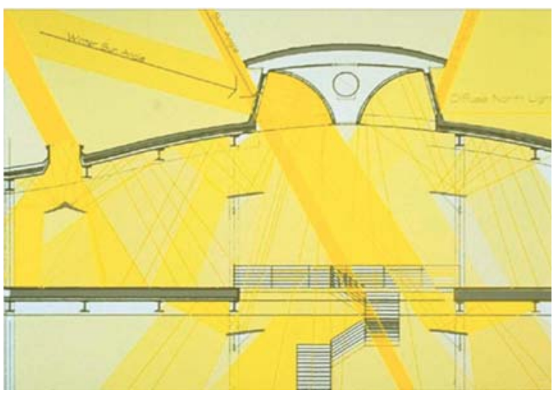
- Narrow wells concentrate light while slanted wells disperse light [depicted in the four bottom images]
- Northern openings admit the best diffused light, east the best morning light, west the best afternoon light, and south the most direct light.
- The position of the sun, latitude, and weather all affect toplighting: see the diagrams at right.

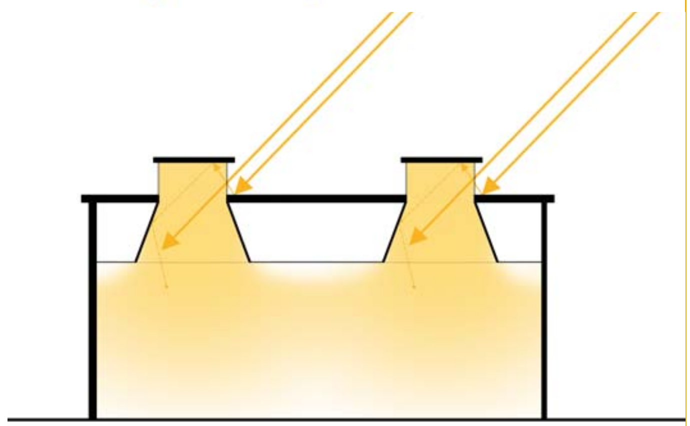


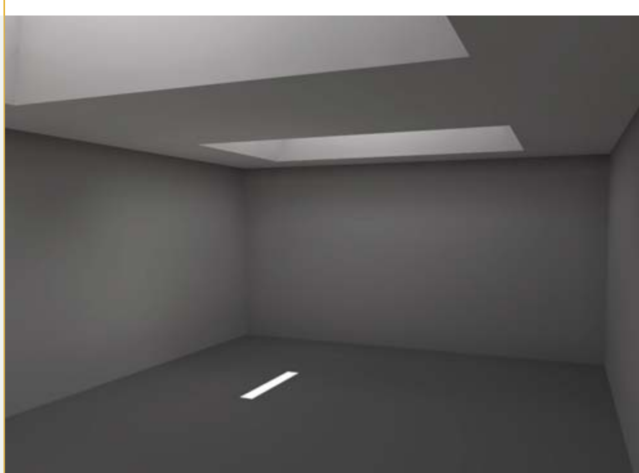
overcast sky: horizontal skylights collect more light

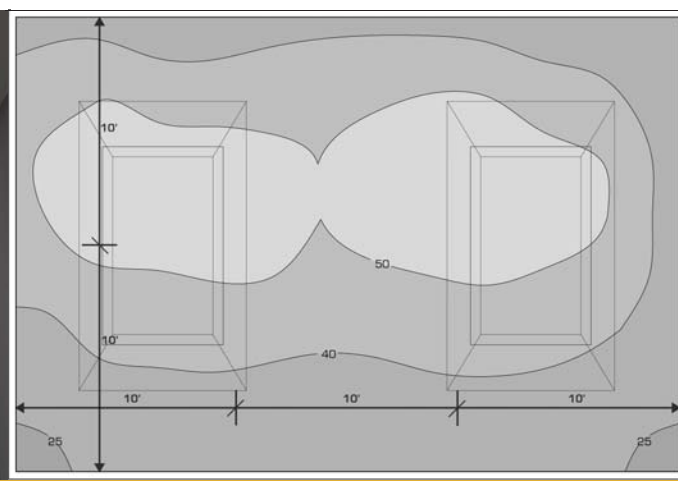
low sun angles and reflected light: vertical clerestories collect more light

high sun angles: horizontal skylights receive maximum heat gain





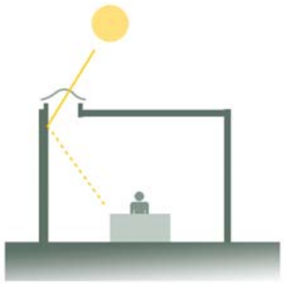


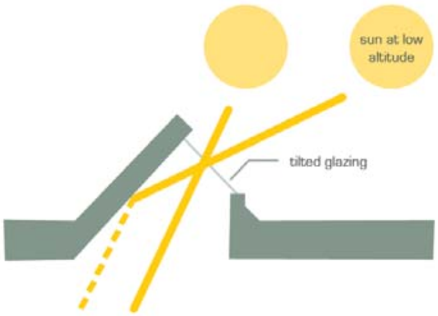


slanted well

Light Monitors

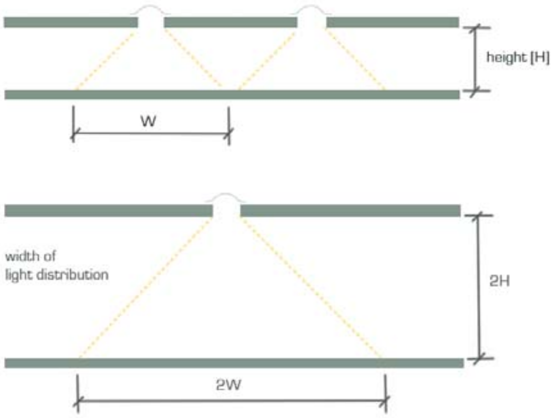
Case Studies: Finnish Embassy 50
Manufacturers 82





- Set the glazing tilt to match seasonal lighting needs
- If retrofitting a building, consider the ceiling height, as loftier ceilings admit more daylight.
- Low-transmission and translucent glazing can cause glare. A large area of low-transmission glass will be required to equal the light transmitted by a small area of clear glass.
- Locate smaller openings where light is needed to avoid admitting too much [large skylights can simulate an overcast sky regardless of actual weather conditions]
- Avoid allowing direct light to hit a work surface by redirecting it by using exterior overhangs, fins, louvers and interior beams, louvers, reflectors, and deep wells
- Baffle skylights on the exterior or tilt and orient glazing to minimize heat gain.

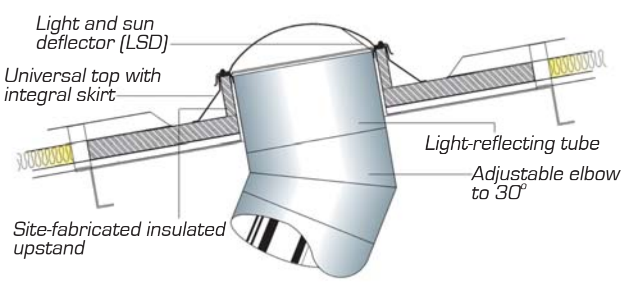
lofty ceilings improve light distribution



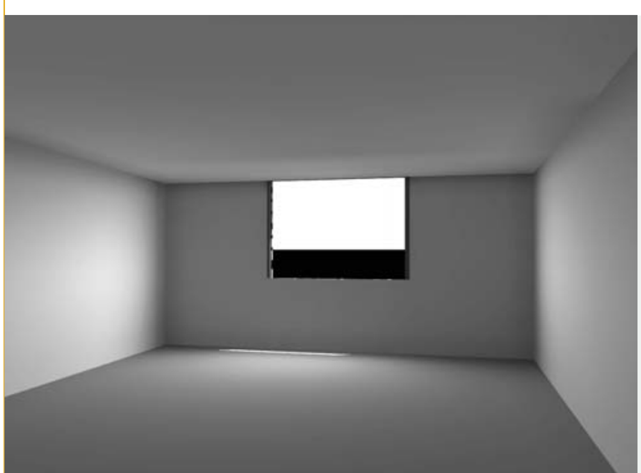
LIGHT TUBES

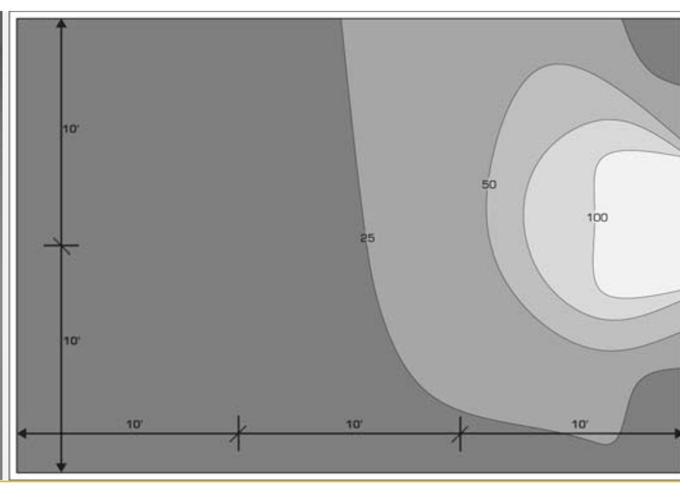
Light Tubes

Light Tube On Standing Seam Roof



Light tubes (also known as sun scoops, tubular skylights, and solar pipes) are tubes or pipes used to transport natural light into an interior space. Light tubes allow is possible to get natural light into the dark core of a building or into underground structures. **Light tubes are made up of three key components the collecting head unit, the duct unit, and the diffuser unit.** The entrance to the tube is usually a dome, which acts to reflect the maximum amount of light into the tube. Mirrors and heliostats can also be employed to reflect light into the tube for better performance. The interior of the tube is highly reflective to help move light downward into the space with minimal loss. Some manufacturers claim up to a .90 - .98 reflection ability inside the tube. At the end of the tube a diffuser unit is usually used to spread the light evenly across the space. Since the light is diffused into a space through the tube, heat gain is minimal. Depending on the product, however, insulation is available to prevent unwanted heat loss. Light tubes work best when integrated with electric lighting and a photo-sensor controlled system, allowing an even amount of light to be maintained during cloudy and dark times of the day.





plain window

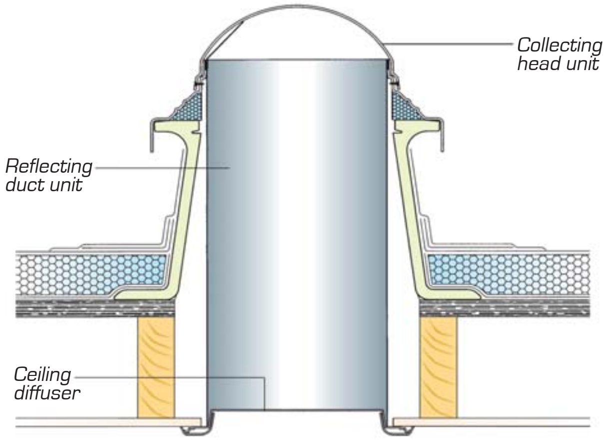
Units: Foot-candles

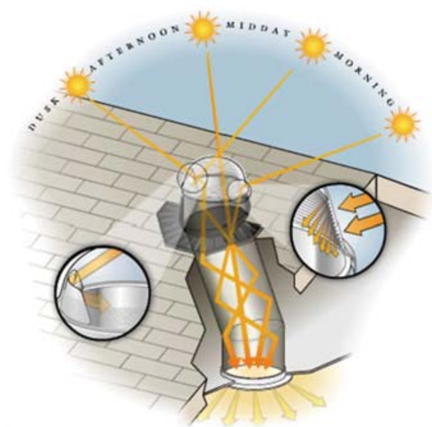
Light tubes are used in a variety of ways and come in multiple shapes and designs. There is a general set of standards:

Reflectance: The interior is usually a mirrored surface for high reflectance. Studies have found that a difference of 0.001 for the interior reflectance value of the tube had a significant change on efficiency. *The standard today is a value of .95 of reflectance.* Other light tubes consist of transparent shafts and prism glass hung in atriums that move light and diffuse it in all directions as it moves downward.

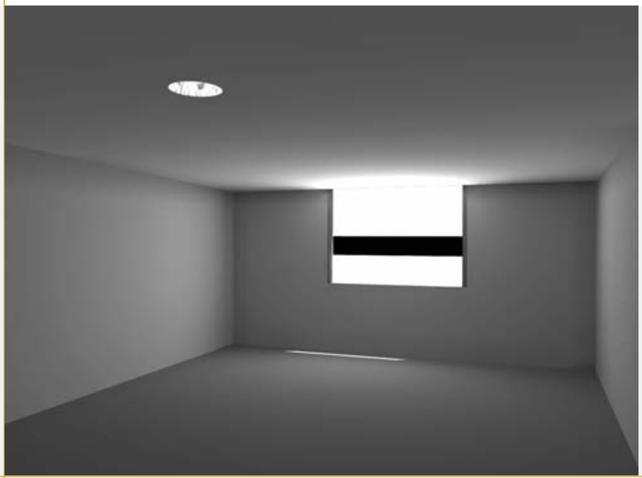
Diameter: The width of the light tube determines the strength of the light and how far it is able to reach. *The standard diameter is approx. 300mm.* A light tube with a diameter of 200mm would transmit around 1/3 of the light of the 300mm, and one of 150mm would transmit about 1/5 the amount. The larger the diameter, the more efficient the light tube is.

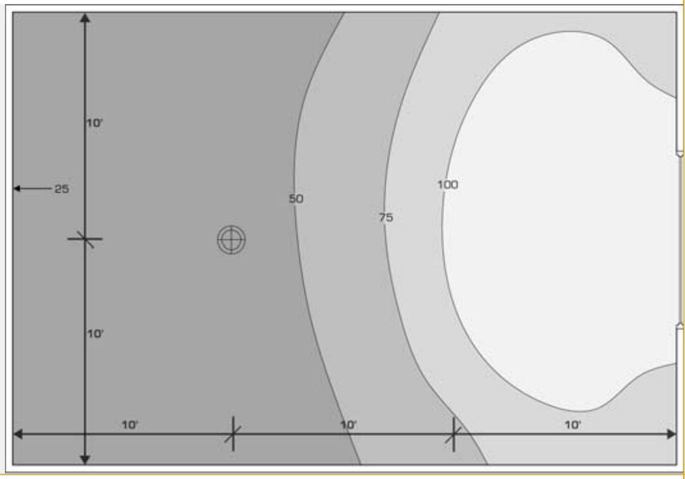
Length: Standard lengths go up to 10m or 30ft, the longer the tube, the less effective it is. Although



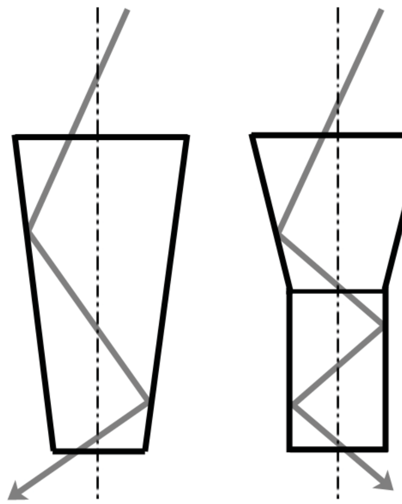


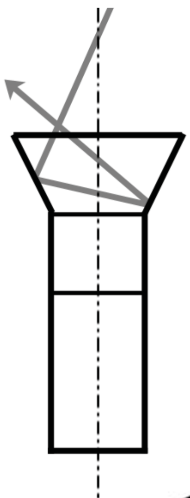
window + light tube





Light Tubes

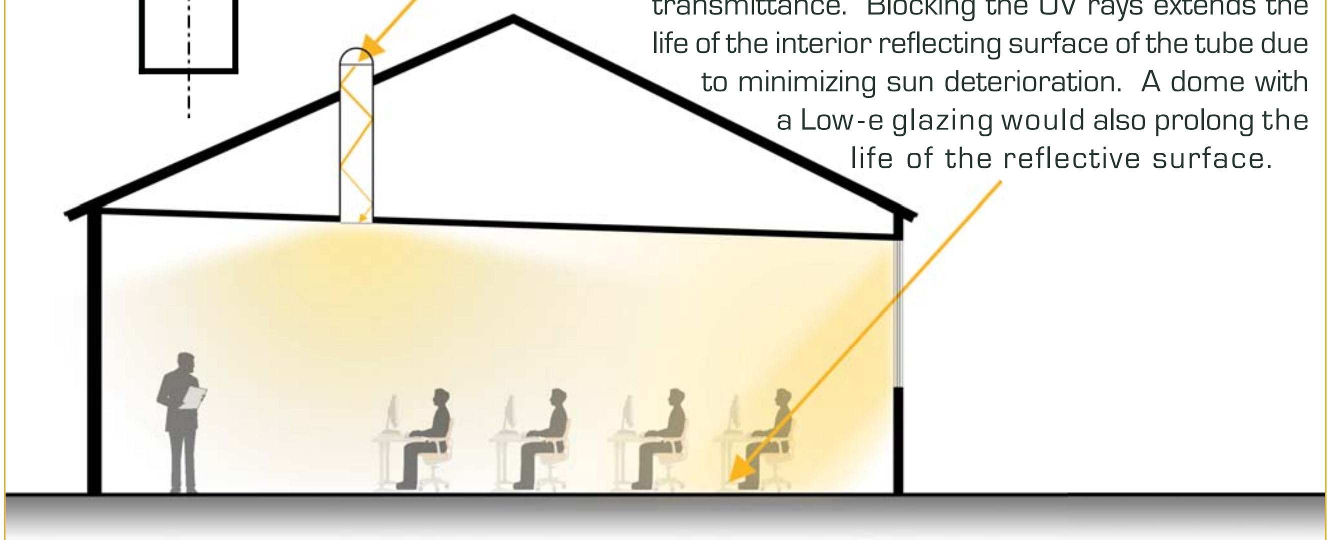




the maximum length typicallymanufactured length is around 30 ft., light tubes with enhanced optics and heliostats have been built up to 120ft.

Shape: A linear light tube is the standard for the majority of products.; however, there have been studies to explore other designs. Concentrating pipes such as tapered or coned light pipes have a higher performance at a lower outside illuminance, but the straight pipe transmits more light during times of higher exterior illuminance. Concentrating tubes are also more sensitive to the sun angle than the linear pipe, which adds to a higher disparity between the seasons.

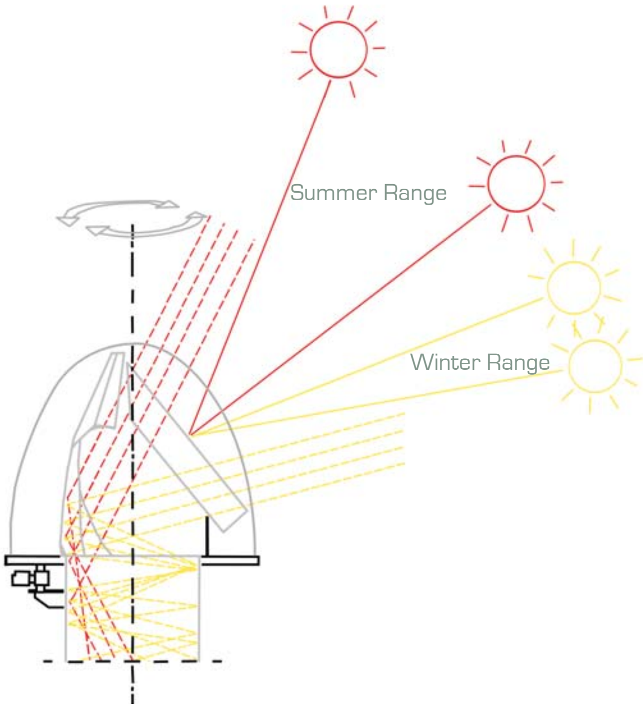
Dome: Generally the light collector glass will be domed. A study showed that the domed collector had higher light transmittance than a planar collector, especially when the sun was at a lower angle. This reduces the difference between the amount of light transferred during various times of the day and the different seasons. The standard material for the dome is an acrylic that has high visible light transmittance and low UV transmittance. Blocking the UV rays extends the life of the interior reflecting surface of the tube due to minimizing sun deterioration. A dome with a Low-e glazing would also prolong the life of the reflective surface.

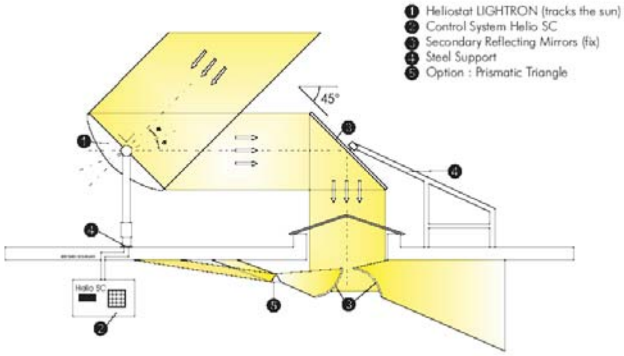


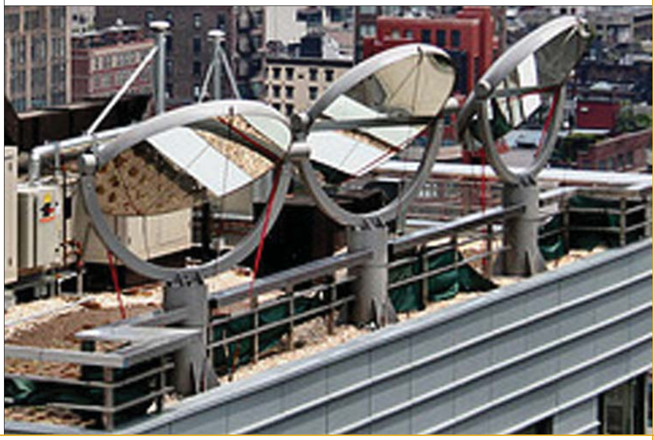
ADDITIONAL TECHNOLOGIES

Heliostats

Heliostats are stationary devices that track the sun, usually to focus light towards a receiver of some kind. They are used for a variety of things from focusing more intense light onto photovoltaic panels, light telescopes, and light transporting systems. There are many kinds and functions of heliostats. Some rely on fixed mirrors cut and shaped to increase the focus of the light onto a single area. Others trace the sun across the sky, using timers and clocks that turn the mirrors in accordance to times and seasons, while certain heliostats directly track the sun's position in the sky throughout the day. These devices, while they are more expensive and require extra maintenance, are far more efficient.



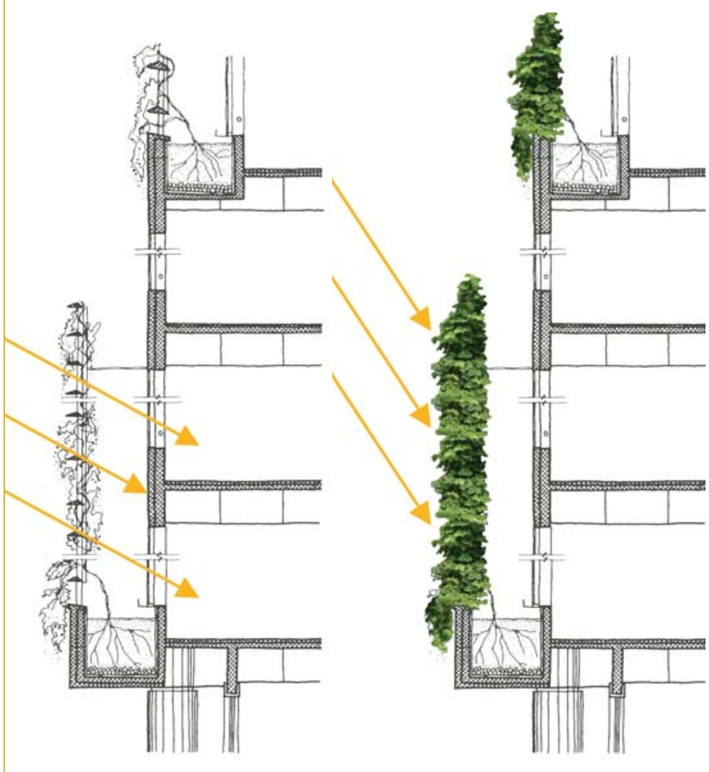




Growth Screens

Case Study: Finnish Embassy 50
Manufacturers 84

Vegetation screens are a natural way of controlling daylight, taking into account different heating and cooling requirements associated with changing seasons. Using deciduous plants allows more daylight and heat to enter the building during the winter while blocking unwanted heat gains during the summer. They can often outperform fixed shading devices because of foliation growth triggered by temperature change. The vegitation responds to seasonal conditions that are warmer or cooler than average, while fixed shading devices are typically designed according to long-term average temperatures. The shading coefficient of plants and vines depends on their density, age, and seasonal growth. Therefore, when planning for a growth screen, it is important to begin planting as early as possible in the construction process.

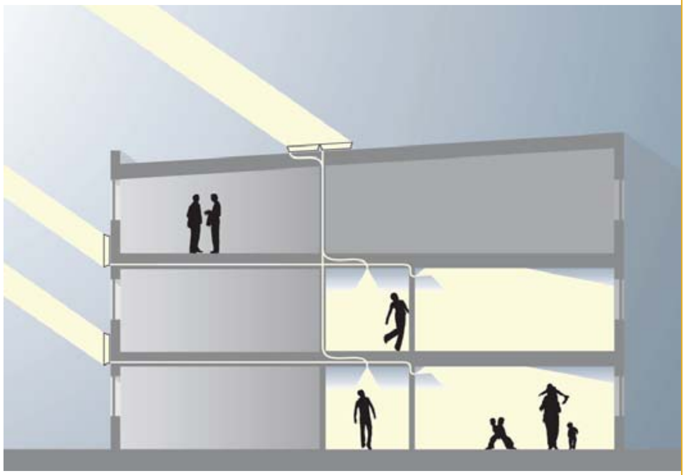


Winter Section Summer Section

Fiberoptic Cables

Case Study: Viktoria Arena Store 60
Manufacturers 85

Fiber optic lighting: Light is collected using a rooftop collector (comprised of heliostats or lenses) and fed into the end of fiber optic cables that then can run through out the building distributing the light. Under full sun conditions the cable can put out 1,180 lumens (about the output of a 100-watt incandescent bulb). Only the visible spectrum of light is allowed through the cable; the ultraviolet light and most of the infrared is filtered out. Certain products claim only a 4% loss of light per 33 feet of cable length. The high cost of glass cable production makes this current technology impractical, but research is being done on using a less efficient but much cheaper plastic cable. Other research is being done on lowering different costs associated with fiber optic lighting. The current length limit is about 45 ft.

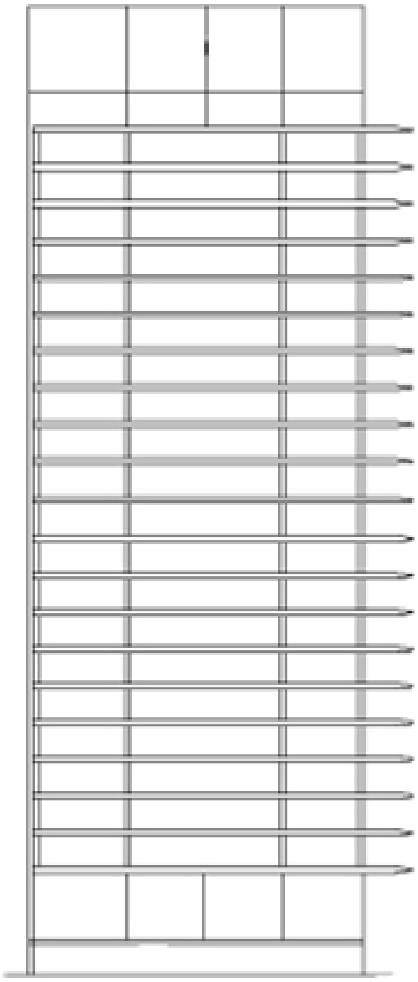


CASE STUDIES

Mondavi Center

Daylighting **ELEMENTS** Employed

- horizontal louvers
- overhead louvers

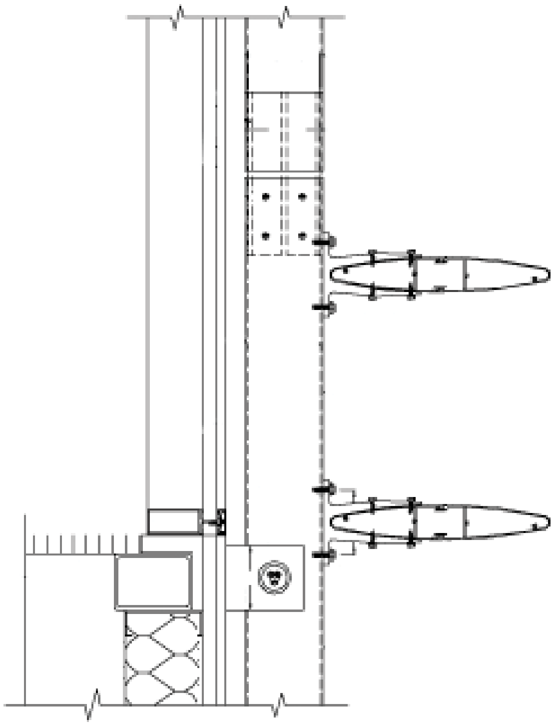


The Mondavi Center is the new performing arts building for University of California-Davis and has quickly become the symbol of the University. Louvers protect the large lobby from direct sunlight and heat gain. The screens and louvers were designed to block the radiant heat from entering the building while maintaining natural illumination and views. The steel trellised canopy over the lobby entrance shields the

FACTS

PORTLAND, OR

Architect: BOORA Architects
Louver Manufacturer: C/S Sun Control Devices
Engineering: Arup
Lighting Design: Auerbach + Glasow
Completed: 2002
Area: 104,000 ft^2
Cost: $57,000,000



exterior walkways and provides further shading for the building as well. The louvers are C/S's horizontal 17" airfoil blades, each supported by aluminum brackets mounted to vertical tubes. The vertical tubes are independent of the curtain wall, helping to prevent heat exchange. The tubes are mounted 18" off center from each other, which easily maintains the views in and out of the building.

Salvation Army Headquarters Chapel

Daylighting **ELEMENTS** Employed

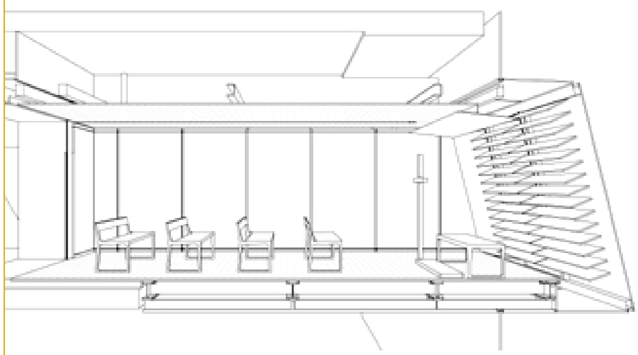
- horizontal louvers

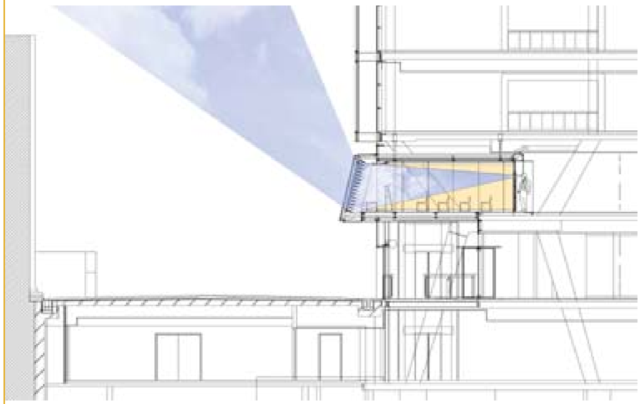
The small chapel in the Salvation Army Headquarters reaches out to the public by overlooking a prominent pedestrian route between the Tate Modern and St. Paul's Cathedral. While being externally iconic, the chapel also needs to keep a serene and peaceful atmosphere in the interior. The architect Sheppard Robson uses louvers to maintain the balance between the public symbol of the organization and the intimate privacy of a chapel. The louvers bring natural light into the chapel and maintain privacy by

FACTS

LONDON

Architect: Sheppard Robson
Lighting Designer: Carpenter/Lowings Architecture & Design
Engineer: Ove Arup & Partners
Year of Construction: 2002-2004



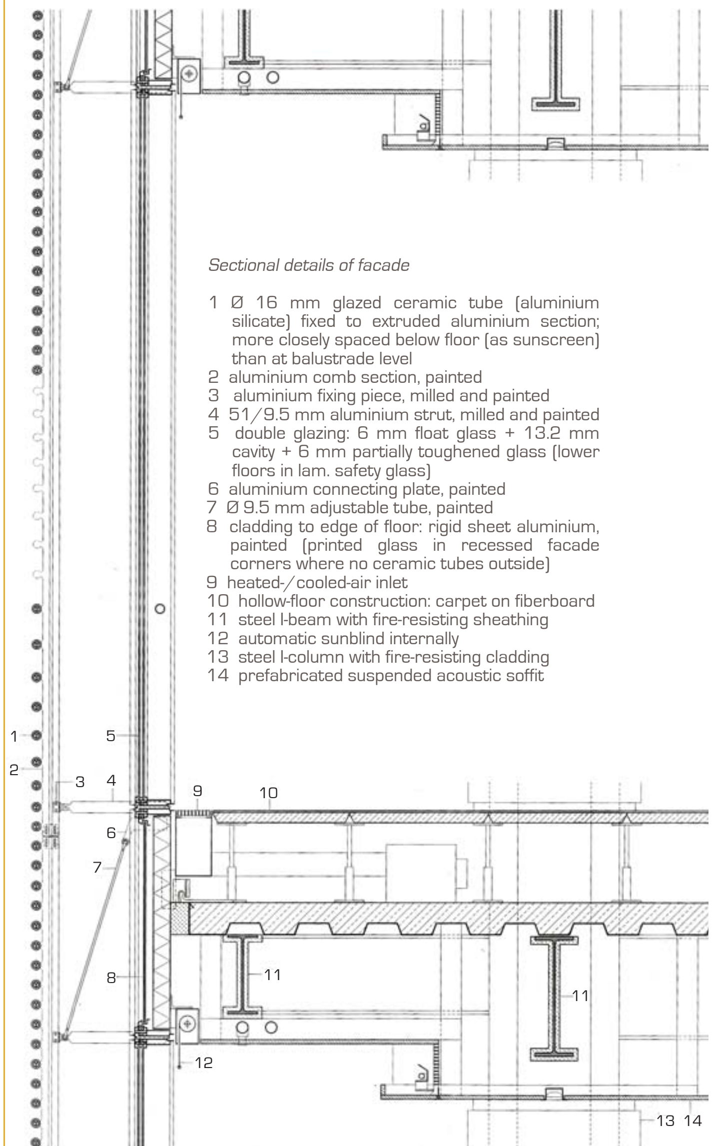


obstructing the view of the building across the street. The louver slats are slightly reflective, projecting a view of the sky towards individuals inside the chapel, giving the impression that you are looking upwards instead of outwards. Each louver is also angled slightly differently to give the impression of a single image of the sky. The effect is a well-lit chapel that is seemingly very open yet maintains privacy in the middle of a crowded city.

New York Times Building

Daylighting **ELEMENTS** Employed

- louvers
- light integration



Sectional details of facade

1 Ø 16 mm glazed ceramic tube (aluminium silicate) fixed to extruded aluminium section; more closely spaced below floor (as sunscreen) than at balustrade level
2 aluminium comb section, painted
3 aluminium fixing piece, milled and painted
4 51/9.5 mm aluminium strut, milled and painted
5 double glazing: 6 mm float glass + 13.2 mm cavity + 6 mm partially toughened glass (lower floors in lam. safety glass)
6 aluminium connecting plate, painted
7 Ø 9.5 mm adjustable tube, painted
8 cladding to edge of floor: rigid sheet aluminium, painted (printed glass in recessed facade corners where no ceramic tubes outside)
9 heated-/cooled-air inlet
10 hollow-floor construction: carpet on fiberboard
11 steel I-beam with fire-resisting sheathing
12 automatic sunblind internally
13 steel I-column with fire-resisting cladding
14 prefabricated suspended acoustic soffit

aluminum silicate

stoneware

porcelin

terracotta

Transparency, a trait that the New York Times strives to maintain, was the initial concept for its New York building. To achieve this transparency while simultaneously controlling harsh sunlight, Renzo Piano employed an innovative louver system. The louvers are made of ceramic tubes placed one and a half feet off the façade and spaced variably. The spacing increases at the apex of the building leaving a lace like structure that crowns the building and allows views to the foliage of a green roof. The ceramic louvers were

FACTS

NEW YORK

Design Architect: Renzo Piano
Architectural Office: FX Fowle
Lighting Design: SBLD Studio
Interior Architect: Gensler
Engineering: Flack+Kurtz
Years of Construction: 2001-2007

chosen because of their reflective properties compared to metals and because the slight irregularities would give off a more textured play between light and shadow. Roller shades are used to block glare during appropriate times, and light sensing dimmers are used to control the artificial lighting that complements the sunlight entering the building. The louvers and sun control devices allow the building to maintain transparency and a useful working environment.

Kogod Courtyard

Daylighting **ELEMENTS** Employed

- overhead louvers (variation)
- skylights

Built between 1863 and 1867, the United States Patent Building (now the National Portrait Gallery) was rescued from demolition in 1958, and transferred to the Smithsonian Institution. The Kogod Courtyard is part of a renovation program for the National Portrait Gallery intended to offer the Institution one of Washington's largest event spaces. The fully glazed roof canopy develops themes first explored in the design of the Great Court at the British Museum. The courtyard serves as an entrance to the surrounding

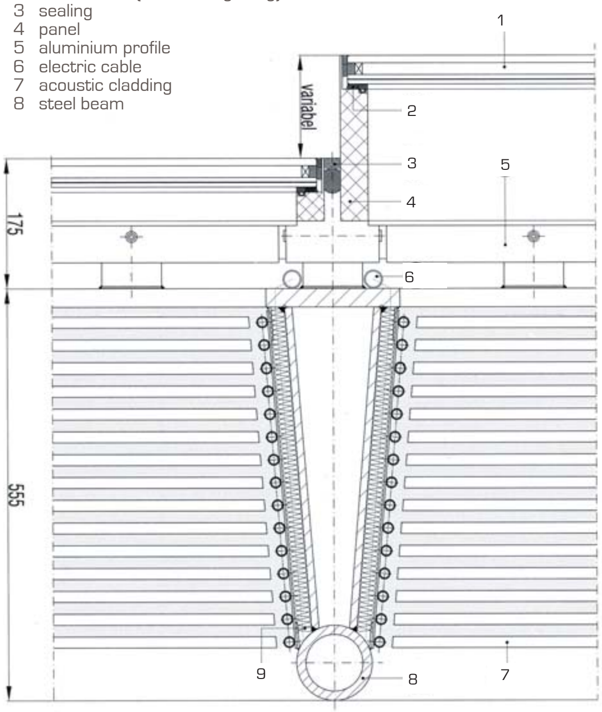
FACTS

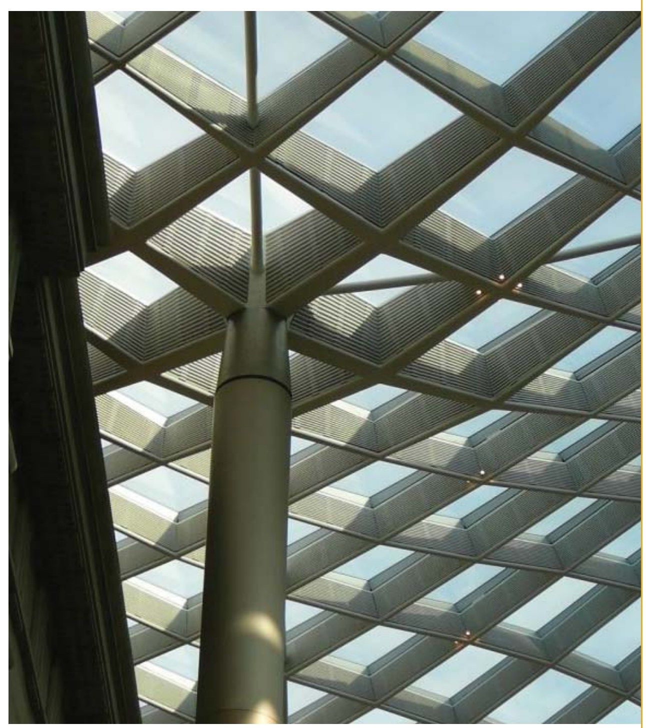
WASHINGTON, DC

Architects: Foster & Partners
Associate Architect: Smithgroup
Engineering Consultants: Buro Happold, URS Corporation
Lighting Designer: George Sexton Associates
Surface Area: 37,500 ft2
Cost: $63 Million

Section

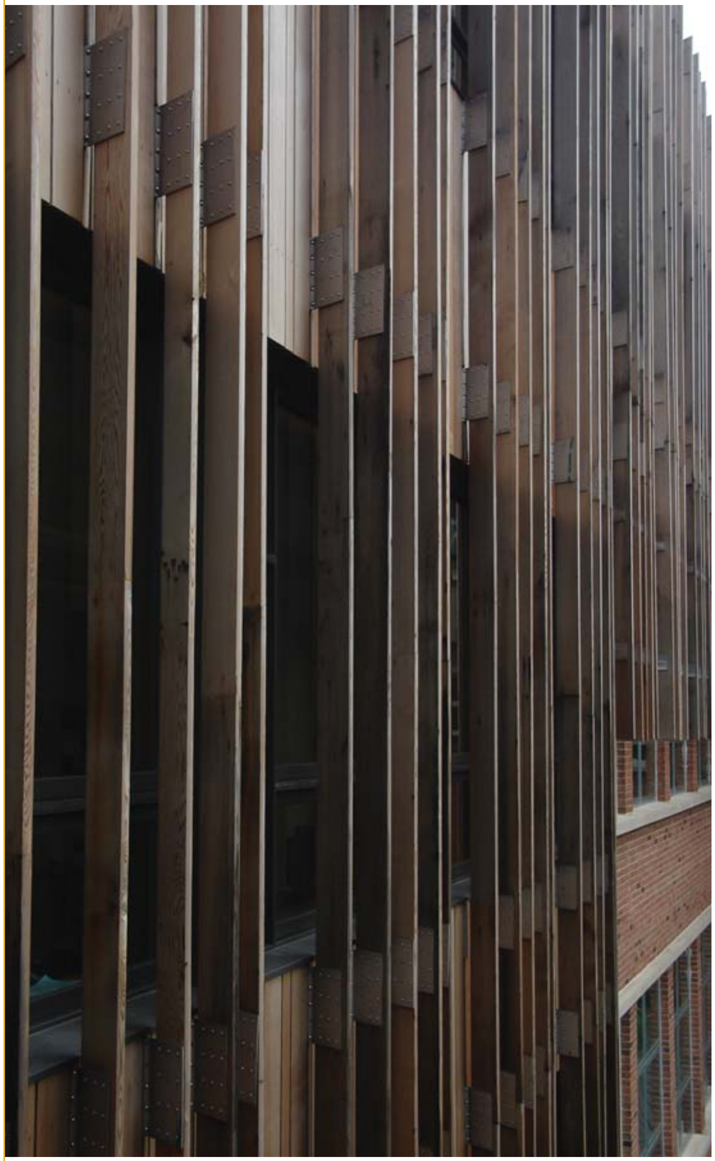
1 double glazed unit
2 silicone seal (structural glazing)
3 sealing
4 panel
5 aluminium profile
6 electric cable
7 acoustic cladding
8 steel beam





galleries and as a special event space after regular museum hours. The fluid form of the fully glazed roof canopy is structurally composed of three interconnected flowing vaults and valleys. The roof was prefabricated and assembled on site in sections. Eight columns entirely support the vaulted canopy, which consists of double glazed panels set within a "diagrid of fins" clad in acoustic material. The fins hide the electric cable which supplies night lighting, and the columns house the drain pipes for the structure.

Sidwell Friends Middle School



Daylighting **ELEMENTS** Employed

- louvers
- light shelves
- skylights
- automated integration

The design for this LEED Platinum certified school optimizes daylight and minimizes solar glare on each building exposure. On the south façade, horizontal solar light shelves both screen out the sun below the shelf level and reflect light into the corridor above the shelf. The reflected light also bounces into classrooms adjoining the hall through clearstory windows. On the east and west façades, vertical solar shading louvers are angled appropriately to block the glare from low-altitude sun rays. Motorized blinds and low-e glazing

FACTS

WASHINGTON, DC

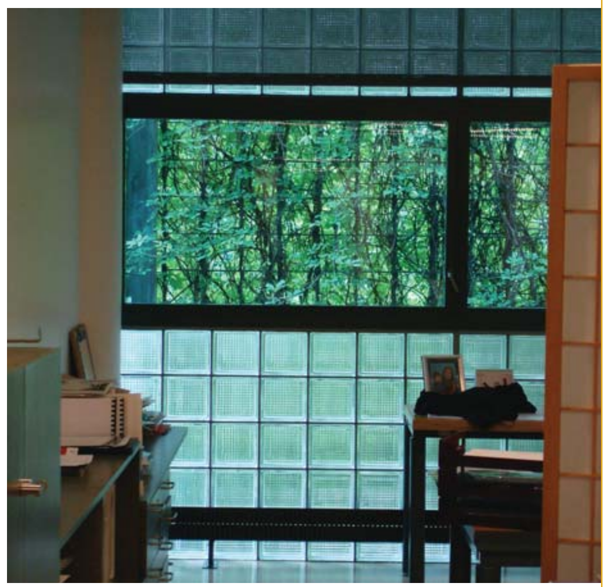
Architect: KieranTimberlake Associates
Sustainability Consultants: GreenShape
Lighting Designer: Sean O'Connor Associates Lighting Consultants, LLC
Area: 72,200 ft^2
Cost: $28 Million
Completed: 2006

on the east and west facades minimize heat gain and maximize daylight. Skylights and large north-facing windows supply additional daylight. To daylight classrooms in the existing 1950 building, the architects installed vertical sunshades to keep out heat and allow light to filter in. Photo-sensors automatically dim or shut off the electric lights when daylight is sufficient. Having this automated integration creates a more constant even distribution of lighting and cuts the price of electric lighting.

Finnish Embassy

Daylighting **ELEMENTS** Employed

- growth screen
- skylights/light monitor (variation)

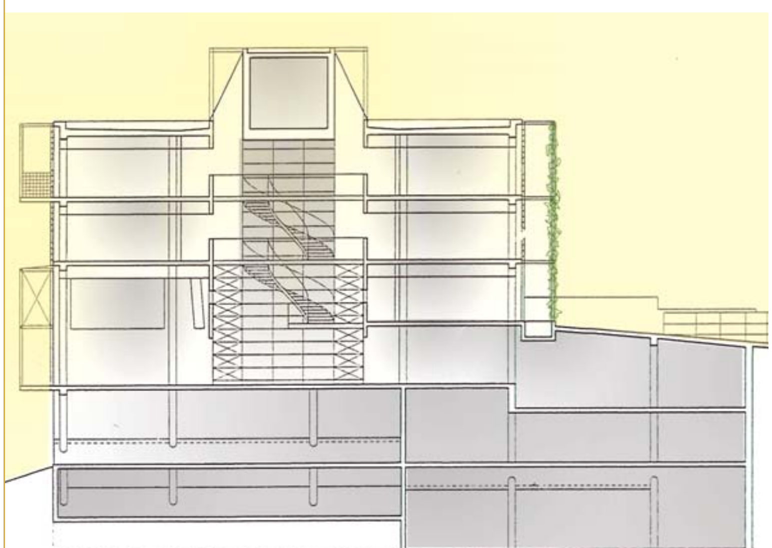


The Finnish Embassy, appearing to be a simple cube from the exterior, is designed to occupy as small of a footprint as possible in order to preserve a wooded site. Glass block, skylights, and growth screens help control natural daylight throughout the building. Sun light penetrates through slanted skylights, naturally illuminating the halls and corridors. A central, copper clad, rectangular cube hangs suspended in the central space and houses conference rooms, a kitchen, and storage areas as well as mechanical systems.

FACTS

WASHINGTON, DC

Architect: Heikkinen-Komonen Architects
Associate Architect: Angelos Demetriou & Associates
Years of Construction: 1992-1994



Daylight reflects off of the copper cladding, projecting onto white walls. Layered planes distinguish the south façade of the building. A bronze grating system set in front of the exterior skin provides natural sun shading by serving as a trellis for deciduous climbing plants. Both the function and appearance of the trellis change with the seasons. The thick growth blocks unwanted direct sunlight and heat gains during the summer. Bare branches allow more direct sunlight and warmth to enter the building during the winter.

High Museum Addition

Daylighting **ELEMENTS** Employed

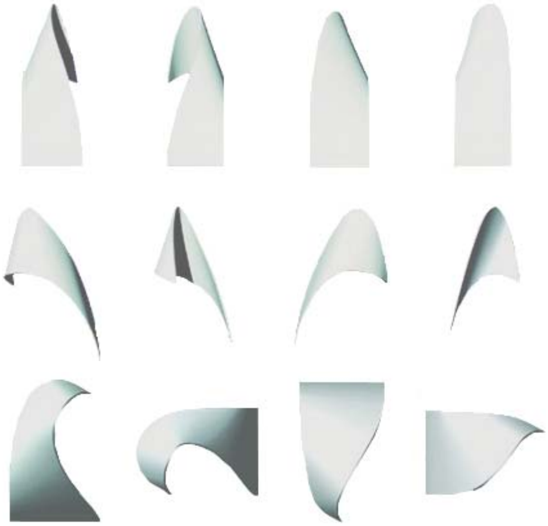
- light tubes

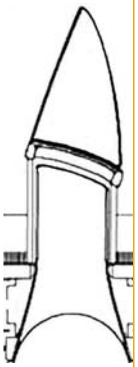
Renzo Piano's High Museum addition takes advantage of the sun to naturally illuminate its permanent gallery space. The top level receives overhead sunlight from a matrix of 1,000 light tubes. Here Piano was hoping to create a gallery that was not simply a white box while avoiding anything that would be so distracting as to take away from the art. He was able to achieve this by employing the changing effects of natural light. Each of the 1,000 light tubes has an aluminum sun scoop shaped to catch the diffused

FACTS

ATLANTA

Architect: Renzo Piano Building Workshop
Collaborating Architects: Lord Aeck & Sargent Architecture
Lighting & Engineering Consultant: Arup Lighting
Years of Construction: 1999-2005



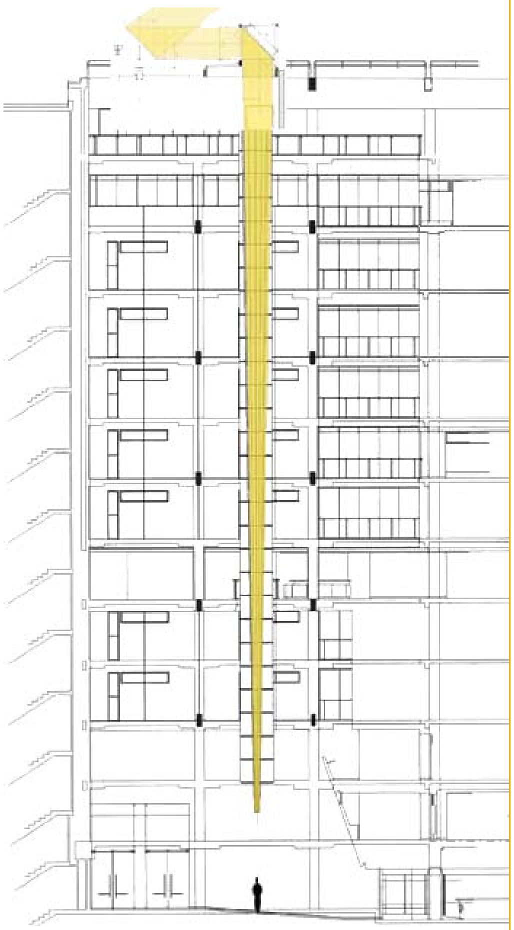


northern light and prevent damaging direct light from entering the gallery. Piano called the aluminum sun shades “velas”, meaning sails in Italian, to communicate the idea being that they catch sunlight just as sails catch the wind. The sun scoops along the parapet of the roof also fold down to form part of the façade. The light scoops of the High Museum add to the aesthetic design of the building while performing the function of filtering sunlight into galleries.

Morgan Lewis International Headquarters

Daylighting **ELEMENTS** Employed

- light tube
- heliostat

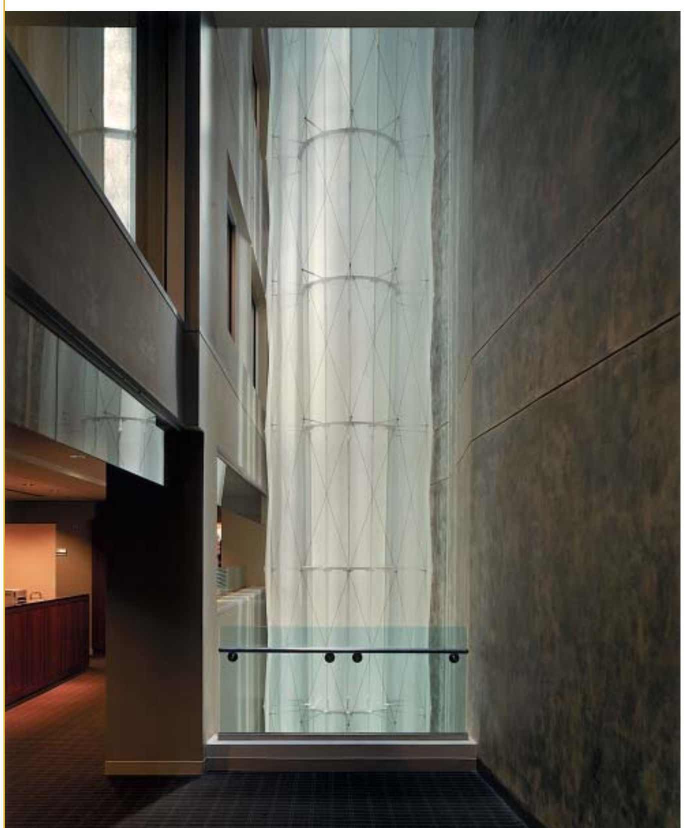


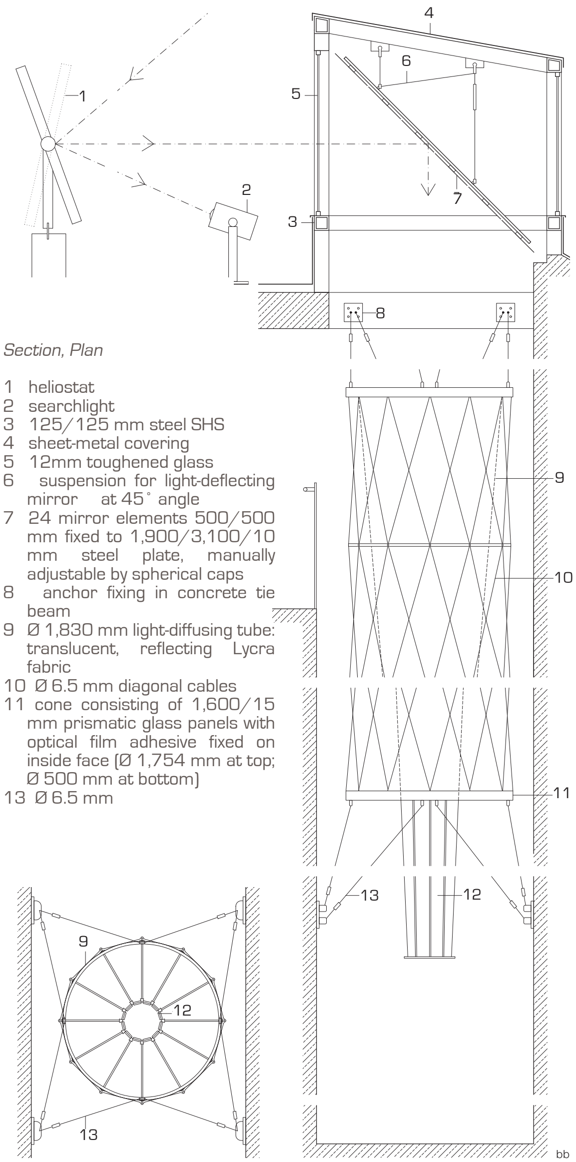
The 120-ft.-long "solar light pipe" at the Morgan Lewis law office brings daylight from the rooftop into its unusually narrow, 14-story atrium. Due to the atrium's proportions, the space's previous skylight allowed daylight to reach only the uppermost floors. The lighting designers devised a variation of a light tube with a double-skin system to bring the sun's illumination down into the space. A rooftop heliostat follows the sun's course and reflects sunlight onto a secondary mirror, which is composed of 24 sub-mirrors and

FACTS

WASHINGTON, DC

Solar Light Pipe Designer: Carpenter Norris Consulting
Night Lighting Designer: Ann Kale Associates
Fabrication & Installation: Carpenter Norris Consulting
Lighting Manufacturers: Space Cannon Illuminations (searchlights); Bomin Solar (heliostat)
Year of Construction: 2001





Section, Plan

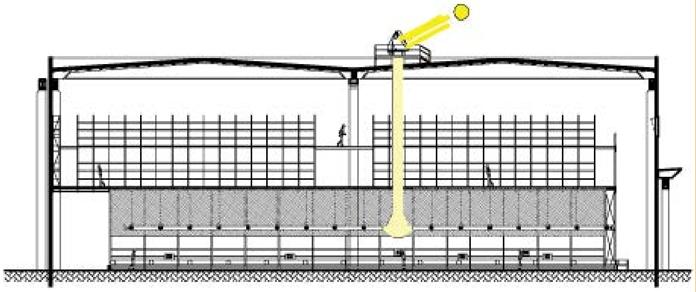
1 heliostat
2 searchlight
3 125/125 mm steel SHS
4 sheet-metal covering
5 12mm toughened glass
6 suspension for light-deflecting mirror at 45° angle
7 24 mirror elements 500/500 mm fixed to 1,900/3,100/10 mm steel plate, manually adjustable by spherical caps
8 anchor fixing in concrete tie beam
9 Ø 1,830 mm light-diffusing tube: translucent, reflecting Lycra fabric
10 Ø 6.5 mm diagonal cables
11 cone consisting of 1,600/15 mm prismatic glass panels with optical film adhesive fixed on inside face (Ø 1,754 mm at top; Ø 500 mm at bottom)
13 Ø 6.5 mm

redirects light into the cone-shaped, prismatic glass core. As sunlight transverses the core, it hits angled pieces of serrated glass, refracting outwards and bouncing off and through the translucent Lycra fabric skin that forms an outer cylinder. The core is held in place by a steel and aluminum support system, and the tensioned fabric is stretched over compression rings held to the core by radiating steel arms. When the heliostat's photo cell senses low-level light, two xenon searchlights switch on, shining into the prism core.

Arthelio Project

Daylighting **ELEMENTS** Employed

- automated integration
- light tubes
- heliostats

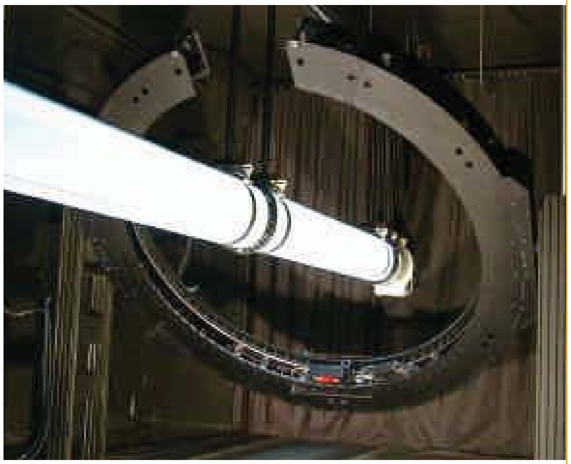


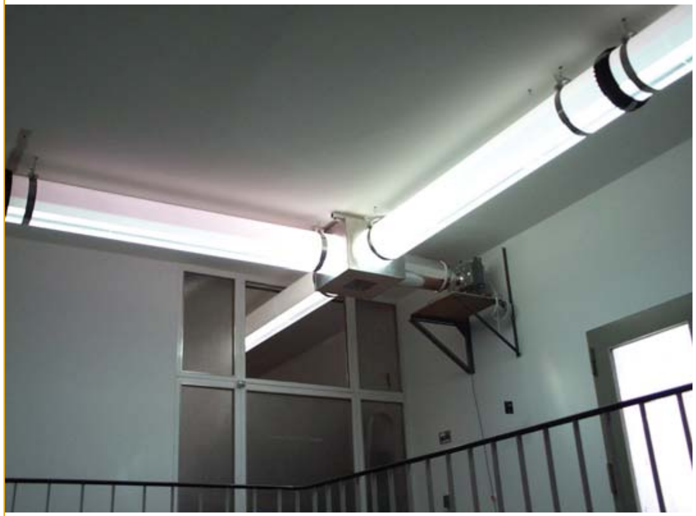
The Arthelio Project is a study which aims to find efficient ways to integrate the use of natural light alongside artificial light. Its goals are to transport natural light over longer distances and deeper into buildings. The project hopes to bring the physiological and psychological benefits of natural light to spaces that are normally only exposed to artificial light during working hours and thereby offsetting the amount of power needed to light the work space. Here sunlight is concentrated by

FACTS

multiple test sites in EUROPE

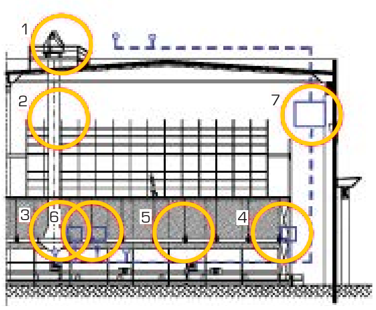
Project Designer: Ricerca & Progetto
Lighting Consultant: Advanced Lighting Control Services (ALCS)
Year of study: continuous





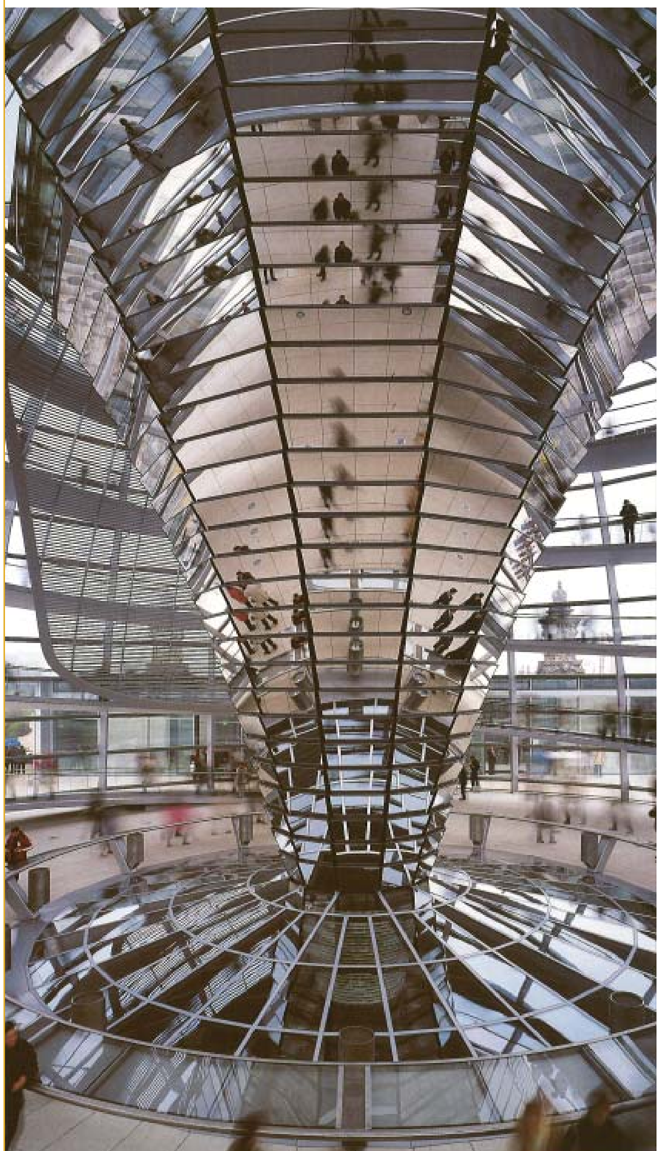
Section

1 collecting head unit (single axis rotation)
2 duct unity (L = 13 m)
3 diffuser unit
4 sulfur lamps
5 hollow light guides
6 coupling and diffuser unit
7 electronic control system to manage integration between daylight and artifical light



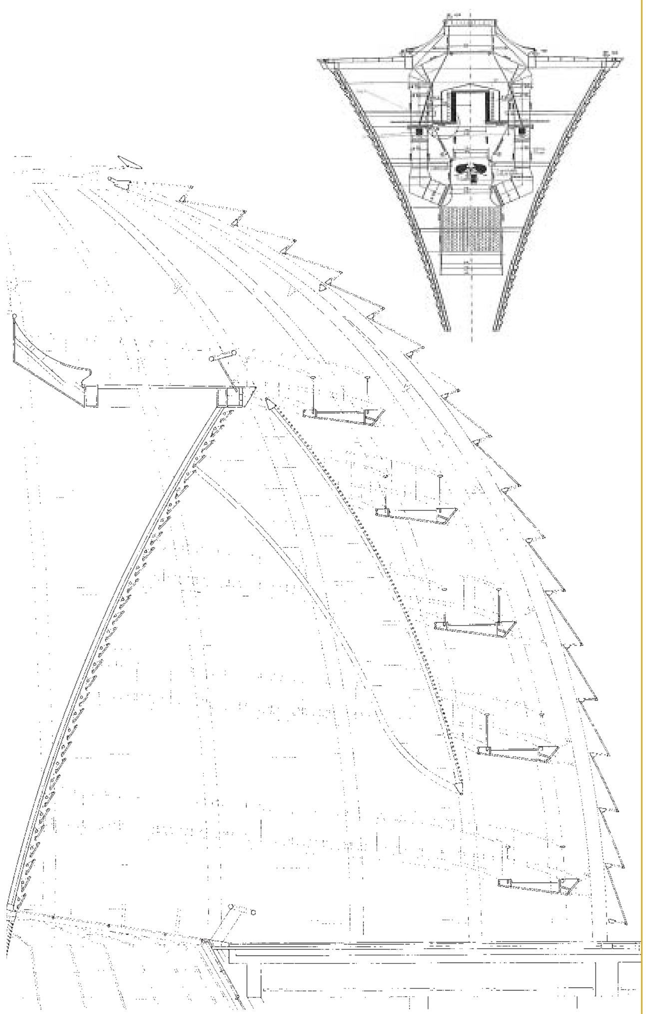
heliostats towards the end of a highly efficient light transporting tube. Sunlight travels through the tubes, which both move and diffuse the natural light as well as artificial light from supplemental energy efficient bulbs. When the sunlight is strong, less artificial light is required; at night the artificial light completely supplies the system. The project hopes to achieve complete natural and artificial light integration rather than having separate lighting systems that work in tandem.

Die Riechstag



Daylighting **ELEMENTS** Employed

- heliostat
- integrated electric lighting



Foster's design for the dome of the Reichstag employs a large-scale, inverted concave cone which is clad with 360 mirrors to reflect daylight into the German Bundestag's debating chamber below. In redirecting the sun's rays, the mirrors operate similarly to a very large-scale heliostat. To prevent excessive amounts of heat gain and glare, a 40 ft tall sun-tracking shade rotates around the cone, preventing too much direct sunlight from reaching the reflecting mirrors during the day. The heliostat sits within the glass dome that is

Architect: Foster & Partners

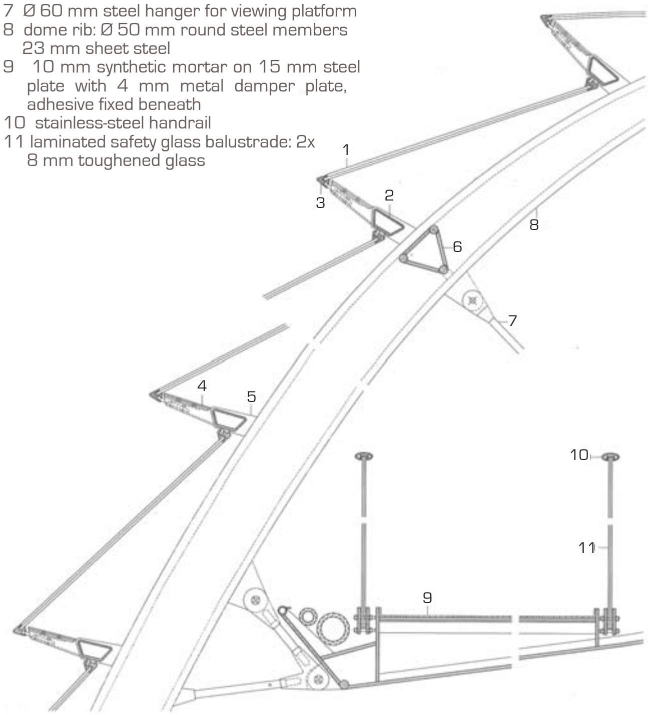
Engineering Consultants: Ove Arup & Partner; Schlaich, Bergermann, & Partner; Leonhardt & Andra

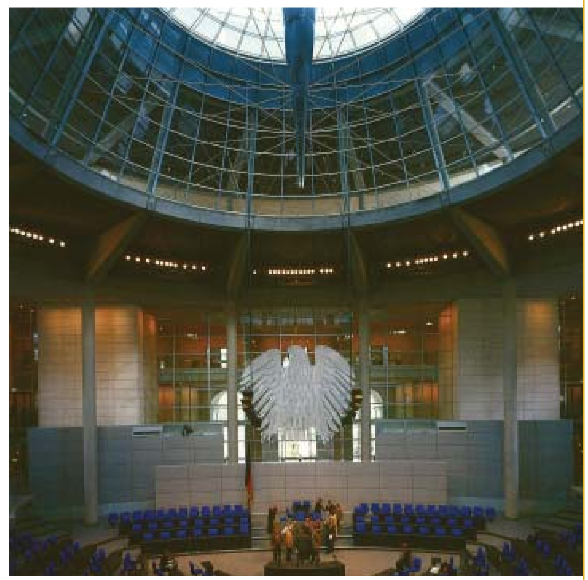
Project Designer: Ricerca & Progetto

Years of Construction: 1992-1999

Sectional detail through cupola

1 laminated safety glass: 2x 12 mm toughened glass
2 210/100 mm steel trapezoidal hollow section
3 aluminum glazing section
4 laminated safety glass: 2x 8 mm toughened glass
5 cast-steel node
6 ring beam: Ø 50 mm round steel members 20 mm sheet steel
7 Ø 60 mm steel hanger for viewing platform
8 dome rib: Ø 50 mm round steel members 23 mm sheet steel
9 10 mm synthetic mortar on 15 mm steel plate with 4 mm metal damper plate, adhesive fixed beneath
10 stainless-steel handrail
11 laminated safety glass balustrade: 2x 8 mm toughened glass



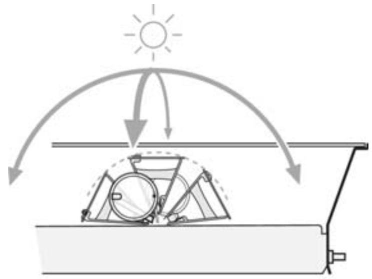


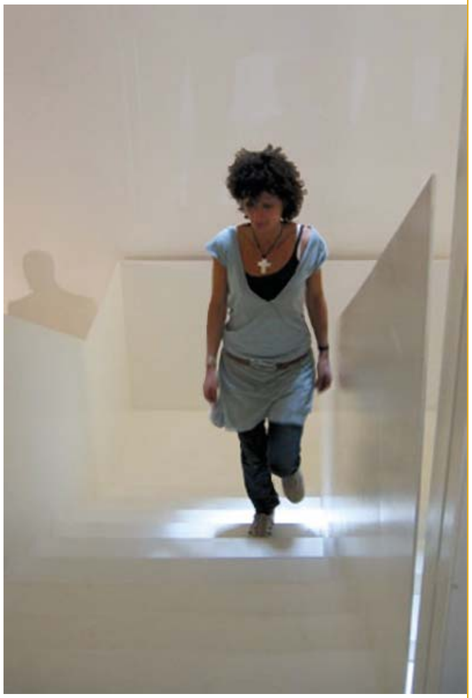
designed to cycle the sun-heated air upwards and out of exhaust vents at the top of the dome. The resulting air flow creates pressure that draws in fresh air at the base of the dome helping to offset solar heat gain. A daylight-sensing dimming system also helps to reduce power needs. At night, lamps reverse the light's path, projecting light outward and causing the dome to become a beacon. A public walkway that ascends into the dome allows the ordinary citizen to symbolically climb above and observe representatives.

Viktoria Arena Fashion Store

Daylighting **ELEMENTS** Employed

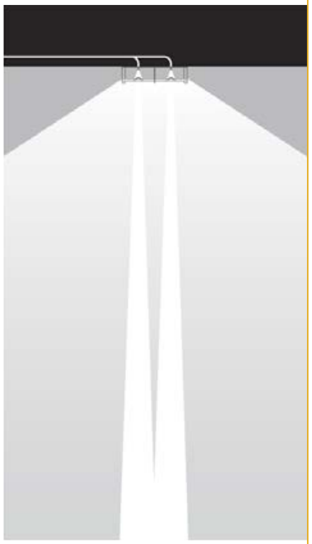
- fiberoptic cables





The Viktoria Arena fashion store in Gothenburg occupies a cinema from the 1910's. The old building had an interior that lacked natural light – the entrance was the only visual connection to the exterior. For this reason, the store installed a fiberoptic luminaire above its staircase to bring additional natural light into the space. To do so, two "sky ports" are mounted on the roof about 33 feet above the fixture. While illuminating the staircase, the fixture also invites guests from the first floor to continue on to the second

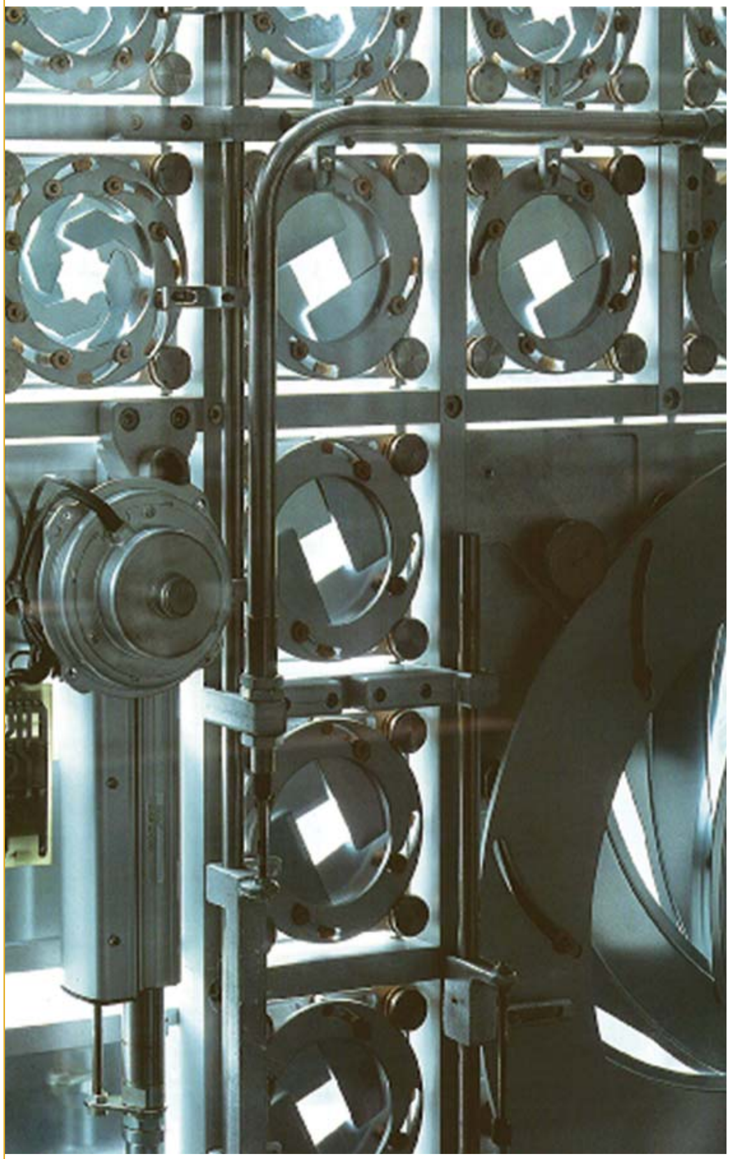
Fiberoptic lighting manufacturer: Parans Solar Lighting

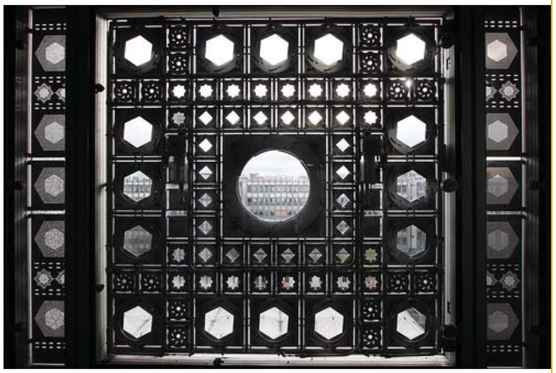


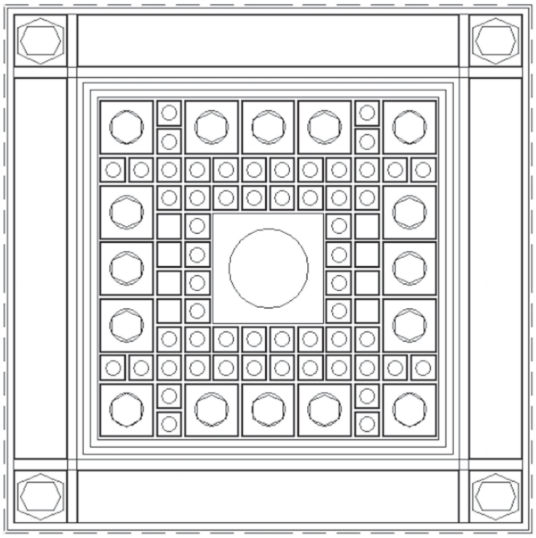
floor. Additionally, this fixture now allows the store's employees to assess the weather by simply looking at the fiberoptic light fixture and noticing changes in light intensity and temperature. This particular fixture is designed to imitate sunlight filtering through the leaves of a birch tree. The unit is available in two variations, with an option of more focused or more diffused beams of light (see diagrams above).

Arab World Institute

Daylighting **ELEMENTS** Employed
- mechanical sunshades





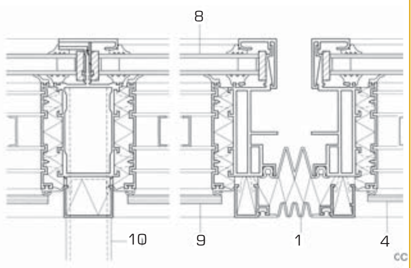


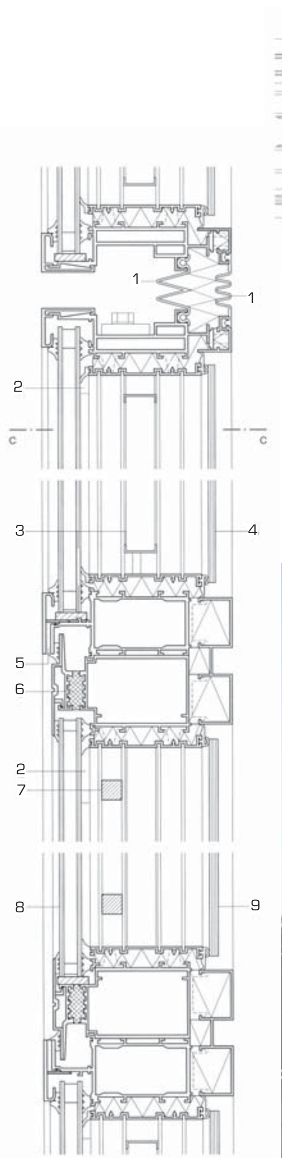
Jean Nouvel's design chosen for the southern façade of the World Arab Institute plays with the ever-changing nature of sunlight. Sunlight filters through shutter-like apertures and projects a variety of geometric forms across the interior surfaces. The intricate geometric patterns reflect the traditional Islamic ornamentation, which helps showcase the institute's purpose of educating the French people about Islamic culture. The shading system is a more advanced version of indigenous mid-eastern methods for

FACTS

PARIS

Architect: Jean Nouvel
Interior Design: Francois Seigneur
Structure: Arcora
Museum Lighting: Licht Design
Years of Construction:1981-1987
Area: 252,630 ft^2
Cost: $64,400,000





Section and Plan

1 EPDM joint
2 seals interrupted to allow ventilation of void
3 perforated infill
4 toughened safety glass, 6 mm
5 vent hole
6 polyurethane thermal break
7 "camera shutter" mechanism
8 insulating glazing, 4 mm + 12 mm cavity + 4 mm
9 toughened safety glass, 8 mm
10 facade support member

filtering sunlight into spaces. The mechanisms that control the sun shades are relatively delicate and require a great deal of maintenance. All of the shades are operated by automatic sensors that respond to the natural light levels outside, causing the southern facade to constantly take on new appearances in response to the changing sunlight. The mechanical sunshades create an effect that is a beautiful mixture of superimpositions, reflections, and shadow.

LEED DAYLIGHTING STANDARDS

Daylight and Views: Daylight of Spaces

GOAL

To reduce lighting load and increase connection with the outdoors by increasing daylight penetration. Site, orientation, and materials are all important in addition to other features such as light shelves, louvers, and fins, as it is important that the light is controlled to allow for even, conditioned light specific to the space it enters.

3 OPTIONS FOR COMPLIANCE

1 Glazing Factor Calculation

NC: EQ 8.1 - Achieve minimum 2% Glazing Factor (GF) in 75% of regularly occupied spaces (1 pt)

CI: EQ 8.1 - Achieve 2% GF in 75% of regularly occupied spaces, (1 pt)

EQ 8.2 - Achieve 2% GF in 90% of regularly occupied spaces (1 pt)

EB: EQ 8.1 - Achieve 2% GF in 50% spaces used for critical visual tasks (1 pt)

EQ 8.2 - Achieve 2% GF in 75% of spaces used for critical visual tasks (1 pt)

2 Daylight Simulation Model

Creation of a Building Information Model that demonstrates minimum percentage of regularly occupied spaces exceeds 25 foot-candles, under clear sky conditions, at noon, on the equinox, at 30" above floor level.

3 Daylight Measurement

Demonstrate, through post-construction measurement, that 75% of regularly occupied spaces meet 25 foot-candles.

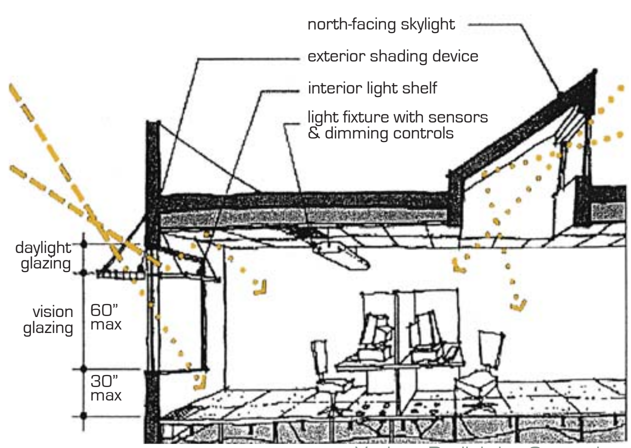
Please refer to the LEED manuals for further information.

	Window Type	Geometry Factor	Minimum Tvis	Height Factor	Best Practice Glare Control
sidelighting	daylight glazing	0.1	0.7	1.4	Adjustable blinds Interior light shelves Fixed translucent exterior shading devices
sidelighting	vision glazing	0.1	0.4	0.8	Adjustable blinds Exterior shading devices
toplighting	vertical monitor	0.2	0.4	1.0	Fixed interior Adjustable exterior blinds
toplighting	sawtooth monitor	0.33	0.4	1.0	Fixed interior Exterior louvers
toplighting	horizontal skylights	0.5	0.4	1.0	Interior fins Exterior fins Louvers

Sample Daylighting Design Criteria

$$\text{Glazing Factor} = \frac{\text{Window Area (SF)}}{\text{Floor Area (SF)}} \times \text{Window Geometry Factor} \times \frac{\text{Actual Tvis}}{\text{Minimum Tvis}} \times \text{Window Height Factor}$$

Glazing Factor Calculation



Various Daylighting Strategies

DAYLIGHT AND VIEWS: VIEWS FOR SPACES

GOAL

To provide indoor work areas with a connection with the outdoors by providing a direct line of sight to exterior perimeter glazing.

COMPLIANCE

Credit is based upon providing the potential for views between 2'6" and 7'6" above floor height for a given percentage of regularly occupied spaces. The space must then be tested in section view to determine if a direct line of sight is indeed present at 42" above floor height. To test these conditions, a spreadsheet is assembled, composed of each space in a building and its associated compliance with the credit requirements. (See below.)

The Requirements are as follows:

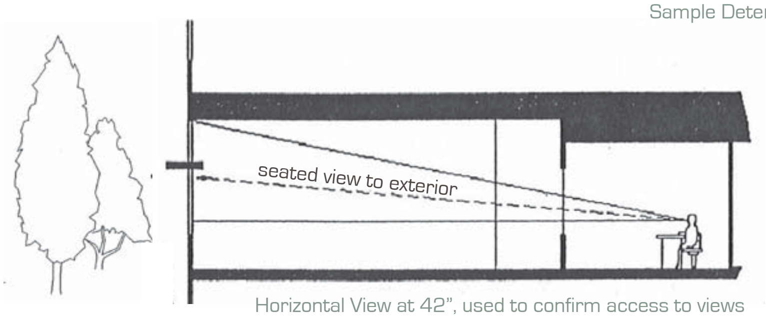
NC:	EQ 8.2 - Views for 90% of regularly occupied spaces	(1 pt)
CI:	EQ 8.3 - Views for 90% of regularly occupied spaces	(1 pt)
EB:	EQ 8.3 - Views for 45% of regularly occupied spaces	(1 pt)
	EQ 8.4 - Views for 90% of regularly occupied spaces	(1 pt)

Successful design strategies include lowering partition heights, interior glazing, and positioning open floor plan office space on the perimeter with private offices and non-regularly occupied spaces toward the core of the building.

Please refer to the LEED manuals for further information.

Room	Regularly Occupied Floor Area (SF)	Plan Area of Direct Line of Sight to Perimeter Vision Glazing (SF)	Calculated Area of Drìect Line of Sight to Perimeter Vision Glazing (SF)	Horizontal View at 42 Inches (Yes/No)	Compliant Area (SF)
101 Office	820	790	820	Yes	820
102 Conference	330	280	330	Yes	330
103 Open Office	4,935	4.641	2,641	Yes	4,641
104 Office	250	201	250	No	0
105 Office	250	175	175	Yes	175
Total	6,585				5,966
Percent Access to View (5,966/6,585) 90.5% Credit Earned					

Sample Determination of Compliance



Horizontal View at 42", used to confirm access to views

GLOSSARY OF LIGHTING TERMS

A

Angle of incidence: the angle between a ray of light falling on a surface and a line perpendicular to the surface

Azimuth: the azimuth of the sun is the angle between the vertical plane containing the sun and the vertical plane oriented to the north (direction of origin)

B

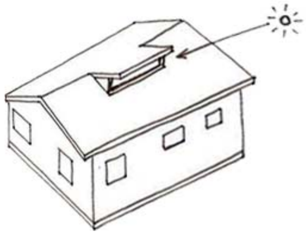
Borrowed light: a window to an internal room that 'borrows' light or view through an adjacent room

C

Candela: the SI unit that measures luminous intensity (how bright a beam of light is)

Candle-power: the amount of illuminance measured at the source (the same source would have a different candlepower and foot-candle measurement since they measure at different points from the light)

Clerestory window: a daylight opening in the upper-most part of a room; often at a change in roof level and part of an exterior wall but may also exist between interior spaces



clerestory window

Contrast: the subjective assessment of the difference in appearance of two parts of a field of view seen simultaneously or successively. It can be defined objectively as $(L_1–L_2)/L_1$ where L_1 and L_2 are the luminances of the background and object, respectively.

Coolness factor: the ratio of the visible transmittance to the shading coefficient. If the value is greater than 1.0, the glass is considered "selective" and will offer better performance in a hot climate than a similar glazing with a lower coolness factor

D

Daylight autonomy: percentage of occupied time per year when target illuminance can be maintained by daylight alone; may be used to express the percentage of electrical lighting energy saved by a daylighting system.

Daylighting: the controlled admission of natural light into a space through glazing with the intent of reducing or eliminating electric lighting. By utilizing solar light, daylighting creates a stimulating and productive environment for building occupants. [from LEED-NC]

Daylight factor: the ratio of light received at a horizontal plane indoors compared to that received on an unobstructed plane outside

Diffuser: a device, object, or surface used to alter the spatial distribution of light

Diffusion: the scattering of light rays so that they travel in many directions rather than in parallel or radiating lines

Direct glare: glare is caused when overly bright parts of the visual field (e.g. unshielded lamps) are seen directly

Direct line of sight to perimeter vision glazing: the approach used to determine the calculated area of regularly occupied areas with direct line of sight to perimeter vision glazing. The area determination includes full height partitions and other fixed construction prior to installation of furniture. [from LEED-NC]

Disability glare: glare or excessive contrast, especially to the extent that visibility of one part of the visual field is obscured by the eye's attempt to adapt to the brightness of the other portion of the field of view; visibility of objects is impaired

Discomfort glare: glare that causes annoyance without physically impairing a viewer's ability to see objects

E

Emission: in electromagnetics, a release of radiant energy

F

Foot-candle: a unit used in the US (not internationally) for measuring light. One foot-candle is the amount of light received on one square foot, one foot from a candle light source. (One foot-candle is equal to about 10.76391 lux and one lumen per square foot.) Though not an SI unit, the foot-candle is still used in architecture, stage lighting, and photography.

G

Glare: a visual condition which results in discomfort, annoyance, interference with visual efficiency, or eye fatigue because of brightness of a portion of the field of view (lamps, luminaires, or other surfaces or windows that are markedly brighter than the rest of the field). Direct glare is related to high luminances in the field of view. Reflected glare is related to reflections of high luminances

Glare index: a numerical index which enables the discomfort glare from lighting to be ranked in order of severity

Glazing factor: the ratio of interior illuminance at a given point on a given plane (usually the working plane) to the exterior illuminance under known overcast sky conditions. LEED uses a simplified approach for its credit calculations. The variables used to determine the daylight factor include floor area, window area, window geometry, visible transmittance (T_{vis}) and window light. [from LEED-NC]


growth screen

Growth screen: a term which can be used to describe a trellis system that provides a plant screen for a building's windows

H

Heliostat: a device that tracks the movement of the sun; typically used to orient a mirror throughout the day to redirect sunlight along a fixed axis towards a stationary target or receiver

Horizontal view at 42 inches: the approach used to confirm that the direct line of sight to perimeter vision glazing remains available from a seated position. It uses section drawings that include installed furniture to make the determination. [from LEED-NC]

I

Illuminance: the amount of light (density of luminous flux) incident on a surface per unit area. The unit is lux, or lumens per square foot. Regardless of surface finish, the illuminance will remain the same.

Incident light: light that strikes an object

Indirect lighting: illumination achieved by reflection, usually from wall and/or ceiling surfaces

Infrared light: a component of sunlight largely responsible for the warmth or heat that the sunlight carries

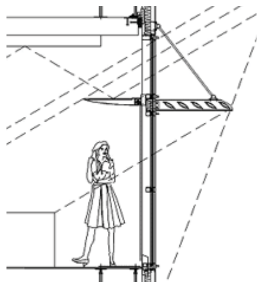
K

Kinetic wall: a generic term which, in daylighting, can be used to describe mechanized sun-shading or light aperture systems

L

Light shelves: horizontal shelves which accompany windows and bounce visible light up towards the ceiling, which reflects it further downward into a room; generally used on a southern exposure

Light-to-Solar-Gain (LSG) Ratio: ratio of visible light transmitted to solar heat gain. A value below one means the glazing transmits more heat than light. A value above one means the glazing transmits more light than heat. Spectrally selective glazing is characterized by having a high LSG value (=1.25).



light shelf

Light tube: a tube or pipe used for transporting light to another location and/or distributing natural or artificial light over its length; also referred to as light pipes, sun pipes, and solar pipes

Light well: an open space reaching from a glazed roof down several stories, typically to the ground floor or basement level

Louvers: a frame with horizontal or vertical slats, which are angled to selectively admit and direct light and/or air; may also keep out rain and noise

Lumen: the SI unit of measurement for light flow, or luminous flux. One lumen is equal to one foot-candle falling over one square foot of area.

Luminaire: a complete lighting unit consisting of a lamp or lamps, along with the parts designed to distribute the light, hold the lamps, and connect the lamps to a power source. Also called a fixture

Luminance: the luminous intensity of any surface in a given direction per unit or projected area of the surface as viewed from that direction; the quantity of light that is reflected off a surface. This value will vary based on reflectance of a material, which is affected by factors such as color, finish, etc.

Luminous flux: also luminous power, is the measure of the perceived power of light, measured in lumens. It differs from radiant flux, the measure of the total power of light emitted, in that luminous flux is adjusted to reflect the varying sensitivity of the human eye to different wavelengths of light.

Lux: the International System (SI) unit of illumination; equal to one lumen per square meter of a surface. One lux is about 0.09 foot-candles.

M

Maintenance illuminance: the lowest value of average illuminance over a task area which should be sustained throughout the life of a lighting system

N

Non-occupied spaces: includes all rooms used by maintenance personnel that are not open for use by occupants. Included in this category are janitorial, storage, and equipment rooms, and closets. [from LEED-NC]

Non-regularly occupied spaces: include corridors, hallways, lobbies, break rooms, copy rooms, storage rooms, kitchens, restrooms, stairwells, etc. [from LEED-NC]

O

Overcast sky: sky completely covered by clouds with no visible sun

P

Photocell: a light sensing device used to control luminaires and dimmers in response to detected light levels

R

Radiance: the amount of energy released from a light source, measured at the source.

Radiation: energy in the form of electromagnetic waves or particles

Radiant flux: also radiant power, is the measure of the total power of electromagnetic radiation (including infrared, ultraviolet, and visible light). The power may be the total emitted from a source, or the total landing on a particular surface.

Reflectance: the ratio of light reflected from a surface compared to the light falling on it (incident light)

Regularly occupied spaces: areas where workers are seated or standing as they work inside a building; in residential applications it refers to living and family rooms [from LEED-NC]

Roof monitor: a raised section of a roof, usually straddling a ridge; has openings, louvers, or windows along the sides to admit light or air

S

SI photometry units:

Quantity	Symbol	SI unit	Abbr.	Notes
Luminous energy	Q_v	lumen second	lm·s	units are sometimes called talbots
Luminous flux	F	lumen (= cd·sr)	lm	also called luminous power
Luminous intensity	I_v	candela (= lm/sr)	cd	an SI base unit
Luminance	L_v	candela per square meter	cd/m²	units are sometimes called nits
Illuminance	E_v	lux (= lm/m²)	lx	used for light incident on a surface
Luminous emittance	M_v	lux (= lm/m²)	lx	used for light emitted from a surface
Luminous efficacy		lumen per watt	lm/W	ratio of luminous flux to radiant flux

Shading coefficient: the dimensionless ratio of the total solar heat gain from a particular glazing system to that for one sheet of clear, 3mm, double-strength glass

Shading device: device used to obstruct, reduce, or diffuse the penetration of direct sunlight

Sidelighting: a daylighting technique where natural light enters through a peripheral window; provides illumination with strong directionality with the potential for glare

Skylight: an opening situated in a horizontal or tilted roof

Spectral selectivity: a window's ability to transmit visible light while reducing solar heat gain, expressed by a number between 0 and 1. Any product rated above 1 is considered spectrally selective.

Sunlight: the total spectrum of electromagnetic radiation given off from the sun; composed of ultraviolet light, the visible spectrum, and infrared light

T

Task lighting: a luminaire that provides a high level of localized light for a visually demanding task

Toplighting: daylight that enters through the upper portions of an interior space; e.g. clerestory or skylight

Transmission: passage of radiation through a medium without change of frequency of its monochromatic components

Transmittance: ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions

T_{vis}: see *Visible light transmittance*

U

Ultraviolet (UV): an invisible component of sunlight which can cause damage to the skin and eyes

U-value: a measure of the thermal conductivity of a window: The lower the U-value, the better a window is at limiting heat loss. A single-glazed window has a U-value of about 6 W/m 2-K, while triple-glazed windows have U-values between 1 and 2.

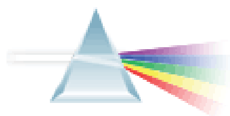
V

Veiling reflections: reflections from bright objects or light sources which overlay or "veil" print, making it difficult to read, such as on glossy magazines

Visible light transmittance (T_{vis}): the ratio of total transmitted light to total incident light. In other words, it is the amount of visible spectrum (380-780 nanometers) light passing through a glazing surface divided by the amount of light striking the glazing surface. A higher T_{vis} values indicates that a greater amount of visible spectrum incident light is passing through the glazing. [from LEED-NC]

Visible spectrum: component of sunlight which is the portion of the electromagnetic spectrum that can be detected by the naked human eye

Vision glazing: the portion of exterior windows above 2'6" and below 7'6" that permits a view to the outside of the project space [from LEED-NC]



visible spectrum

W

Working plane: the height at which a visual task is carried out, usually around 2.5 ft above the floor

Z

Zenith: the direction pointing directly above a particular location

ADDITIONAL RESOURCES

Publication & Websites

Architectural Lighting

Egan, M. David. *Architectural Lighting*. McGraw-Hill, New York: 2002.

"Extensively revised, this Second Edition offers architects and designers the most current thinking and practice in their profession on the scientific properties of light, the uses of natural and electric light in buildings, lighting effects and applications, and design tools and processes. To help the reader on the job, there is full coverage of lighting calculation methods, including the Lumen Method, as well as a number of useful CAD and computer rendering solutions."

DAYLIGHT & ARCHITECTURE Magazine by VELUX

http://da.velux.com/veluxcommon/resources/cache/site/da.velux.com/Non-Image/PDF/DA07_Complete.pdf

Inspirational graphic magazine displaying creative ways that daylighting has been employed.

Daylight in Buildings: A Source Book On Daylighting Systems and Components

Ruck, Nancy. *Daylight in Buildings: a source book on daylighting systems and components*. A report of IEA SHC Task 21/ ECBCS Annex 29. July 2000. <http://gaia.lbl.gov/iea21/>

"This book is the result of a coordinated international effort to gather the most up-to-date information available about the application and evaluation of advanced daylighting systems to enhance daylighting in non-residential buildings. Although the text emphasizes the performance of daylighting systems, it also includes a survey of architectural solutions, which addresses both conventional and innovative systems as well as their integration in building design. Innovative daylighting systems are assessed according to their energy savings potential, visual characteristics, and control of solar radiation."

Daylight Performance of Buildings

Fontoynont, Marc. *Daylight Performance of Buildings*. James and James: 1999.

"The daylighting behavior of 60 buildings was observed and measured during a three-year period. Buildings of many different types, sizes and ages were included – from offices to museums, libraries, churches, houses, airports and factories; from Classical buildings to modern constructions and from a small single room to an office of over 100,000 square meters. The results of the study of each building are presented, extensively illustrated in color, with the unusual features and main lessons highlighted. The book also includes details of the monitoring procedures, the results of and comparison with simulations, the outcome of post-occupancy evaluation and a summary of the major findings. These show the extraordinary potential of daylighting techniques to improve amenity and energy performance for the benefit of the occupants and building managers. They also demonstrate how often opportunities are missed, and the frequency of problems of overheating or glare. Above all, they demonstrate the beauty, elegance and scope of daylight design."

Daylighting

Ander, Gregg D. “Daylighting.” http://www.wbdg.org/resources/daylighting.php. July 31, 2008.

Gregg D. Ander, FAIA, presents an architects view on general daylighting guidelines.

Daylighting Benefits Healthcare

Lewis, John. “Daylighting Benefits Healthcare.” 2008. <http://www.cbpmagazine.com/article.php?articleid=203>

A guide revealing statistics on how daylighting affects patients’ length of stay and use of pain medications.

Daylighting Collaborative

http://www.daylighting.org/

Sponsored by the Energy Center of Wisconsin, this website presents analyses, resources, training opportunities, and general information about daylighting.

Daylighting and Human Performance

Heschong, Lisa. “Daylighting and Human Performance.” ASHRAE Journal 44:66, 65-67: 2002.<http://bookstore.ashrae.biz/journal/journal_s_article.php?articleID=395>

The article provides a brief synopsis of daylighting benefits found in retail, office, and learning environments.

Daylight Illumination of Building Interiors

McCluney, Ross. “Daylight Illumination of Building Interiors [Daylighting]”. Florida Solar Energy Center: A research institute of the University of Central Florida. July 31, 2008. <http://www.fsec.ucf.edu en/consumer/buildings/basics/windows/slideshows/slides/IntroDaylighting.pdf . >

A slideshow presentation on daylighting general guidelines, benefits, and energy cost comparisons

Daylighting Performance and Design

Ander, Gregg D. *Daylighting Performance and Design*. New York, NY: Van Nostrand Reinhold, 1995.

“Daylighting is the process of incorporating natural lighting into the design of buildings. The new edition of this concise resource makes theory, calculations, and execution crystal clear with straight-to-the-solution examples and uncluttered language. In a practical, applied approach, this book covers daylighting strategies, materials, and methods of construction, including significant advances in lighting and daylighting technology.”

Daylighting and Productivity at Lockheed

Miller, Thayer B. Daylighting and Productivity at Lockheed. Fuel and Energy Abstracts, Volume 36, Number4, July 1995 , pp. 287-287(1). < http://66.102.1.104/scholar?hl=en&lr=&client=firefox-a&q=cache:_NW7AUUPFOAJ:www.betterbricks.com/LiveFiles/12/280/Lockheed.pdf+author:%22Thayer%22+intitle:%22Daylighting+and+Productivity+at+Lockheed%22+>

Miller presents the financial benefits Lockheed reaps annually from energy savings and most of all, human productivity. "This daylit office building in Sunnyvale, California saves Lockheed Martin about $500,000 each year in energy bills. Higher employee productivity in the building, due largely to the daylighting design, saves even more. In their first year in 'Building 157,' Lockheed saved half a million dollars on energy bills and several times more due to reduced absenteeism and improved employee productivity."

Daylighting and Retail Sales

Heschong, Lisa. *Daylighting and Retail Sales*. State of California Energy Commission. October 2003.

This technical report provides the in depth study conducted by the Heschong Mahone Group.

Designing Quality Learning Spaces: Lighting

Designing Quality Learning Spaces: Lighting. Developed by BRANZ Ltd for the New Zealand Ministry of Education. 2007. ISBN: 0-478-13619-6

http://www.minedu.govt.nz/index.cfm?layout=document&documentid=11663&data=l

"These guidelines have been developed by the Building Research Association of NZ (BRANZ) for boards of trustees, principals and teachers to help them understand the importance the internal environment plays in the design of quality learning spaces. It will also help boards of trustees brief consultants and trades people on their school's requirements when planning alterations or maintenance."

Detail Magazine

http://www.detail.de

An architecture periodical with information for architects and construction engineers including detailed plans, sections, and building materials. The office currently has a subscription for this periodical.

Energy Design Resources

http://www.energydesignresources.com//technology/daylightingdesign.aspx

Offers web references to explore daylighting more in depth.

Façade Construction Manual

Herzog, Thomas, Roland Krippner, and Werner Lang. *Façade Construction Manual*. Basel, Switzerland: Birkhauser, 2004.

"The new first edition of the Facade Construction Manual provides a systematic survey of contemporary expertise in the application of new materials and energy- efficient technologies in facade design, and represents an invaluable addition to our series of Construction Manuals. It surveys the facade design requirements made by various types of buildings, as well as the most important materials, from natural stone through to synthetics, and documents a diversity of construction forms for a wide range of building types. Over 100 international case-studies in large-scale, detailed drawings are presented in the comprehensive project section."

Green Building Costs and Financial Benefits

Kats, Gregory H. Green Building Costs and Financial Benefits. Massachusetts Technology Collaborative: 2003. www.masstech.org.

A guide providing examples of how green buildings payoff in the long run in terms of energy efficiency and occupants' performance.

Heschong Mahone Group, Inc.

http://h-m-g.com

The Heschong Mahone Group, Inc. (HMG) website, a group that provides professional consulting services in the field of building energy efficiency, lists extensive case studies regarding daylighting and its economical, psychological, and physiological effects in various building types.

In Detail Solar Architecture: Strategies, Visions, Concepts

Schittich, Christian. *Solar Architecture: Strategies, Visions, Concepts*. Basel, Switzerland: Birkhauser, 2003.

"Insulating glazing, multi-functional facades and organic solar cells are examples of important new developments in the field of solar thermal technology, photo-voltaics, heating and ventilation technology which are suitable for a wide range of uses from large-scale urban-planning projects to individual single family houses, and can make significant contributions to the conservation of natural resources in sustainable building. Carefully selected articles provide information on planning methods and techniques which will enable the user to assess and apply appropriate measures. The essays are complemented by a selection of built examples which demonstrate innovative solutions and the importance of an integrated planning process in realized projects, complete with full plans and large scale details."

National Clearinghouse for Educational Facilities

http://www.edfacilities.org/rl/daylighting.cfm

A list of daylighting references that are beneficial especially for educational facilities.

NREL's A Literature Review of the Effects of Natural Light on Building Occupants

http://www.nrel.gov/docs/fy02osti/30769.pdf

This paper is a compilation of studies concerning the introduction of natural light in work spaces.

Skylighting and Retail Sales

Heschong, Lisa. "Skylighting and Retail Sales." Daylighting Initiative: Design tools and information from the pacific gas and electric company. August 20, 1999.

Heschong's synopsis of her study "Daylighting and Retail Sales".

Square ONE Research

http://squ1.org/wiki/Concepts

Website containing tools to analyze daylighting. "To assist in this process, the Square One Wiki contains a wide range of background information and technical detail on a growing list of important building analysis concepts."

Sun, Wind, and Light: Architectural Design Strategies

Brown, G.Z. and Mark DeKay. Sun, Wind, and Light Architectural Design Strategies. Second Edition. New York, NY: John Wiley and Sons, Inc., 2001

This book addresses designing with sun, wind, and light in mind by case studies and raw data. "How to design buildings that heat with the sun, cool with the wind, light with the sky, and move into the future using on-site renewable resources."

Windows and Classrooms

Heschong, Lisa. Windows and Classrooms: A Study of Student Performance and the Indoor Environment. State of California Energy Commission. October 2003.

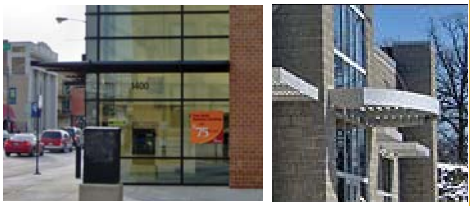
A technical report on the effects of daylighting on student performance.

MANUFACTURERS

LOUVERS

The Airolite Company, LLC
27855 State Road Route 7
Marietta, Ohio 45750
T: 715-359-6717
E: sales@airolite.com
http://www.airolite.com

Architectural Grills and Sunshades, Inc.
9981 W. 190th Street Suite G.
Mokena, IL 60448
T: 708-479-9458
F: 708-479-9478
E: denise@agsinc.org
www.agsinc.org



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Portsmouth, NH 03802-1140
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E: info@asca-design.com
http://www.asca-design.com

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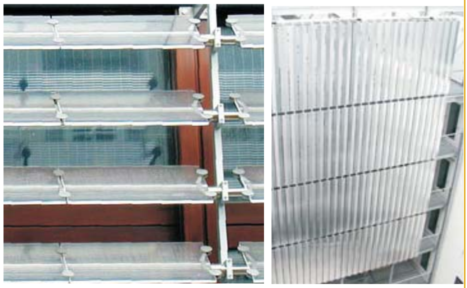
F: +49-7621-54368
E: info@bomin-solar.de
http://www.bomin-solar.de/English/heliostats.htm



Construction Specialties, Inc. (C/S Group)
for contact information refer to page:
http://www.c-sgroup.com/sales-locations
http://www.c-sgroup.com

Industrial Louvers, Inc.
511 S. 7th Street
Delano, MN 55328
T: 800-328-3421
E: ilinfo@industriallouvers.com
http://www.industriallouvers.com

McGill Architectural Products
1734 Orangebrook Court
Pickering, Ontario
L1W 3G8 Canada
T:888-624-4557
E: sales@mcgillarchitectural.com
http://www.mcgillarchitectural.com

Savannah Trims
T: 561-656-2556 or 888-640-0850
F: 561-656-2599
http://www.suncontrolers.com

LIGHT SHELVES

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9981 W. 190th Street Suite G.
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www.agsinc.org

Construction Specialties, Inc. (C/S Group)
for contact information refer to page:
http://www.c-sgroup.com/sales-locations
http://www.c-sgroup.com

LIGHT MONITORS/SKYLIGHTS

Sunoptics Prismatic Skylights: *as seen in Sidwell Friends MS*
6201 27th Street,
Sacramento, CA 95822
T: 916-395-4700 or 800-289-4700
F: 916-395-9204
E: Pure.energy@sunoptics.com
http://www.sunoptics.com

Velux America Inc.
450 Old Brickyard Rd
Greenwood, SC 29648-5001
T: 800-888-3589
http://www.veluxusa.com/products/commercial/roofMonitors


LIGHT TUBES

Heliobus AG
Sittertalstrasse 34
CH-9014 St.Gallen
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T: +41 71 278 70 61
E: info@heliobus.com
http://www.heliobus.com/pages_e/frames.html


The Sun Pipe Co., Inc.
P.O. Box 5760
Elgin, IL 60121-5760
T: 847-888-9222 or 800-844-4786
F: 847-888-9444
E: sunpipe@sunpipe.com
http://www.sunpipe.com


HUVCO Daylighting Systems
Post Office Box 3
Rohrersville, Maryland 21779
T: 301-432-0678 or 800-832-6116
F: 301-432-7185
http://www.huvco.com/index.php


SunScope Tubular Skylights
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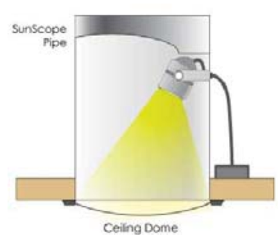
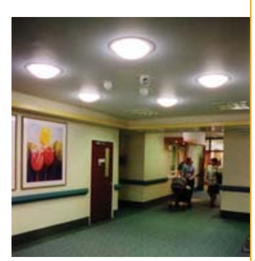
Canada T5M 3V9
T: 780-438-6770 or 800-449-0644
F: 780-702-1599
E: info@sunscope.com
http://www.sunscope.com





Tru-Lite Tubular Skylights

13695 E. Davies Place
Centennial, Co, 80112-4004
T: 303.783.5700 or 800.873.3309
F: 303-781-9196
E: sales@tru-lite.com
http://www.tru-lite.com

Solatube International, Inc.

2210 Oak Ridge Way
Vista, CA 92081-8341
T: 888.765.2882
http://www.solatube.com

Sun Tunnel Tubular Skylights – Velux

Velux America Inc.
450 Old Brickyard Rd
Greenwood, SC
29648-5001
T: 800-888-3589
http://www.veluxusa.com/products/commercial/commercialSunTunnels

HELIOSTATS

Bomin Solar

Colt International GmbH Architectural Solutions vorm. Bomin Solar
Industriestr. 8-10
D-79541
Loerrach/Germany
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F: +49-7621-54368
E: info@bomin-solar.de
http://www.bomin-solar.de/English/heliostats.htm

GROWTH SCREENS

Green Screen

1743 S. La Cienega Blvd.
Los Angeles, CA 90035
T: 800.450.3494
F: 310.837.0523
E: sales@greenscreen.com
www.greenscreen.com

FIBEROPTIC CABLES

Parans Solar Lighting AB
Kämpegatan 4a
SE-411 04 Göteborg
Sweden
T: 46 31 20 15 90
F: 46 31 20 15 84
http://www.parans.com

Himawari
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Himawari Building, 7-8 Toranomon 2-chome, Minatu-Ku
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http://www.himawari-net.co.jp

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Oak Ridge, TN 37838
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F: 865-483-5997
info@sunlight-direct.com

AUTOMATED INTEGRATION

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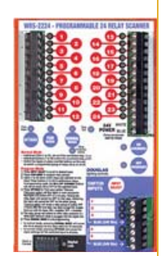
Peachtree City, GA 30269
T: 800-553-3879
F: -800-954-7016
E: controls@cooperindustries.com
http://greengate.coopercontrol.com/cooperControls

Douglas Lighting Controls
T: 604-873-2797 or 877-873-2797
F: 604-873-6939
E: lighting@DouglasWest.com
http://www.douglaslightingcontrol.com/



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EnOcean Inc.

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C: 801-652-4960
E: jim.ocallaghan@enocean.com
http://www.enocean.com/en/building-automation

Hubbell Building Automation Inc.

Lighting Virginia – East
596 Central Drive Ste 110
Virginia Beach, VA 23454
T: 757-463-1100 or 757-463-0010
http://www.hubbell-automation.com

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F: 800-665-5332
E: info@ledalite.com
http://www.ledalite.com

Lutron Electronics Co., Inc.: *as seen at Sidwell Friends*

for contact information refer to page:
http://www.lutron.com/lutron/contact.asp#
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