

Daylighting Guide for Buildings

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Objectives for this Guide

The intent of this article is to explain daylighting design principles for buildings and to assist designers in locating useful sources of tools and information.

Upon reading the article, the reader will know:

- The benefits of design for daylighting
- The challenges associated with daylighting
- The principles of good daylighting practice
- How to perform basic daylight calculations to apply these principles in their own designs
- Where to find web tools for daylighting design



The Pantheon in Rome, with its dome-top “oculus” shows how daylighting was exploited in the construction of early large buildings. In today’s architecture, much of the design rigor used in the consideration of daylighting has shifted towards the design of electric lighting. This article will refocus attention on the science of daylighting and acknowledge its ability to kindle the artistry in architecture.

*Figure 1: Klosterenga project, Oslo Norway
Double layered glazing provide daylighting and ventilation of living spaces*

Daylighting Definitions

The following definitions are provided as a reference to better understand the terms used in this article:

Luminance is the measured brightness of a surface and is expressed in candelas per square metre (cd/m²). Humans perceive light in logarithmic fashion along a vertical scale (a doubling of brightness is perceived as an increase of about 50 percent).

Candela (cd) is the *intensity* of the light source. A light source may emit one candela in a narrow beam, or in all directions. The intensity of the light would remain the same, but the *amount* of light would be different.

Lumen describes the amount of light produced by a light source. A 60-watt incandescent bulb produces 900 lumens; a 36-watt T8 fluorescent tube produces around 3000 lumens. The amount of energy that strikes a surface is usually measured in lux.

Lux describes the amount of light that strikes a surface. A lighting designer may try to achieve a light level of 500 lux at desk height in an office. Lux is a unit of illumination equal to one lumen per square meter. The imperial measure is “footcandle”, which is one lumen per square foot.

Daylight Factor (DF) is a measure of natural daylight in an interior space, representing the amount of light at a given point in a space relative to the simultaneous amount of daylight available outside.

Energy rating (ER) is a rating system that compares window products for their heating season efficiency under average winter conditions.

Low-emissivity (low-e) are coatings applied to window glass to reduce heat loss from inside without reducing solar gain from outside.

Solar Heat Gain Coefficient (SHGC) is equal to the amount of solar gain through a window, divided by the total amount of solar energy available at its outside surface.

Solar south is 180 degrees from true (not magnetic) north.

Switchable glazing describes glazing materials that can vary their optical or solar properties under the influence of light (photochromic), heat (thermochromic) or electric current (electrochromic)

The Benefits of Daylighting

Daylight is a full-spectrum source of light to which human vision is adapted. Recent studies have shown that proper daylighting of a building can increase productivity, decrease sick time, and even increase sales.¹ Daylighting has two general benefits: it can improve the quality of light in a space, and reduce the amount of electrical lighting required.

More importantly, daylight provides tremendous psychological benefits to building occupants; this should be a main goal of daylighting rather than the simple reduction of electrical lighting requirements. Good daylighting design requires consideration of a range of complex concerns. Since Canadians spend as much as 90 percent of their time indoors, our good health is directly associated with receiving optimal levels of quality light.

Fluctuating light levels influence even our hormonal levels and biological rhythms. Daylight can have other physiological effects as well. Studies on the affect on student health of daylighting in American schools have consistently shown results of increased attendance, improved academic performance, increased growth, and reduced cavities.²

Building related productivity and health benefits are often difficult to characterize, let alone cost, so designers are left with energy performance to carry most of the argument for daylighting. Reduced peak electricity demand is a major benefit for buildings that experience their greatest load during daylight hours. Cooling loads can also be reduced in buildings occupied during daylight hours, since daylight provides more energy as visible light and less as heat, compared to electrical lighting.

With proper building integration and lighting controls, daylight can significantly reduce the need for artificial lighting. Integration of daylighting strategies with electrical controls can provide automatic adjustments to provide minimum light levels with minimum electricity use.

Daylighting should be considered an integral part of sustainable building issues. Before electric lighting, daylight was the primary illumination source for all building types. Designers now tend to rely on electric lighting, especially in plans with deep floor plates. However, even northern window orientations provide useful daylight because of diffuse sky radiation.

Solar Resources for Canada

Energy from the sun reaches us as direct, reflected, and diffuse radiation. Direct radiation is greatest on a surface that is perpendicular to the sun's rays and provides the greatest amount of usable heat. Diffuse radiation is energy from the sun that is scattered in the atmosphere by clouds, dust, or pollution and becomes non-directional. On a cloudy day 100 percent of the energy available may be as diffuse radiation, whereas on a sunny day less than 20 percent may be diffuse. Daylighting techniques have been used successfully in all parts of Canada, including the far north.

¹ Environmental Building News "Daylighting: Energy and Productivity Benefits", Vol. 8, No. 9, Sept 1999.

² http://www.healthyschools.org/downloads/Lighting_Guide.pdf (registration required for access to reports)

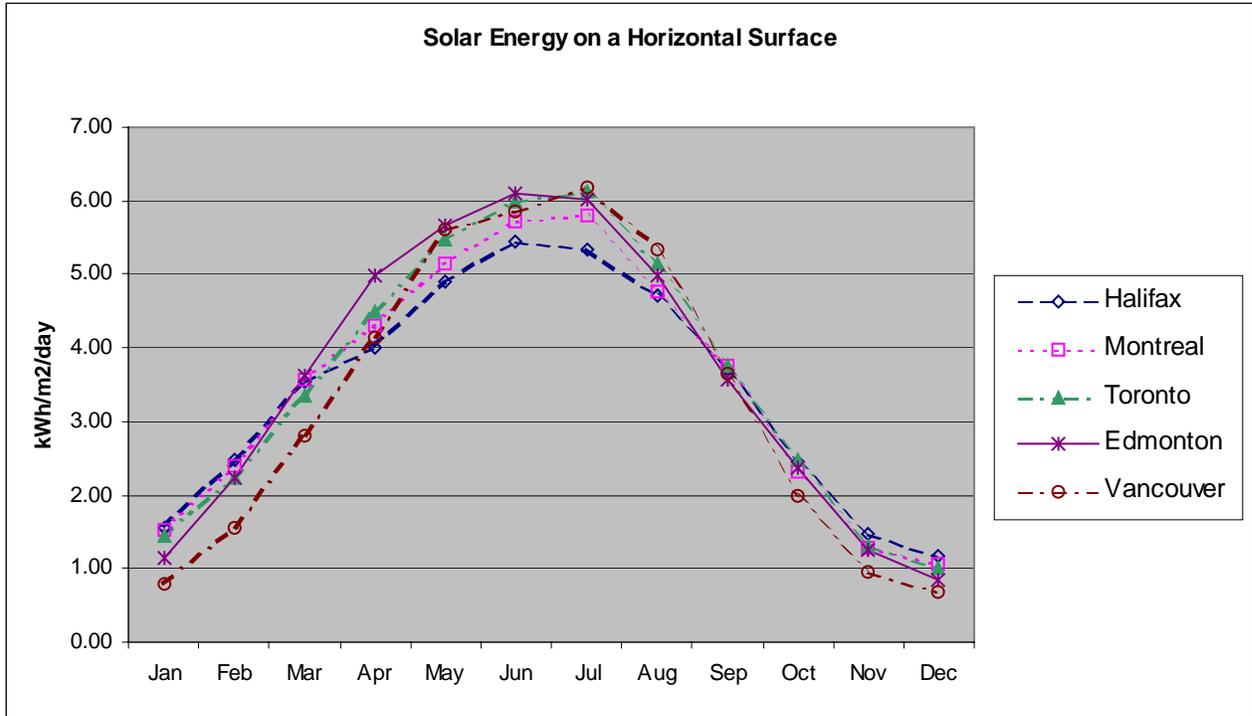


Figure 2. kWh/m²/day on a horizontal surface, for selected Canadian cities (from RETScreen, NRCan)

Principles of good daylighting practice

The level and distribution of natural light within a space depends primarily upon the following three factors: The geometry of the space, the location and orientation of windows and other openings, and the characteristics of the internal surfaces.

Daylighting design shapes these factors to accommodate the lighting requirements of activities within the space and the aesthetic intent of the design. Certain usage patterns require particular light levels and overall distribution patterns.

Office buildings generally need to light a deep floor plan with a relatively low floor-to-ceiling height, with windows usually along one wall only. Industrial buildings generally try to provide high levels of omni-directional light to all parts of spaces that often have large internal volumes and relatively high ceilings. Residential buildings usually have many relatively small rooms with exposure in only one or two directions. The aim is to provide adequate light levels even if the only window, for instance, faces away from the sun.

Daylight Factor

The Daylight Factor (DF) is a measure of natural daylight in a space. It quantifies the amount of light at a given point in a space relative to the simultaneous amount of daylight available outside. A DF of 2% would mean that the indoor daylight is 2 percent of the available outside daylight. i.e.: if the outside light is 8,000 lux, the indoor daylight would be 160 lux. A DF of 1% will provide a low level of light. A DF of 2% will be an “average” daylit space. A DF of 4% will be perceived as a bright daylit space. A simplified method for calculating the DF is included in the “Calculations” section.

Natural daylight illumination can vary from 5,000 lux in a heavily overcast sky to over 40,000 lux in direct sunlight. These are much greater than that needed for adequate indoor lighting. Typical indoor illumination requirements are less than 500 lux for workspaces. Other areas, such as churches, appear bright with much lower lighting depending on their function. Ten to fifty lux could be acceptable in corridors, if the occupant’s eye is adapted to the indoor illumination.

Daylighting Challenges

The following points outline the fundamental challenges in daylighting design. Subsequent sections provide strategies to deal with each of these challenges.

- 1. Integration of daylighting design** into all design stages. Special efforts need to be taken by the design leader to ensure that the design specialties that influence, or are influenced by daylighting design contribute to the design and construction process.
- 2. Difficulty in achieving daylight penetration** into deep building spaces.
- 3. Shading by obstructions.** Obstructions can have a significant effect on the daylighting potential of a site. For low to mid rise projects, obstructions usually arise from buildings, terrain, or trees. For larger buildings the obstructions are usually other large buildings.
- 4. Thermal comfort.** Heat loss from windows and resulting lack of comfort near windows on cold days. Overheating in summer, especially with the desire for panoramic views achieved by large window walls.
- 5. Glare and control of contrast** are problems in all seasons, especially for tasks requiring computer use. When there is too great a difference between the light entering and the lighting on an object, contrast is a problem. Daylighting is most effective in areas that can tolerate high variability in lighting conditions.

Integrate Daylighting Design at the Concept Design Stage

Poor integration of daylighting technologies can lead to discomfort and unreliable performance. Building floor plate depth, window orientation, size and angles as well as shading and transmission characteristics all must be considered. To get the maximum cost and energy savings, these decisions must be considered with integrated input from the developer, tenant, mechanical, acoustic and electrical engineers, landscape designers, etc. at the earliest concept stages. Such an interdisciplinary team is most effective in establishing daylighting objectives and resolving lighting issues at the design concept stage. For example, the design goal may be to maximize the benefits of daylighting of a building, while eliminating the problems mentioned above, which are of an interdisciplinary nature.

Building Form and Daylight Penetration

To maximize daylighting potential, a shallow floor plate is preferred. Alternatively, inner courtyards, roof monitors and atriums can bring light into central cores, especially in low buildings. This article provides information that is primarily relevant for perimeter daylighting conditions. The document *Daylighting Design for Canadian Commercial Buildings* provides a good overview of techniques for daylighting the core of buildings with large floor plates, through the use of skylights, roof monitors, and clerestory windows.

The **amount** of light that penetrates a room depends upon the window orientation, size and glazing characteristics. The **distance** that adequate daylighting will penetrate into a room depends upon window location, and interior surfaces. There is a direct relationship between the height of the window head and the depth of daylight penetration. Typically adequate daylight will penetrate one and one half times the height of the window head, although it may penetrate a distance of twice the height under direct sunshine.

Daylight penetration into a space can be increased by using lightshelves. This is a horizontal element with a high reflectance upper surface that reflects light onto the ceiling and deeper into a space. Light shelves can be exterior, in which case they also can provide shading, or interior. In Canadian buildings with sprinkler systems, interior light shelves cannot exceed 1200 mm (4 ft) in width or the design will require integration with the sprinkler system to cover the floor area under the light shelf area. A lightshelf requires higher than average floor-to-ceiling height to be effective (e.g. 3 m) and is only applicable for southern exposures. Lightshelves also require increased maintenance and any window coverings used must be coordinated with the light shelf design.

Elephant & Castle Eco-Tower, a proposed 30-storey new multi-function highrise in London UK has been designed by architect Ken Yeang of T.R. Hamzah & Yeang to exploit the benefits of daylight. The building was designed maximize daylight by the use lightwells and a 3-foot-square lightpipe whose reflective interior surfaces project 400 lux of daylight onto the interior floor plate forty feet away.³ Capital costs and heat loss are two issues which need to be addressed when considering this application. Also, since lightpipes

depend on the high reflectivity of the interior surface, a maintenance program may be required. The *advancedbuildings.org* website provides information on light tube systems available in Canada. http://www.advancedbuildings.org/_frames/fr_t_lighting_light_pipes.htm

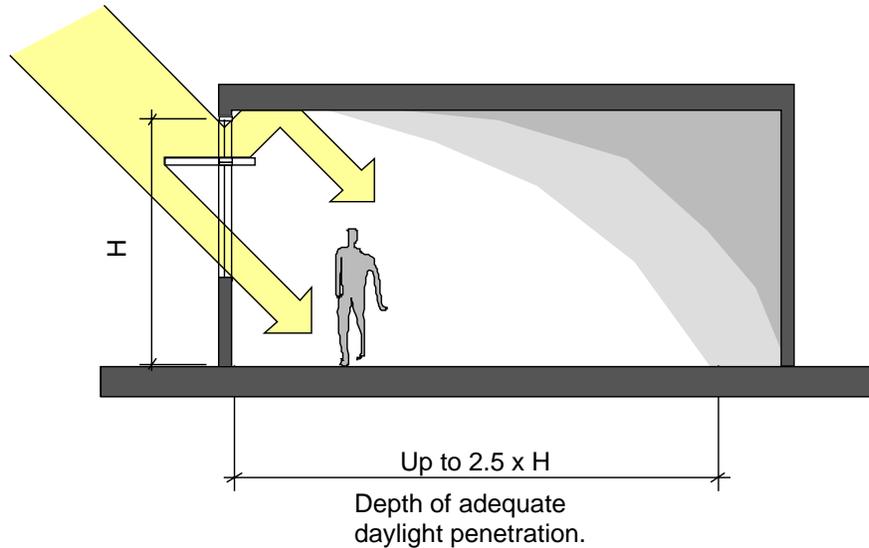


Figure 3: Light Shelf.

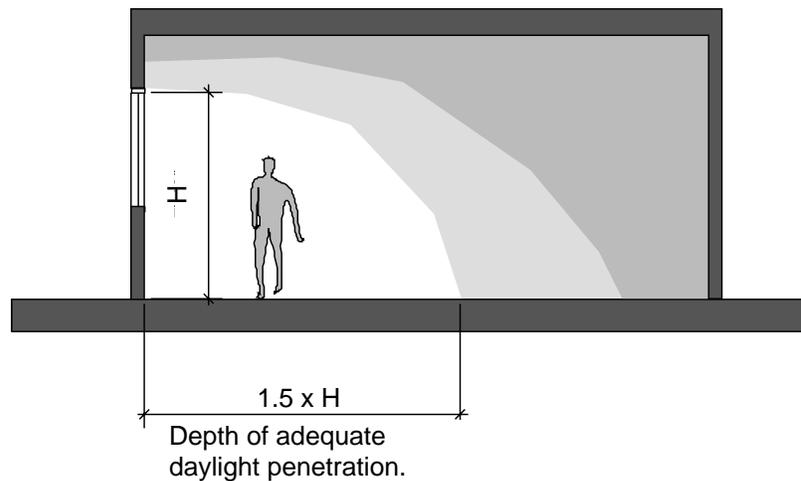


Figure 4: Approximate Daylighting Penetration

Skylights and light-pipes can provide daylight through a roof to the interior spaces below. Skylights often also allow heat gain in the summer time, and can be a potential source of glare. Diffusing glazing can help alleviate this problem. Light pipes collect light through an exterior transparent dome, and bring it to the interior through a reflecting metal pipe and a diffuser at the ceiling level of the space. The efficiency of fixed light pipes is reduced by absorption from the walls of the pipe. The light is reflected repeatedly as it travels through the pipe. The light loss is proportional to the length-to-width ratio of the pipe (the more times the light is reflected within the pipe, the more light is absorbed). Properly sized light pipes are effective at bringing daylight to interior spaces without the associated heat gain and glare problems of skylights. To maximize useful daylight, service spaces should be in areas with the least daylight access. However,

designers should consider providing daylighting to stairways and corridors, as views of the outside will encourage users, and allow light to penetrate deeper into the building.

Work areas in west facing zones should be avoided, because the low level of the sun in late afternoon is difficult to control, causing glare and overheating.



In residential buildings, the double loaded corridor configuration allows windows on only one wall in most suites. Corner and “through” units can have better light penetration, reduced glare, and better natural ventilation. Positioning the stairwells to provide daylight into corridors is one way to promote a better daylit connection to the outdoors, and to encourage the use of the stairs. The *District Lofts* building in Toronto, shown at left, is an example of a building with a single loaded corridor configuration that provides view, daylighting and ventilation advantages for the occupants.

Figure 5: The District Lofts building in Toronto

Some standard floor plates for multi-family buildings are shown below. The third plan indicates one way to introduce more daylighting (and cross ventilation) to each unit by stepping back each unit.

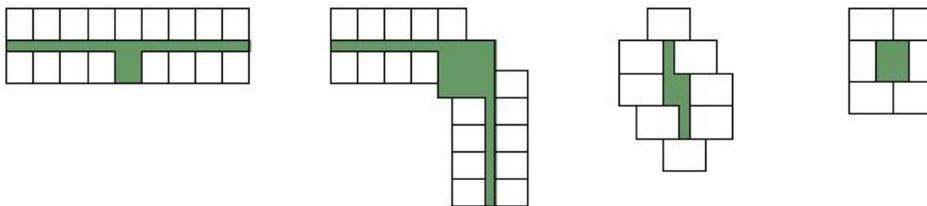


Figure 6: Variation of the central core and double-loaded corridor building forms.

The *Urban Villa* project below shows another approach to integrated solar design. A multi-disciplinary design process was used for the Urban Villa apartment building in the Netherlands. It employs an atrium space to provide daylighting and air preheating for the attached units. The atrium is ventilated on hot days. The south-facing windows of the units are shielded from overheating by shading devices on the balconies and by ventilating windows. For more information about the other solar design features of this demonstration project, visit CMHC http://www.cmhc-schl.gc.ca/en/imquaf/himu/buin_018.cfm)

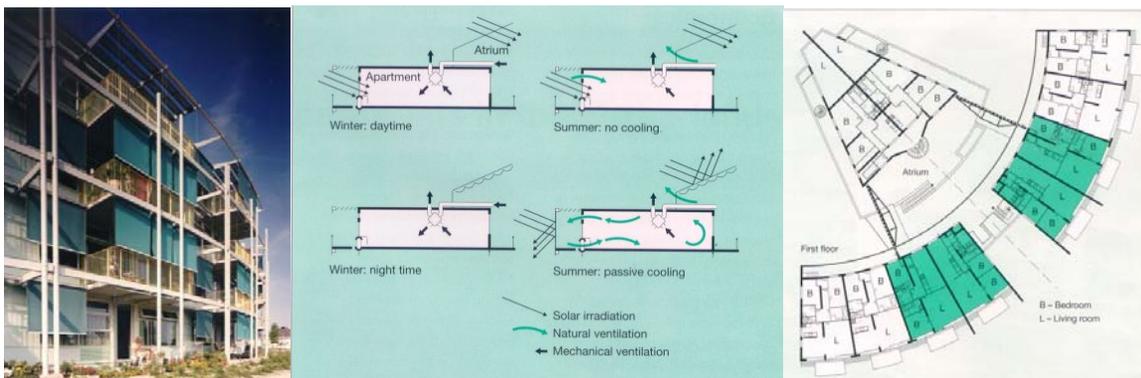


Figure 7 Urban Villa, Amstelveen, NL

Obstructions

Outside obstructions can reduce daylighting potential. The sky exposure angle is the amount of sky that can be seen from a window. It is defined as the vertical angle of sky between the top of an obstruction and the vertical, and is typically measured from a point two metres above the floor. The “Daylighting Guide for Canadian Commercial Buildings” identifies the following sky exposure angles that are required for adequate daylight:

<u>Latitude</u>	<u>Required Sky Exposure Angle</u>
42 to 46°	59°
46 to 50°	62°
50 to 54°	64°
>54°	66°

Obstructions can be identified on the sun path chart shown in Figure 9. East and west obstructions can be beneficial in reducing solar gain in the summer, while admitting energy in the winter when the sun rises in the southeast and sets in the southwest. This allows one to establish the setback required from an existing obstruction. The sky exposure angle from a point in an existing building can also be used to determine the maximum building height and setback required for a new project to allow adequate light to reach existing buildings.

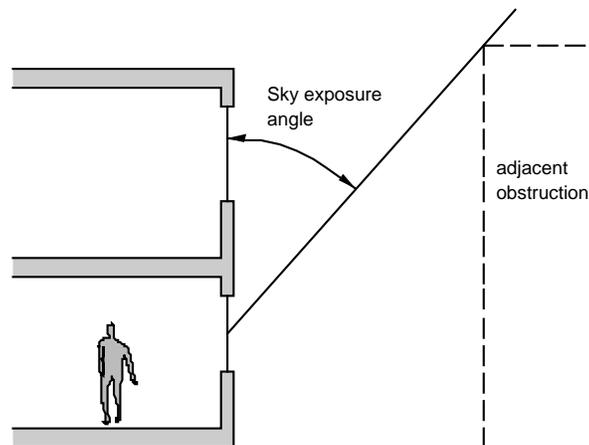


Fig 8. Sky exposure angle.

Building Orientation

To maximize daylighting advantages, buildings can be located and oriented to take advantage of the sun’s movement throughout the day, as well as seasonal variations. As a general rule, buildings that have their long axes running east and west have a better daylighting potential. This creates the dilemma of having half of the units facing south, and half of the units facing north in apartment buildings with a typical double-loaded corridor arrangement. However, the diffuse light of a northern exposure still provides more than enough illuminance to serve interior lighting needs. Buildings with a north-south axis have greater potential for overheating in the non-heating season, and get little advantage of solar heat gain in the winter. *All orientations have daylighting potential*, since the average illumination level in overcast skies at 46 degrees latitude is 7500 lux, 15 times more than required for normal indoor tasks. (NRCan *Daylighting Guide for Canadian Commercial Buildings*, 2002)

A good design strategy to address building orientation is to ‘tune’ windows to admit or exclude solar energy based on their orientation. Generally, south-facing windows should admit winter solar gain, and east and west facing windows should exclude low angle daylight. Overhangs and fins may be used to prevent glare and overheating. All glazing should be selected for the appropriate shading and insulating qualities. Refer to the “Windows” section for discussion of window selection.

Another strategy that addresses orientation is to provide shallower spaces on the north side, and deeper spaces on the south side, to accommodate the varying depths of daylight penetration.

Window Orientation

We receive the greatest amount of energy from the sun at noon on any given day in the year. The greatest amount of energy received *through a window* is when the sun is perpendicular to the window, and 30 to 35 degrees above the horizon (see Figure 9). A south-, east-, or west-facing window will receive about the same annual maximum of solar radiation. The time and date that the maximum energy is received depends on the buildings latitude and the wall orientation. The Earth rotates 15 degrees every hour; therefore, when a window is oriented 30 degrees east of south, the maximum heat gain will be about two hours before solar noon. East and west facades experience their maximum solar gain during the summer, whereas a south-facing surface receives its annual maximum in the late fall or winter.

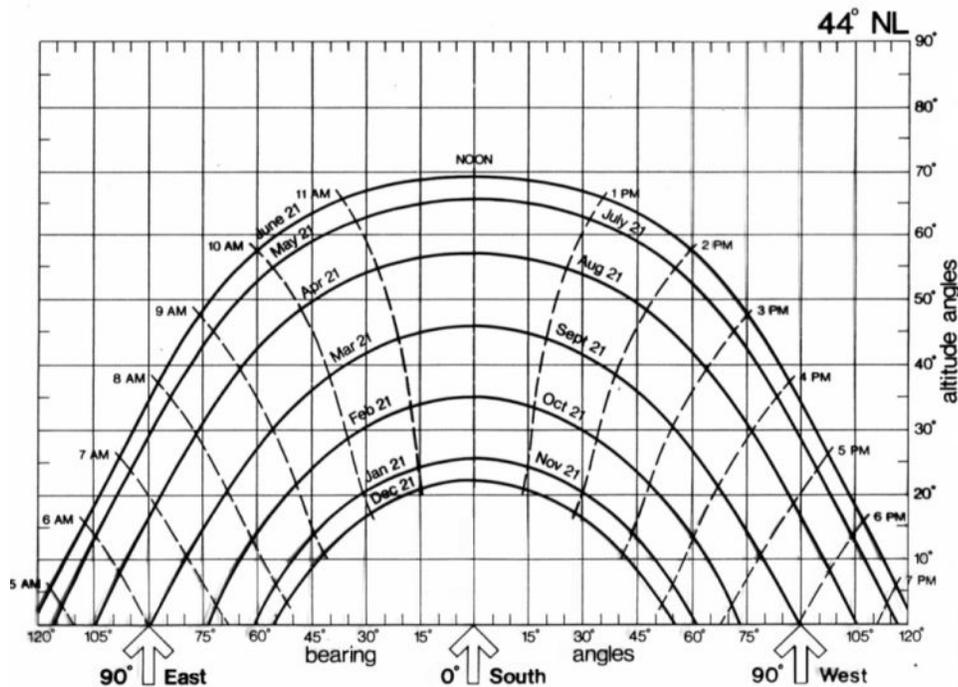


Figure 9: Sun Path Chart

Adapted from Edward Mazria "Passive Solar Energy"

Figure 9 shows a sun path chart for 44 degrees north latitude. The sun's path varies by a project's latitude. The X-axis indicates the direction of the sun; the Y-axis indicates the sun's angle above the horizon. The curved lines show the arc of the sun across the sky on the 21st day of each month. The dashed lines show the time of day. By plotting the time of day and month, an accurate location of the sun can be determined.

Obstructions by buildings and trees are also plotted to show when a building will be shaded. Sun charts for any latitude can be generated through an online program available through the University of Oregon.

<http://solardat.uoregon.edu/SunChartProgram.html>

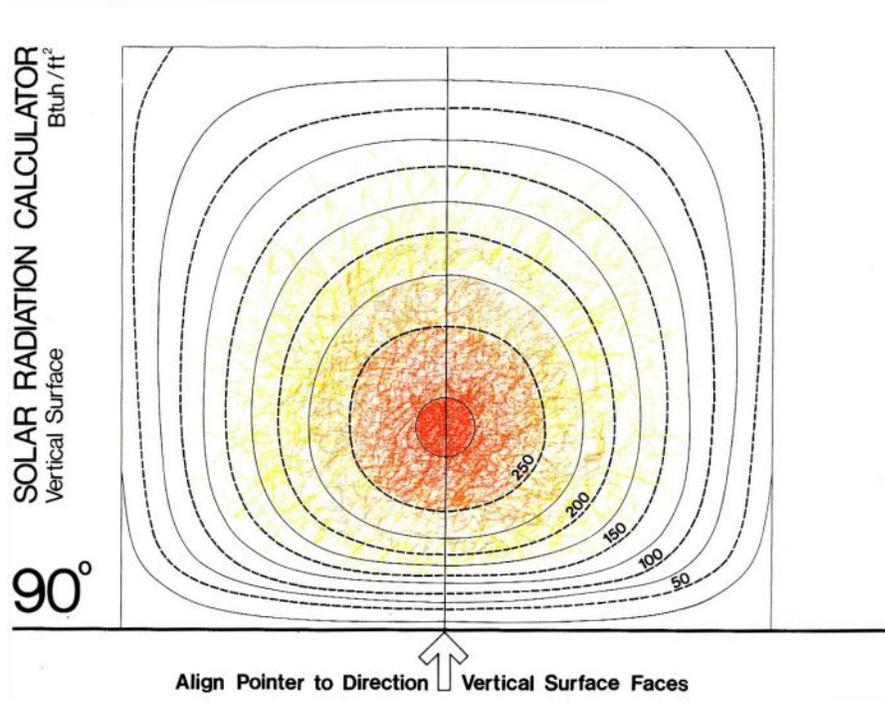


Figure 10: Solar Energy Intensity

Figure 10 shows the intensity of the solar energy striking a vertical surface facing the sun. The maximum energy that enters a window occurs when the sun is 30 to 35 degrees above the horizon, and directly in front of the window.

By superimposing the Solar Intensity chart over the sun path chart, we can indicate the effect of window orientation on solar gain.

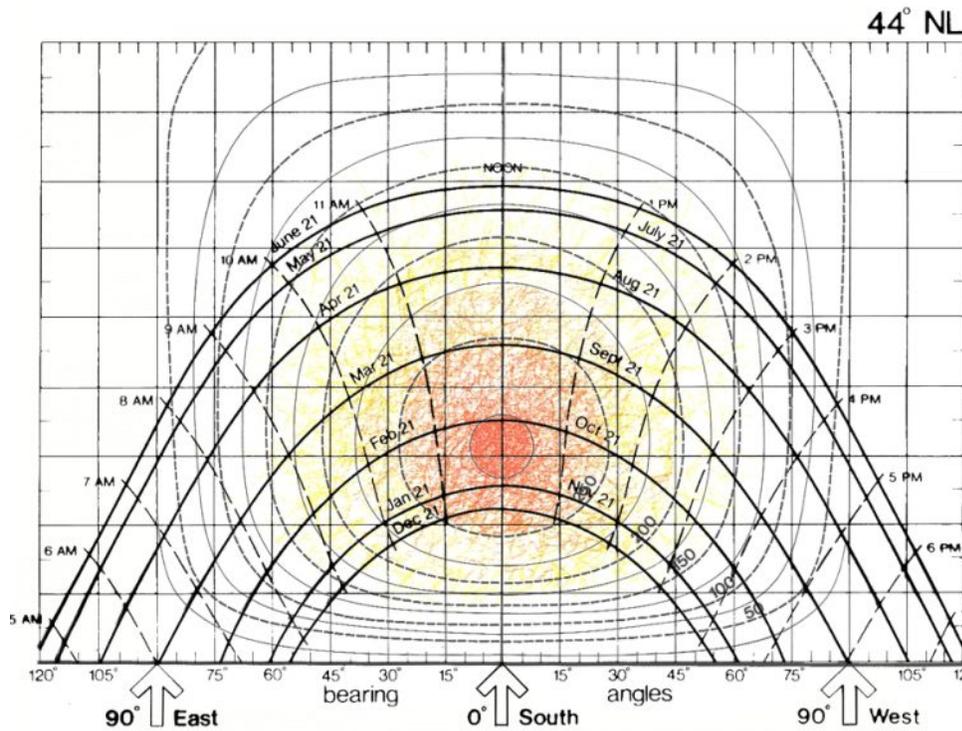
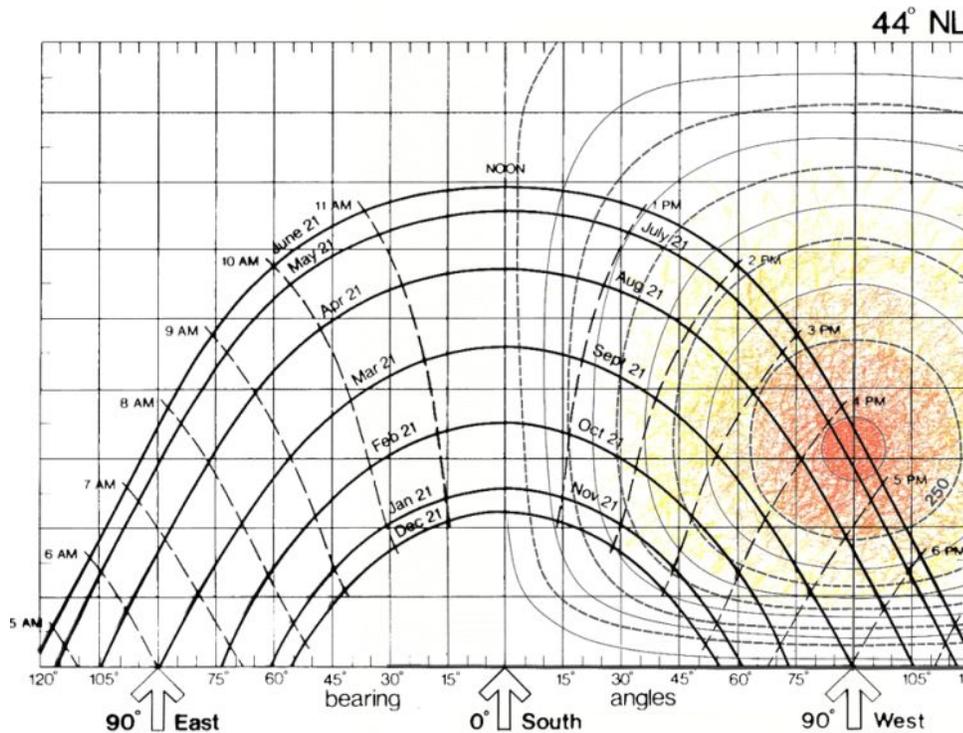


Figure 10 aligns the solar intensity chart to “South” on the sun path chart. This graphically indicates that the maximum solar gain occurs at noon during October and February.

Figure 11: Energy striking a south window for 44 degrees North latitude. Adapted from Edward Mazria “Passive Solar Energy”



To indicate the effect on a west window, align the solar intensity chart with “West” on the sun path chart. This shows how window orientation affects the time of day and the time of year of maximum solar gain.

Figure 12: Energy striking a west window for 44 degrees North latitude.

Adapted from Edward Mazria “Passive Solar Energy

North-facing windows provide consistent indirect light with minimal heat gains, but can also create heat loss and comfort issues during the heating season. **South-facing** windows provide strong direct and indirect sunlight. The light intensity varies during the day, and controlling heat gain can be an issue in the cooling season. Shading is easily done with horizontal shading devices. **East** and **west-facing** windows can create more problems with glare and heat gain, and are more difficult to shade because the sun is closer to the horizon. In our northern locations the sun is at a low angle in the sky during winter, when sunlight is most needed to contribute to heating. South-facing clerestory windows have the advantage over horizontal roof glazing for this purpose. However, the sun also creates glare and overhangs over south windows may need to be large to prevent this. Also, when the sun is low, buildings and trees can create shading which is desirable in some seasons, and perhaps less so in others.

It is important to note that south-facing surfaces receive more energy in the winter, and less in the summer than east and west-facing surfaces. A general design strategy to control overheating is to maximize window area on the south, and use less on the east and west. For predominantly cloudy regions where overheating is less of a problem, interior spaces benefit from larger windows (including the north façade) to allow more light into a building. Be aware that there can be a tradeoff between allowing more daylight and increasing heat loss.

In predominantly clear regions, glare and heat gain are more problematic. In direct sunlight, smaller windows can provide adequate daylight. Direct sunlight can also be reflected and/or diffused with window shading devices.

Window Performance and Tuning

Orientation, size, layout and the performance characteristics of a window play important roles in daylighting. Proper glazing and frame selection can enhance the daylighting and energy performance of windows, just as good water-shedding and energy performance can be achieved by sound watershedding and air barrier design details. General rules for tuning window orientation include:

- Determine the window size, height and glazing treatments for each façade separately.
- Maximize southern exposure.
- Optimize northern exposure.
- Minimize western exposure, when the sun is lowest and most likely to cause glare and overheating. Windows themselves can be oriented differently from the plane of the wall.

Daylight calculations are generally based on overcast conditions. In this case, the amount of daylight that a window receives is directly proportional to the amount of sky that can be seen from the centre of the window.

Adding small openings gives better daylighting performance than by increasing window size. Larger windows cause more glare and require more shading. In increasing daylight factors from 3 to 4 percent (by increasing window size by 33 percent), the daylighting period during the year will increase by only 5 percent.

Larger window areas increase the risk of glare, overheating in summer, and discomfort from heat loss in winter. For areas with direct sun, shading needs to reduce transmittance to 10 percent or less to prevent glare.

Glare from windows can occur when the incoming light is too bright compared with the general brightness of the interior. Punched windows can create strong contrasts between windows and walls when viewed from the interior. Horizontal strip windows **on the other hand** provide more even daylight **distribution**, and often provide better views. Other interior design guidelines that deal with glare are discussed later in this article.

Window sizing

The calculations section of this article provides a simple formula for calculating window size based on the desired level of natural lighting. The links in the tools and resources section show tools that allow you to optimize window sizes for the most effective use of daylighting.

Exterior Shading

A good shading system will permit lower levels of artificial illumination to be specified, because the eye can accommodate itself without strain to function within a wide illumination range.

Exterior shading devices are effective at controlling solar gain. Interior window shading will allow much of the solar energy into the building, and will allow more heat, sometimes an unwanted partner of daylight, to enter the building. Light-coloured interior shading will reflect some of this energy back through the window.

South facing windows are the easiest to shade. Horizontal shading devices, which block summer sun and admit winter sun, are the most effective. East- and west-facing windows are best shaded with vertical devices, but these are usually harder to incorporate into a building, and limit views from the window. On lower buildings, well-placed deciduous trees on the east and west will reduce summer overheating while permitting desirable winter solar gains.

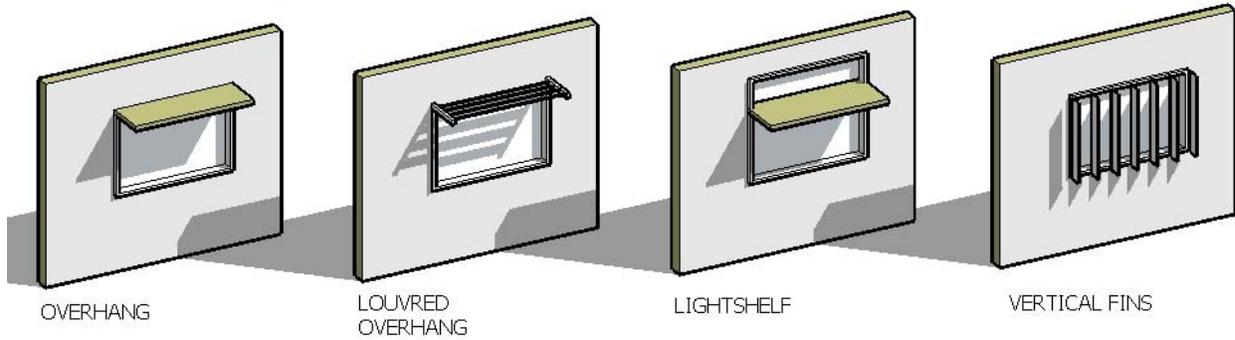


Figure 13: Common types of exterior shading.

Interior shading is most effective at controlling glare and offers the ability to be controlled to suit the tolerances of the occupants, especially if using shades which draw upward instead of down.

Window Elements for Daylighting Design

Solar Heat Gain Coefficient (SHGC)

A useful measure of a window's ability to admit solar energy is the Solar Heat Gain Coefficient or SHGC. A given window's SHGC is equal to the amount of solar gain it allows, divided by the total amount of solar energy available at its outside surface. This is a number between zero (solid wall) and one (open window). The SHGC can be measured for the entire window unit, including the frame, or for just the glazed area. The higher the SHGC, the better the window will perform as a solar collector. Likewise, where overheating is a concern, windows with a low SHGC will reduce cooling loads by excluding solar energy.

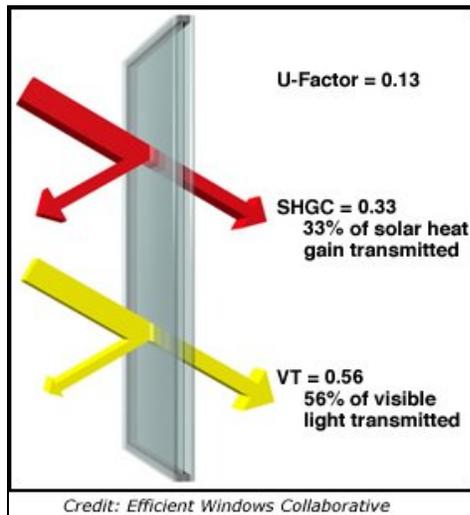


Figure 14: Solar Heat Gain Coefficient

source: Efficient Windows Collaborative

Glazing

A single pane of clear glass facing the sun will admit most of the visible solar radiation, some of the infrared radiation and very little ultraviolet radiation. It will also have the highest heat loss from the inside to the outside. There are a number of ways of modifying windows to enhance their performance.

Adding a second or third layer of glass can dramatically lower the U-value (increase the R-value), while maintaining a large SHGC. Additional layers of glass also permit thin low-emissivity (low-e) coatings to be applied onto a protected glass surface. Low-e coatings still allow solar gain (short wavelength radiation) and they help retain heat by reflecting long wave radiation back into a room. This is very helpful from a passive solar heat point of view. There are also a number of reflective coatings that block out unwanted solar gain (reduce the SHGC) usually to reduce the cooling load. There are many types of spectrally

selective glazings that block out selective wavelengths (colours) and generally result in a lower SHGC, for various levels of visible light transmittance.

Evacuating the space between the panes, using an inert gas such as argon or krypton, or using a transparent insulation can reduce heat loss by conduction and convection. Because gas fills perform well and are low cost, they should be used whenever a low-e coating is used in a glazing unit.

Apart from the energy and comfort benefits, by using high performance windows it may be possible to move heating outlets further from the windows, potentially eliminating ducting or piping.

A more recent development in glazing technology is “switchable glazing”. These include glazing materials that can vary their optical or solar properties according to light (photochromic), heat (thermochromic) or electric current (electrochromic). Initial computer simulations indicate that electrochromic glazing holds the most promise for improving occupant comfort. These systems are in prototype stages and are not yet in commercial production. They will likely be able to reduce cooling loads and glare, and improve visual comfort in commercial applications that do not require high solar transmittance. These may have poorer optical properties, and therefore might not be as suitable in multi-unit residential buildings.

Visible Light Transmittance

Visible light transmittance (VT) is the measure of the visible spectrum that is admitted by a window. Typical daylight strategies require windows with a high VT. A low SGHC is also desirable where heat gain is a concern. Reflective glass is not recommended for daylighting.

Typical values for light transmittance and SHGC of common glazing systems are shown in the following table.

Visible Light Transmission/Solar Heat Gain Coefficient (percent)				
Glazing system (6 mm glass)	Clear	Bluegreen	Grey	Reflective
Single	89/81	75/62	43/56	20/29
Double	78/70	67/50	40/44	18/21
Double, hard low-e, argon	73/65	62/45	37/39	17/20
Double, soft low-e, argon	70/37	59/29	35/24	16/15
Triple, hard low-e, argon	64/56	55/38	32/36	15/17
Triple, soft low-e, argon	55/31	52/29	30/26	14/13

Figure 15: (source: ASHRAE Fundamentals 1997, Table 11, page 29.25)

Frames

Frames are often the weakest thermal part of a window. Although frames, sash and mullion assemblies comprise only 10 to 25 percent of the window area in commercial buildings, they can account for up to half of the window heat loss and can be the prime site for condensation.³

Thermal performance of frames is improved either by using a low-conductivity thermal break in metal frames, or by using a frame built of a low-conductivity material such as wood, vinyl or fibreglass. Using low-conductivity window frames will reduce energy consumption in all types of buildings. Apartment and commercial buildings with punched windows can use frames of low-conductivity materials. In Canada, fire code requirements state that the area of windows with combustible framing materials must be less than 40 percent of the building wall area, and that windows must be separated by non-combustible materials.⁴

Spacers

Spacers separate the panes of glass in a sealed window, to prevent the transfer of air and moisture in and out of the glass cavity. Warm-edge spacers use low conductivity materials, rather than aluminum, and are important in reducing heat loss through the window. By reducing the likelihood of condensation on the

³ Internet site: Advanced Buildings: Technologies and Practices.
http://www.advancedbuildings.org/_frames/fr_t_building_low_conduct_window.htm

⁴ Internet site: Advanced Buildings: Technologies and Practices.
http://www.advancedbuildings.org/_frames/fr_t_building_low_conduct_window.htm

glass surfaces, they can also influence the daylighting performance of windows. The low cost and good performance of warm-edge spacers make this technology suitable for all window systems and should be considered mandatory whenever low-e coatings and inert gas fills are used.⁵

Interior Design Guidelines

Glare

Glare occurs when luminaires, windows or other sources seen either directly or by reflection, are too bright compared with the general brightness of the interior. Glare can impair vision and cause visual discomfort. Paradoxically, a high level of direct sunlight may also require a high level of general artificial light to reduce the contrast.

Solar control is necessary in most buildings for reducing discomfort glare from windows. This may be in the design of the building's overall form and orientation, or in the use of external screens (including overhangs and vertical side-fins) and louvres, window glass of low transmittance, or internal blinds and curtains.

Increasing the luminance (using light colours) of interior materials and surfaces can reduce glare from windows.

To increase daylight effectiveness, don't use large areas of dark color. Generally avoid dark colors except as accents, and keep them away from windows. Dark surfaces impede daylight penetration and cause glare when seen beside bright surfaces. For good distribution throughout the room, it is especially important that the wall facing the window be light-coloured. Mullions or other solid objects next to windows should be light-coloured to avoid silhouette contrasts. Keep sills and other reveal surfaces light to improve daylight distribution and soften contrast. Dark artwork can reduce daylight effectiveness. Splayed jambs and sill also reduce the contrast in light levels between the window and wall.

Supply window coverings that allow individual control to accommodate different glare tolerances. The design of workspaces must take major light sources into consideration and shield computers from glare and high levels of backlighting. One simple solution is to use blinds that rise from sill level, rather than drop down from above. These can reduce backlighting and glare on work surfaces while still allowing daylight to penetrate deeply into the room through the unshaded upper part of windows.

Aim for recommended surface reflectances. Desirable reflectances (Illuminating Engineering Society recommendations): ceilings >80 percent; walls 50-70 percent (higher if wall contains a window); floors 20-40 percent; furniture 25-45 percent.

Choose matte over shiny surface finishes. Matte finishes are better than specular surfaces for good distribution of daylight because they reduce reflected glare (hot spots).

Use light-transmitting materials. Interior windows, transoms, and translucent or transparent interior partitions allow daylight to pass through to other spaces. These are most effective when the Daylight factor at their surface is 1 percent or more, and the glazed area is as large or larger than the neighbouring exterior window area.

A sloped ceiling at the exterior wall to allow for higher windows can increase light penetration. Also, contrasts and glare can be reduced by curving or angling the interior window surround. Positioning windows in different walls allows better light distribution and visual comfort.

Lighting Integration

To be effective, daylight strategies must be integrated with the electric lighting system. Relying on occupants to manually switch lights off when there is adequate daylight has shown to be inconsistent and ineffective. Therefore, automated systems perform best. There are two types of automated daylighting control systems: dimming and switching. Dimming control adjusts the light output to provide the desired light level. Switching controls turn individual lamps on or off to provide the appropriate light level. Both

⁵ Internet site: Advanced Buildings: Technologies and Practices.
http://www.advancedbuildings.org/_frames/fr_t_building_warm_edge_windows.htm

systems can save significant energy cost when properly integrated. Integration with electrical design will save electrical costs; integration with mechanical design can also reduce heating and cooling costs.

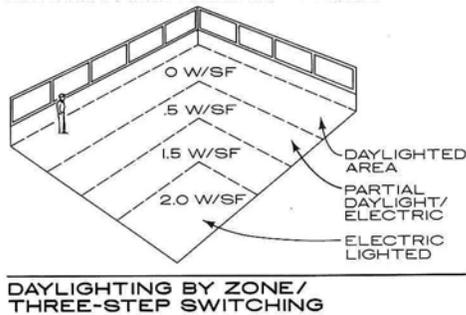


Figure 16: Daylighting controls

Source: *Architectural Graphic Standards*

Dimming systems are best suited to offices, schools and any areas where desk work is being performed. Switching systems can be used in areas with high natural light levels (e.g., atria, lobbies) and where non-critical visual tasks are being performed (lounges, cafeterias, hallways and stairs.)

Switching systems are less expensive than dimming systems for most applications. Occupants generally prefer dimming systems because of a more gradual change in lighting levels.

Proper commissioning and calibrating is critical to the success of the daylighting control system. Calibrate the controls during daylight conditions that are predominant for the region.

Other Design Considerations

Simple systems often perform better than complicated approaches. The amount of daylight that enters a building depends upon the amount of sky that can be seen from inside, the luminance of that sky section, and the area and transparency of the window. Interior daylight reaching inside is related to the absorbing surfaces compared to the window area, and surface reflectances, especially those directly hit by incident light, such as the floor. Because of this, additional reflective surfaces will reduce daylight penetration through the reduction of the solid angle of light collection and by adding more light absorption into the process. Thus, greater daylight control measures can reduce luminous performance. Also, reflective surfaces can lose more than 50 percent of their reflectance when dust, condensation or corrosion reduces their optical qualities.

Another aspect of daylighting is its thermal impact in building interiors. In the Daylight Europe study, six buildings were monitored for their energy performance, using ESP-r (from the Energy Simulation Research Unit of the University of Strathclyde, Glasgow), and compared to buildings without daylighting features. RADIANCE 2.3 Synthetic Imaging System (G² Ward Lawrence Berkley Laboratory 1993) was used to investigate the optical and glare performance. As expected, annual lighting savings tended to be large. The thermal impact was not always positive, but when there was an increase in thermal loads, they were still smaller than the electricity savings due to natural lighting. Glare and the reduction of diffuse light penetration were critical, as high glare resulted when atrium walls received direct sunlight.

Atria and Overhead Glazing

The best daylighting performance is offered by horizontal roof openings, which collect daylight from a large section of sky with few obstructions. However, these can also have issues of glare, summer heat gain, and winter heat loss. Roof monitors and sawtooth roof glazing were commonly used in large factories at the turn of the 20th century, because they can appropriately illuminate large interior spaces during daytime. Northern light is best for avoiding glare and strong reflections. South facing clerestories should be shaded from direct sunlight, (or the view of the sun must be hidden from the occupants). Translucent or diffusing glazing can also alleviate glare problems associated with direct sunlight. West- and east-facing openings should be avoided. Reflective roof surfaces can be used to advantage to increase light entering monitors and clerestories, by bouncing the light off the ceilings. Sunlight hitting a north wall can be an excellent diffused light source.

Architects can consult *Daylighting Design for Canadian Commercial Buildings* for more information about daylighting of large floor plate areas.

By acting as thermal buffer spaces atria can help reduce heat loss in winter, but need to be designed to avoid overheating through ventilation design and proper shading. If an atrium is added to retrofit a courtyard, the daylight reaching the original windows may be reduced by half. In this case, interior windows that face the atrium need to be large - at least 50 percent of the wall surface - to add to the lighting needs within. For the two lower floors of an atrium space to benefit from the atria daylighting, floor finishes in atria need to be reflective.



Day light from above can have a sculptural effect, but must also fulfill the visual criteria of glare control and distribution in the space. Le Corbusier's Chapel Notre Dame du Haut, in Ronchamps, France is a well-known example of the sculptural effect of daylighting strategies.

Figure 17: Notre-Dame-du-Haut, Ronchamps, Le Corbusier, architect
Photographer and Source : Nick Ladd



Figure 18: St-Benoit-du-lac, Québec, Dan S.Hanganu, architect
Source: Barry Craig

More details on the sizing of atria for daylighting can be found in the *Daylighting Guide for Canadian Commercial Buildings* at http://www.advancedbuildings.org/Daylighting_Guide_for_Canadian_Buildings_Final6.pdf

Fully heated and cooled atria can be energy gluttons. The Urban Villa, mentioned above, is an example of an atrium used as an unheated buffer zone in a multi-family residential building, which is tied to an overall solar energy system.

Another example is the Windsong Co-housing project in Langley BC. The CMHC website <http://www.cmhc-schl.gc.ca> provides more details on these buildings.

Design Tools and Resources:

The oldest and most-used daylighting tool is the scale model, since light follows the same basic rules in a scale model as in full sized buildings. The one drawback is that it over-predicts illuminance.

Natural Resources Canada and the National Research Council of Canada have launched a free-to-use online computer tool called the *Lightswitch Wizard* to guide decisions by building designers. This program, based on *Radiance* software, can analyze available daylight for offices and the performance of automated controls. It is available at <http://www.buildwiz.com/lightswitch/index.cfm>

Building Design Advisor (BDA) is a free software program designed by the Lawrence Berkeley Laboratories that allows optimization of daylighting design and controls. The *Daylighting Guide for Canadian Commercial Buildings* includes a brief tutorial. Free download of BDA is available at <http://gaia.lbl.gov/bda/>

Radiance is a suite of programs for the analysis and visualization of lighting in design. Input files specify the scene geometry, materials, luminaires, time, date and sky conditions (for daylight calculations). Calculated values include spectral radiance (ie. luminance + color), irradiance (illuminance + color) and glare indices. Simulation results may be displayed as color images, numerical values and contour plots. <http://radsite.lbl.gov/radiance/framew.html>

Commercial Building Incentive Program (CBIP): CBIP, a federal government initiative to reduce energy use in commercial buildings, is an incentive to better exploit daylighting. Building owners are given a

financial incentive of three times the annual energy savings if the predicted building energy use is 25 percent below that required by the Model National Energy Code for Buildings. Computer simulations are done using NRCan's free EE4 software.

Daylighting Calculations

For those practitioners who wish to do their own daylighting calculations, there are a number of methods of calculating the Daylight Factor (DF). The equation below is a simplified method that calculates the Average Daylight Factor for a rectangular room whose depth is less than 2.5 times the window head height, under an overcast sky. A sample room could be used to run through the calculation, and provide some commentary on the result.

$$\text{ADF} = \frac{\text{VT} \times \text{angle of sky visible} \times \text{area of glass}}{2 \times \text{Total Surface Area} \times (1-\text{LR average})}$$

Alternatively, the same formula can be modified as follows to determine the approximate area of glass required to provide a desired Daylight Factor.

$$\text{Required area of glass} = \frac{2 \times \text{Total Surface Area} \times \text{ADF} \times (1-\text{LR average})}{\text{VT} \times \text{angle of sky visible}}$$

where:

VT is the visible transmittance of the glazing (see notes below)

Angle of Sky is the vertical angle between the lowest and highest points of the sky that are visible from the centre of the window. For a vertical window, this value will be between 0 and 90 degrees.

Total surface area is the total area of interior surfaces (walls, floor, ceiling and doors.)

Area of glass (not including frame) is approximately 80 percent of the overall window size.

LR Average is the area-weighted average of the interior surfaces. Calculated by:

$$\frac{\text{Wall Area} \times \text{Wall Reflectance}}{\text{Total Surface Area}} + \frac{\text{Floor area} \times \text{floor Reflectance}}{\text{Total Surface Area}} + \dots \text{ etc.}$$

Visible Transmittance data is available from window suppliers. Daylight design should use windows with as high a VT as possible. A table of typical VT and SHGC values is provided in the "windows" section of this article.

References:

1. *Innovative Building case studies*, Canada Mortgage and Housing Corporation. http://www.cmhc-schl.gc.ca/en/imquaf/himu/buin_009.cfm
2. *Tap the Sun Passive Solar Techniques and Home Designs*, CMHC 1998. Guide for house design with calculation software provided.
2. *Techno Towers, architecture*, pp.52-53, by C.C. Sullivan, Dec. 2002
4. *Daylight Performance of Buildings*. Ed. Marc Fontoynt, 1999, James and James

In the 1990s, sixty buildings throughout Europe were monitored and assessed as part of the Joule II "Daylight Europe" study. Case studies and guidelines are provided.

Daylighting Guide for Canadian Commercial Buildings, NRCan, NRCC 2002. Online guide

Lightswitch Wizard, NRCan, NRCC, 2003. www.buildwiz.com (non-expert software) The Wizard is a daylighting analysis tool to support daylighting-related design decisions in commercial buildings during the early design stage. It offers comparative and fast analysis of the daylight amounts required in peripheral offices as well as lighting energy performance of automated lighting controls compared to standard on/off switches. Blinds are either manually or automatically controlled.

More technical information and links to daylighting and lighting can be found at the NRCC website at <http://irc.nrc-cnrc.gc.ca/ie/light/links.html>

DAYSIM is NRCC software developed for experts in daylighting design. <http://www.irc-nrc.gc.ca/ie/light/daysim.html>

Square One research, Wales. <http://www.squ1.com/site.html>. Good on-line daylighting information.

The Advanced Building web site is supported by a consortium of Canadian government and private organizations. <http://www.advancedbuildings.org/index.htm>

Tips for Daylighting, Lawrence Berkeley National Laboratory, 1997 Guidelines for an integrated approach to cost-effective design of commercial buildings perimeter zones. Practical rules of thumb and "how to".

Questions:

1. How can natural lighting reduce a building's cooling load?
2. What design decisions affect the amount of light that penetrates a room?
3. How far will light typically penetrate into a space that has windows that are 2.4 metres from the floor to the top of the glass?
4. What is meant by 'tuning' windows?
5. Identify three challenges associated with west-facing windows?
6. What are the two types of automated daylighting lighting control systems?
7. What is 'Daylight Factor'?
8. From the Sun Path Chart in Figure 11 determine the months of the year that a south facing vertical window would receive maximum solar gain.
9. From the Sun Path Chart in Figure 12, determine the time of day that a west facing vertical window will receive maximum solar gain in May.
10. What are the advantages of using 'warm-edge' spacers in a window?

Answers:

1. Daylighting provides more light with less heat than most electric lights. Since a portion of the cooling load is from electric lighting, properly integrated daylighting controls that switch lights off when there is adequate daylight will reduce the electrical use and the cooling demand.
2. Generally, the amount of light is determined by the window size, orientation, and glazing characteristics. The other significant influence is obstructions, or the amount of sky that the window can 'see'.
3. A rule of thumb is that light will penetrate one and one half times the window head height, or 3.6 metres, in this example. The reflectance of the interior surfaces also plays a role in the depth of light penetration.
4. The window characteristics for each façade should be addressed separately. A common strategy is to maximize solar gain on south windows, exclude low angle solar gain on east and west windows (by smaller windows or low SHGC glazing), and design northern windows for daylighting (larger), or energy efficiency (smaller or high performance glazing.)
5. Heat gain, glare, and shading. West-facing windows have their greatest heat gain on summer afternoons, increasing the cooling load. Glare and discomfort can be a problem for the late afternoon low angle sun. West windows are difficult to shade with overhangs.
6. Dimming and switching. Dimming systems control the output of the luminaires in reaction to the available daylight. Switching systems turn off lamps or luminaires when there is adequate daylight.
7. The Daylight Factor (DF) is a measure of the amount of light at a given point in a space relative to the simultaneous amount of daylight available outside. It provides a useful guide to establishing the perceived brightness of a space, and is the basis for simple window sizing calculations.
8. Maximum solar gain through a vertical surface occurs when the sun is 30 to 35 degrees above the horizon. For a south-facing window in a project that is at 44 degrees North latitude, this occurs around February and October. This is shown graphically in Figure 11 where the February/October path (arc) passes closest to the maximum solar intensity.
9. As in the previous question, maximum solar gain through a vertical surface occurs when the sun is 30 to 35 degrees above the horizon. The May 21st sun path line is the second curve from the top. A west facing vertical window (270°) will receive maximum solar gain where the May sun path passes nearest the maximum solar intensity, or at about 4:00 PM.
10. Warm-edge spacers are less conductive, and thus have less heat loss and provide higher resistance to condensation at the edge of the window.