European Commission

General information

Shading systems

Solar shading for the European climates

ENERGIE

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Shading Systems

Solar Shading for the European climates

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For the European Commission Directorates-General
Research and Energy & Transport

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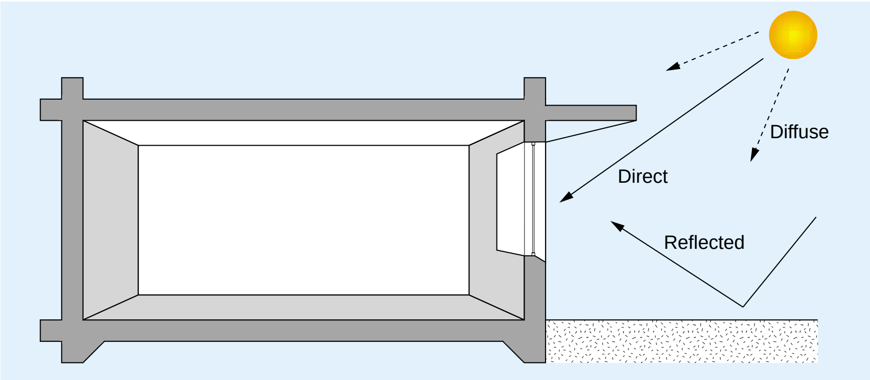
Introduction

Beyeler Foundation Museum (Source: Ove Arup & Partners)

Central to any cooling strategy is protection of the building from unwanted solar gain and this is most readily achieved by blocking the sun's rays before they reach the building. Protection of the building's apertures is the first and most fundamental consideration in the design of shading systems. When designed well they may also protect the opaque surfaces, including the roof.

In designing efficient cooling strategies for buildings the sun is the most important concern. Correctly designed shading systems can effectively control the sun's direct radiation, and partially block diffuse and reflected radiation.

Direct radiation emanates straight from the sun in parallel beams, casting sharp shadows: it is by far the most important component the shading system has to address. Diffuse radiation emanates from the entire area of the sky vault and thus from all angles within the horizons. Reflected radiation comprises both direct and diffuse radiation reflected from the ground and buildings. It is therefore usually at a low incident angle. The intensity of reflected radiation is strongly influenced by the reflectance properties of the insolated surface: grass will reflect 20-30% of the incident sunlight and snow more than 70%.



Direct, diffuse and reflected radiation

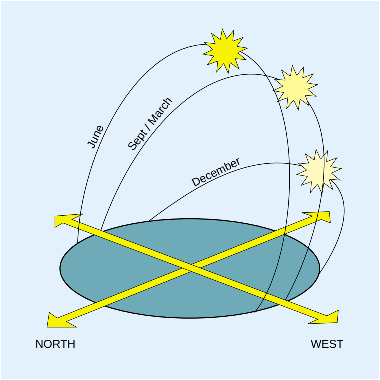
Natural cooling refers to those design techniques which prevent or moderate heat gains, and is achieved by manipulating:

- building form, layout and site design;
- solar control;
- microclimate design;
- thermal insulation;
- internal gain control;
- occupancy patterns.

Control of solar radiation can be achieved through:

- shading devices;
- orientation and aperture geometry;
- control of solar-optical properties of opaque and transparent surfaces;
- urban design – shading by neighbouring buildings;
- vegetation – planting of trees, vines, shrubs.

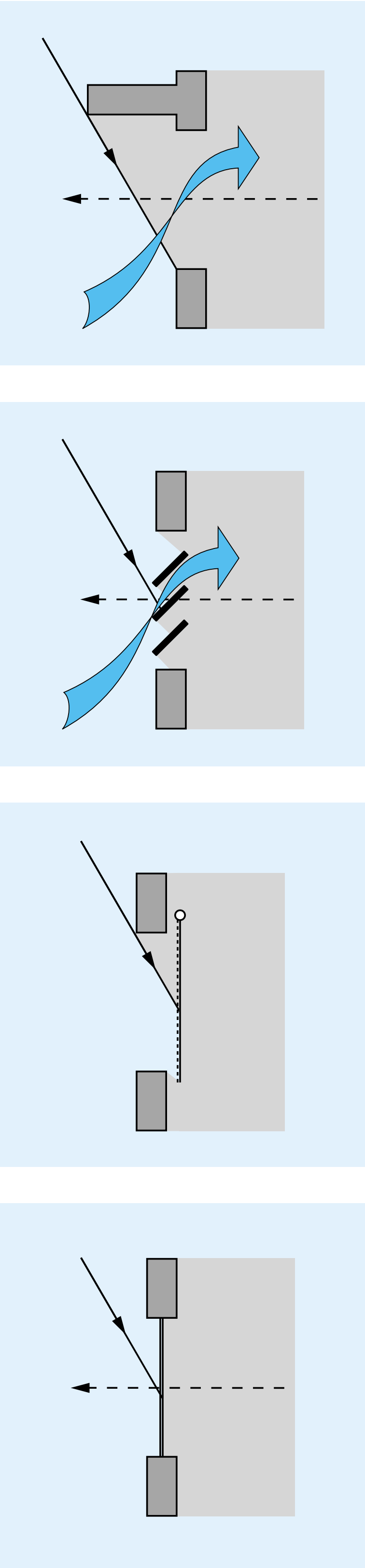
Shading against solar heat gain is the most readily applicable and flexible method of cooling and can be applied in all climate types in which the sun's influence is significant, and to almost all modern buildings irrespective of latitude. The key to good daylighting and thermal performance lies in the design of the building envelope. Shading devices can be an integral part of the envelope, and thus influence thermal and daylighting performance. They may be located at the external or internal face of the facade, or within double- and triple- glazed window or curtain wall systems. In each case solar radiation is prevented, wholly or partly, from entering the building. By intercepting solar radiation before it reaches the building, external devices are the most



Summer, winter, equinox sunpath

effective at preventing the build up of solar heat gain inside. Internal devices with a reflective external coating can reflect solar radiation to the outside, but transfer some of their solar heat gain to the room by convection. While shading systems must provide good sun protection during the cooling season, they should not obstruct solar gains in the heating season, reduce natural lighting, nor impede natural ventilation. When properly designed for building type, latitude and climate they can actually enhance natural ventilation and daylighting. Shading devices also offer many possibilities for architectural expression.

The full potential of shading is often not fully utilised, particularly when it is not considered at the early stages of design. Unfortunately the widespread preference for large glazed areas in commercial buildings has created an artificial need for evermore sophisticated and elaborate shading devices. Such over-glazed buildings are often subject to intense solar radiation and resultant internal heat build-up and glare, and can only be effectively shaded at considerable expense, sometimes involving automated devices whose reliability may be a concern. However, if shading needs are properly addressed at the early design stages, simple shading devices fitted internally and externally can effectively shade even extensively glazed facades and, if designed for a light-admitting function, can improve internal illuminance.


External devices showing obstruction of direct radiation

The Role of Shading Systems

The traditional roles of shading systems are to improve thermal and visual comfort by reducing overheating and glare, and to provide privacy. Shading devices may perform one or all three roles. The advent of air-conditioning in the early years of this century, however, saw the use of traditional natural cooling techniques dwindle. For a period they were almost completely ignored, until the energy crisis of the early 1970s prompted a revival. This revival has filtered through to commercial buildings only in the 1990s, however, and has yet to regain its original standing.

Shading devices may be designed to limit the amount of direct solar radiation entering the building by shielding the opaque as well as the transparent surfaces. A secondary role is to limit the diffuse and reflected radiation entering the building.

Solar radiation is composed of electromagnetic radiation in equal proportions in the visible and invisible regions of the spectrum. The invisible region comprises ultra-violet and infra-red wavelenghts. The visible region of the spectrum represents approximately 50% of the sun's energy and is described in terms of luminous flux, illuminance, luminance and luminous intensity. The luminous flux is the quantity of electromagnetic radiation in the visible region of the spectrum arriving, leaving or passing through a surface, and is measured in lumens (lm). The illuminance is a measure of the overall light, (or luminous flux), incident on a surface of unit area. It is measured in lux (lx), which is equal to one lumen per square metre. In clear sky conditions in summer, a horizontal surface receives about 100,000 lux from the sun: the standard overcast sky often used for building design has a value of 10,000 lux. Luminous intensity refers to the quotient of the luminous flux leaving the light source in a given direction. Luminance is a measure of the light reflected by a surface in a particular direction, or the luminous intensity emitted by a unit surface area.

Solar radiation incident on a surface may derive from three sources: direct radiation from the sun (shortwave radiation), diffuse radiation from the sky vault, and radiation reflected from surrounding surfaces and buildings. External shading devices can block the direct component (normally the largest), and reduce the impact of the diffuse and reflected components, but can also influence daylight, glare, view and ventilation. Climatic conditions and building type and use influence the relative importance of these factors. Direct solar gain may be welcome in a residence during the heating season, for instance, but unwelcome in a hospital at all times, regardless of climate.

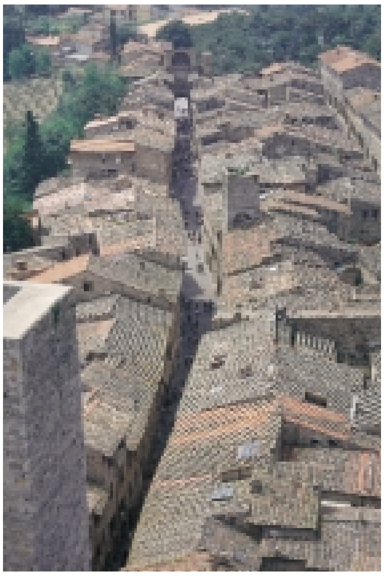
The design of shading systems should consider concurrently solar control, daylighting and ventilation needs. Internal daylighting levels and natural ventilation should not be compromised to the extent that extra artificial lighting or mechanical ventilation are required.

The objectives of good shading can therefore be simply defined as:

- moderating or blocking direct solar radiation at required periods;
- controlling diffuse and reflected radiation;
- preventing glare from external and internal sources;

such that daylighting and ventilation are not compromised.

Traditional Shading Systems



Urban design: street layout providing shade (Source: Derry O'Connell, UCD)

Urban design to provide shading and a cooler, more comfortable environment has long been a feature of Europe's hotter climates. A compact urban layout can provide mutual shading by neighbouring buildings. This is discussed in more detail in the section on Urban Morphology.

Vegetation: planting of trees, vines, shrubs and ground cover has traditionally been used for shading and daylighting purposes. Deciduous vines used in conjunction with a pergola is a common traditional shading system. The shading effect of vegetation is discussed in detail in the section on vegetation.

Traditional external shutters, Portugal (Source: AJ Stack, ERG)

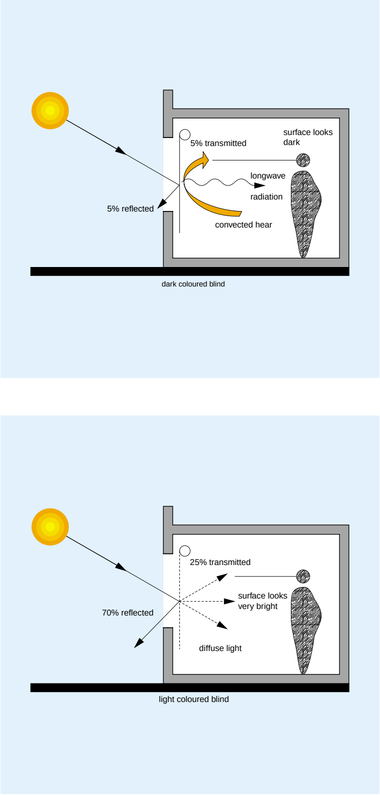
The **traditional external shutter** or blind common to the Mediterranean is a very effective shading device that also has a daylighting function, and is in fact a sophisticated and efficient light redirection system[1]. The horizontal slats of the shutter successfully reduce solar heat gains while allowing illuminance and ventilation. Direct and diffuse radiation are blocked by the shutter, but reflected light is permitted to pass. As the reflected light passes through the shutter it may be redirected upwards to the ceiling which, ideally, has a reflective (typically matte white) surface. The result is a more even light distribution in the space, improved visual comfort and reduced heat gains.

Horizontal beam overhangs are a common traditional, fixed shading system in hot climates. On a south façade, they can block high summer sun but admit the lower angle winter sun. Although overall illuminance levels in the space are reduced, uniformity of light distribution can be improved. In summer, the structure is traditionally used for drying of fruit and vegetables, providing an effective barrier against direct solar radiation. In winter, the beams are left bare to admit the welcome sun.

The **traditional pergola** of the Mediterranean region is a highly efficient and practical system that provides shading through the use of climbing vines, typically the grape vine. The vine is integral to the system and without it the pergola will not perform its intended shading function. In summer, the unwanted high angle sun is blocked by the leaves. In winter, with the absence of leaves, the low angle sun is admitted. In recent years, however, use of the pergola has changed, with the absence of vine planting, to performing a purely decorative role. Its original shading function has been corrupted to the point where, in the absence of vines, high-angled summer sun is admitted and low-angled winter sun is partially obstructed.

Shading and Energy: Cooling

Shading systems perform a number of roles, the most apparent of which is protection from direct solar radiation and the resultant unwanted build up of heat inside the building. This protection is best achieved by shading the building's windows and other apertures. Shading the building facades and roof can also significantly reduce unwanted heat build-up, particularly when these elements are uninsulated. Shading the building envelope and apertures directly reduces the need for cooling: the potential of shading systems to reduce building cooling loads should not be under-estimated.



Light and dark internal blinds

Apart from commercial buildings that experience high internal heat gains from office equipment and occupants, solar radiation represents the major influence on cooling loads in buildings. The direct component is more influential than the diffuse, and exerts its most immediate impact on cooling load when it reaches windows and other apertures because it is transmitted directly to the building interior. As the direct component

Type of activity	GI_{max} (Artificial light sources)	GGI_{max} (Daylight)
Public spaces with dark surroundings (A)	22	24
Simple orientation for short temporary visits (B)	25	26
Working spaces where visual tasks are occasionally performed (C)	19	22
Performance of visual tasks of high contrast or large size (D)	16	20
Performance of visual tasks of medium contrast or average size (E)	13	18
Performance of visual tasks of low contrast or very small size (F)	10	16

Maximum glare index values: the Glare Index (GI) is a function of the weighted ratio of the light source (natural or artificial) and background illuminance.

of solar radiation is of predictable direction, it can be effectively blocked by external shading devices. The diffuse and reflected components, due to their wider angles of incidence, are more difficult to control and are thus more effectively controlled by internal or mid-pane devices. The effectiveness of most internal shades in preventing heat gain to the internal space, however, is limited.

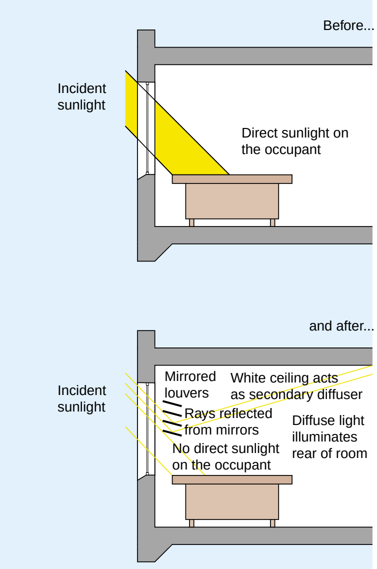
Both direct solar radiation and high external air temperatures will produce conduction heat flow through the building facade and into the building. The rate of conduction heat flow is determined mainly by the thermal insulation and mass properties of the facade elements. A shaded facade will still be subject to the influence of external air temperature and diffuse and reflected solar radiation, but will be free of the influence of the direct radiation. A shaded wall, therefore, conducts less heat to the building interior than an unshaded wall, and so will lead to a lower cooling load.

While the cooling load may be reduced by shading, any associated reduction in daylight levels in the space may lead to a higher artificial lighting load. This may lead to a partial negation of the benefits derived from a reduced cooling load.

A system that is able to distribute light evenly throughout the space – i.e. reduce glare at the window area and increase illuminance at the rear – is therefore preferable. Solar heat gains should be reduced without compromising illuminance or ventilation. Moveable external devices usually best achieve this: ideally, moveable external light shelves with a reflective upper surface finish. Yener[2], however, describes a mathematical model for designing fixed shading devices in which the load on the artificial lighting system is not significantly increased, and both thermal and visual comfort requirements are met. This is achieved by ensuring that glare is within allowable limits.

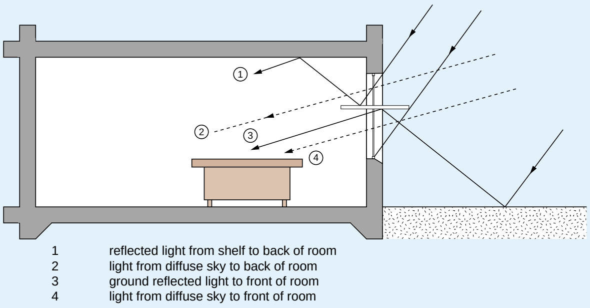
Shading and Energy: Lighting

Although overall illuminance in a space is important, it is the distribution of light in the field of vision that determines the quality of the lighting environment. Shading devices that are able to redirect and redistribute light throughout a space are thus especially useful. Such devices range from the light shelf to advanced glazing systems, and include blinds, reflective louvres, external fins and glass coatings. Their main function is to improve the uniformity of lighting levels. This may involve reducing excessive levels near the window, redistributing light to the rear of the space, or both.



Internal mirrored louvres

The various systems perform differently but they have one objective in common: they improve lighting uniformity throughout the space, typically by redistributing light from the window area to the rear of the space. Potential glare spots are avoided by redirecting the light. Tests have shown that people will tolerate lower overall light levels providing unduly bright and comparatively dark areas are avoided. When light is evenly distributed throughout the space, people are less inclined to switch on the lights, even when the actual light levels are lower than ideal. When the human eye has to adapt to a higher illuminance gradient, the temptation to turn on the lights is greater.

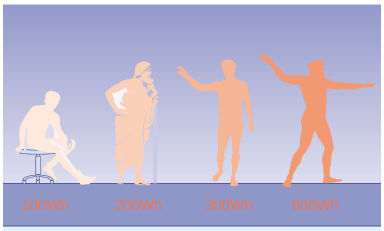


Light shelf

Shading devices that perform the double role of protection against solar radiation and redistribution of available daylight, therefore, have the potential to minimise overall energy consumption in two ways. Firstly, by reducing cooling loads through their shading function, and secondly, because of the better luminous efficacy of daylight, by reducing the use of artificial lighting through their light distribution function.

Shading and Comfort

Direct insolation of the interior of a building is desired in some building types during the heating season, such as dwellings, but not in others, such as offices or hospitals. The relationship between sunlight and human comfort addresses thermal and visual requirements. In the right circumstances, sunshine can be a source of delight, but it can also produce feelings of thermal and visual discomfort. The sensation of direct sunlight on the skin can make occupants feel overheated, and direct sunlight on internal surfaces can cause glare and resultant eye strain.



ACTIVITY	W/m^2	met
Resting		
Sleeping	40	0.7
Reclining	45	0.8
Seated, quiet	60	1.0
Standing, relaxed	70	1.2
Walking (on the level)		
0.89 m/s	115	2.0
1.34 m/s	150	2.6
1.79 m/s	220	3.8
Office Activities		
Reading, seated	55	1.0
Writing	60	1.0
Typing	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking about	100	1.7
Lifting, packing	120	2.1
Driving / Flying		
Car	60-115	1.0-2.0
Aircraft, routine	70	1.2
Aircraft, instrument landing	105	1.8
Aircraft, combat	140	2.4
Heavy vehicle	185	3.2
Miscellaneous Occupational Activities		
Cooking	95-115	1.6-2.0
House cleaning	115-200	2.0-3.4
Seated, limb movement	130	2.2
Machine work		
sawing (light table)	105	1.8
light (electrical industry)	115-140	2.0-2.4
heavy	235	4.0
Handling 50kg bags	235	4.0
Pick and shovel work	235-280	4.0-4.8
Miscellaneous Leisure Activities		
Dancing, social	140-255	2.4-4.4
Calisthenics / exercise	175-235	3.0-4.0
Tennis, singles	210-270	3.6-4.0
Basketball	290-440	5.0-7.6
Wrestling, competitive	410-505	7.0-8.7

Thermal Comfort

Thermal comfort may be simply defined as the sensation of satisfaction with the thermal surroundings. Activity levels and clothing, and micro-climatic factors such as air temperature, air humidity and air velocity, are basic parameters affecting human thermal comfort. Discomfort is usually due to a general feeling of excessive coolness or warmth. It may also be caused by an unwanted draught or a large temperature difference between the lower and upper regions of the body.

The human thermal system allows us to adapt to a wide range of changes in our thermal environment. The basis of this control system is the hypothalamus gland, which has a set point temperature of 37^{o}C. As the hypothalamus detects a temperature change, a series of physiological responses is initiated to return the body to 37^{o}C. When the body's responses, such as sweating or shivering, are unable to cope with the temperature change we experience discomfort.

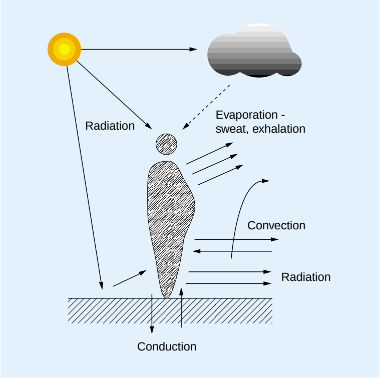
According to Szokolay's[3] method, the point at which the individual feels neither hot nor cold is called Thermal Neutrality (Tn). It is governed by climatic variables and physiological factors and correlates with the outdoor mean temperature (Tav) as:

$Tn = 17.6 + 0.31 \times Tav$,
provided that $18.5 < Tn < 28.5^{o}$C.

Any thermal equilibrium attained is a dynamic one because the temperature within a building changes throughout the day. Apart from the influence of building services, there are two main reasons for this:

1. the internal temperature is constantly trying to adjust to the altered rates of heat gain and loss due to changes in solar radiation and external temperature;
2. the mass of the building does not react immediately to changes in radiation and external air temperature.

Hence, the microclimate within a building is in constant flux. The human heat gain and loss processes are due to the influences of the heat generation and transfer mechanisms of conduction, convection, radiation, metabolism and evaporation. Thermal balance exists when



Heat gain and loss processes

$$Met - Evp +/- Cnd +/- Cnv +/- Rad = 0$$

where:
metabolism = Met
conduction = Cnd
convection = Cnv
radiation = Rad
evaporation = Evp

Visual Comfort

Visual comfort is normally the main factor determining lighting requirements. It is subjective and is influenced by age, the task to be performed, and diurnal and seasonal variation. A satisfactory luminous environment is possible when the following are achieved:

- appropriate illuminance, light direction and distribution for the task;
- glare control;
- appropriate contrast rendering for the task;
- appropriate colour rendering for the task.

Recommended illuminance	
Offices, Workshops and Shops	
storage spaces	150 lux
machine workshops	300 lux
offices	500 lux
drawing offices	750 lux
assembly tasks	1000 lux
precision tasks	1500 lux
Private Houses	
halls	50-100 lux
dining rooms	100 lux
living room, kitchen	200 lux
study	300-500 lux

Adequate illuminance is the first requirement in designing for daylighting in buildings. Correct distribution of the light is important for visual comfort. Merely providing good surface illumination is inadequate. As noted above, uniform daylight distribution can compensate for reduced illuminance.

Luminance ratio

background of visual task : environment
3 : 1

background of visual task : peripheral field
10 : 1

light source : adjoining fields
20 : 1

interior in general
40:1

When the eye adjusts from bright sunlight to a dimly-lit interior it experiences a time lag in adjusting to the changing illuminance, causing temporary blindness. This is also the reason for the discomfort caused when the eye has to cope with glare. Studies have shown that glare from natural light is more easily tolerated than that from artificial light sources. Nevertheless glare be avoided.

The colour rendering of artificial light sources should be as close as possible to that of natural daylight. Natural daylight provides the best possible colour rendering. Ideally, advanced glazing systems (e.g. prismatic glazing) should not interfere with the colour quality of daylight.

Adaptive Comfort

The European standard for thermal comfort in buildings is ISO 773. The standard gives a method for measuring levels of human thermal comfort, expressed in terms of Percentage of Persons Dissatisfied and Predicted Mean Vote. It accounts for the six variables of air temperature, air humidity, air velocity, mean radiant temperature, activity level and clothing, and is based on the conventional heat-balance model. The underlying work included tests conducted in climate laboratories in which each of these variables was altered to produce different thermal conditions. However the ideal comfort temperature suggested by ISO 733 is often perceived as either too high or, in the case of cooling load calculation, too low. This may be because the conventional heat-balance model does not account for the ability of people to adapt to their surroundings.

When the internal thermal environment is altered so that discomfort results, people will, given the means, perform a variety of actions to adapt. These conscious and subconscious actions may include adjusting internal or external shading devices, shedding excess clothing or opening a window. The sensation of discomfort will occur when the internal temperature (and to a lesser extent humidity) is unanticipated, changes beyond accepted bounds, or changes too quickly for adaptive measures to be effective. Discomfort is also less tolerable when the individual has no control over the immediate environment – a factor of often-unrecognised importance.

Position of Shading and type of sun protection	Solar gain factors (S)* for the following types of glazing: Single	Double
No shading		
No protection	0.76	0.64
Heat reflecting glass, gold (seated unit when double)	0.26	0.25
Internal shading		
White venetian blind	0.46	0.46
Cream holland linen blind	0.30	0.33
Mid-pane shading		
White venetian blind	-	0.28
External shading		
Canvas roller blind	0.14	0.11
White louvred sunbreaker 45° blades	0.14	0.11

** All glazing clear except where stated otherwise. Factors are typical values only and variations will occur due to density of blind weave, reflectivity and cleanliness of protection.*

Solar gain factors

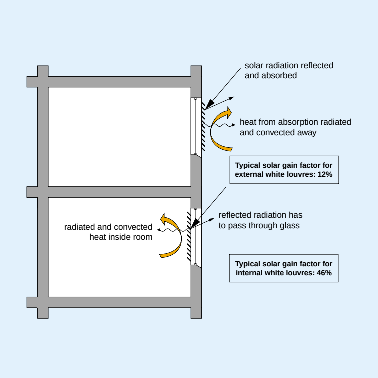
Typology of Shading Systems

As indicated above, shading devices may be external or internal, seasonal, fixed or moveable, and may also serve as daylighting, or even insulating, devices. Some devices may perform dual roles. Insulated internal blinds or louvres, when closed at night and combined with a correctly designed pelmet, can act as a thermal barrier, greatly reducing heat loss to the outside. Treated glasses and prismatic devices can, like louvres with specular faces, provide selective shading and redirection of light.

Choice of shading strategy is determined by building and site location, orientation, building type and use, sky conditions (the direct, diffuse and reflected solar radiation components) and other light sources such as intrusive street lighting. The overall cooling, heating and daylighting strategies adopted in the design phase also influence the choice of shading system.

The quantity of solar radiation entering the building is influenced by the reflection and absorption properties of the external surface. The colour and the material of the shading element influence its effectiveness. Fixed devices are often preferred because of their simplicity, robustness, low maintenance and generally lower construction cost. They perform well in excluding summer sun while allowing in low angled winter sun, but they can seriously affect daylighting in overcast conditions. Unless reflective surface materials are used, most fixed shading devices reduce daylight access, especially in overcast skies.

Moveable shading devices are more flexible. They respond better to the movement of the sun and allow better control of diffuse radiation and glare. In addition, moveable or retractable devices can be manipulated so daylight access in overcast sky conditions in winter is unobstructed. Proper operation of moveable shading devices is required for optimal effect. It should be noted that in some spaces, provision of shade in summer is more important than solar access in winter.



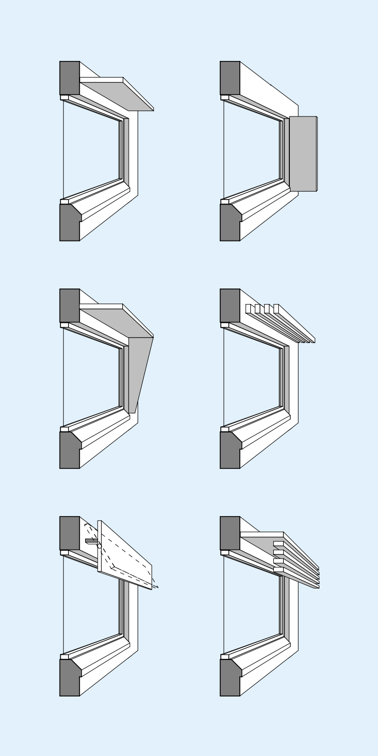
External versus internal louvres

External Devices

Of the various types of shading system, external devices are the most effective in reducing heat gains because they intercept and dissipate (largely by convection) most of the heat in solar radiation before it reaches the building surface. However, they tend to be more expensive to install and maintain, and have a greater impact on the aesthetic character of the building.

Seasonal external shading can be provided by vegetation, typically deciduous and evergreen trees, vines, and shrubs. *Fixed* external shading is generally in the form of horizontal overhangs, vertical fins and permanent awnings or shutters. *Moveable* external shading refers to louvre, blind, awning and shutter systems that can be adjusted to different climatic conditions, and can be fully retractable and automated.

Moveable shades are more suited to the Northern European climate but need to be robust and able to resist wind damage. Maintenance can be difficult, expensive and dangerous if not adequately foreseen. Adjustable and fully retractable external shutters or louvres are effective but can be costly if automated or used in commercial applications. They are very effective at controlling direct, diffuse and reflected light, and are thus able to modulate heat gains as well as daylight levels. They can also provide unobstructed ventilation across the aperture and façade and, when retracted, cause no obstruction to light in overcast sky conditions. Power-assisted external shades should include a manual override in case of breakdown or power failure.



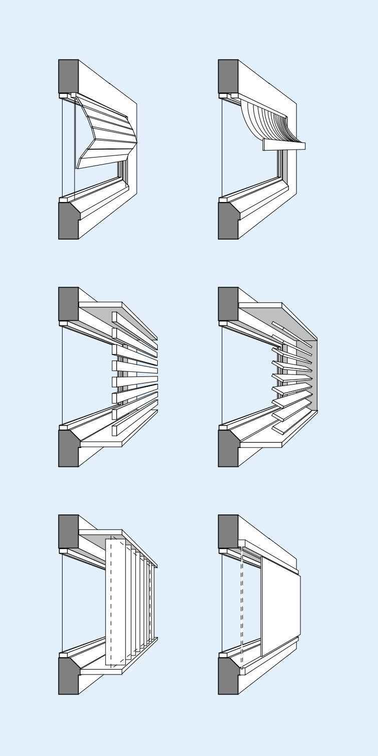
External shading devices (1)

Internal Devices

Internal shading is almost always adjustable or retractable, and is typically in the form of roller or venetian blinds or curtains. It is easily adjusted and maintained, and can provide night-time blockout. It is also generally cheaper and is particularly effective at controlling diffuse and reflected light, major causes of glare. Curtains and blinds can moderate brightness, and louvres can redirect the light. Internal devices do not obstruct direct sunlight until it has passed through the glazing: once the short-wave radiation has been absorbed, there is a heat build-up in the room. They are thus thermally inefficient (unless they are highly reflective) and, since they can readily manipulate diffuse and reflected light, should more appropriately be considered in terms of daylighting and glare control. Where shading is required for preventing overheating they are of little benefit.

If properly adjusted, venetian blinds admit diffuse light while excluding direct sunlight, and can also act as a daylighting device by redirecting light onto the ceiling. However they are normally operated by occupants, which can result in inefficient use. Automation may prove cost-effective in large office buildings.

Internal devices protect occupants against the immediate effects of direct sunlight and against glare, but most of the heat absorbed is released into the room and must be dissipated by ventilation or mechanical cooling. Reflective blinds reduce this effect by reflecting solar radiation to the outside. If reflective glazing is used in conjunction with reflective blinds, however, some of the reflected heat maybe re-reflected back inside.



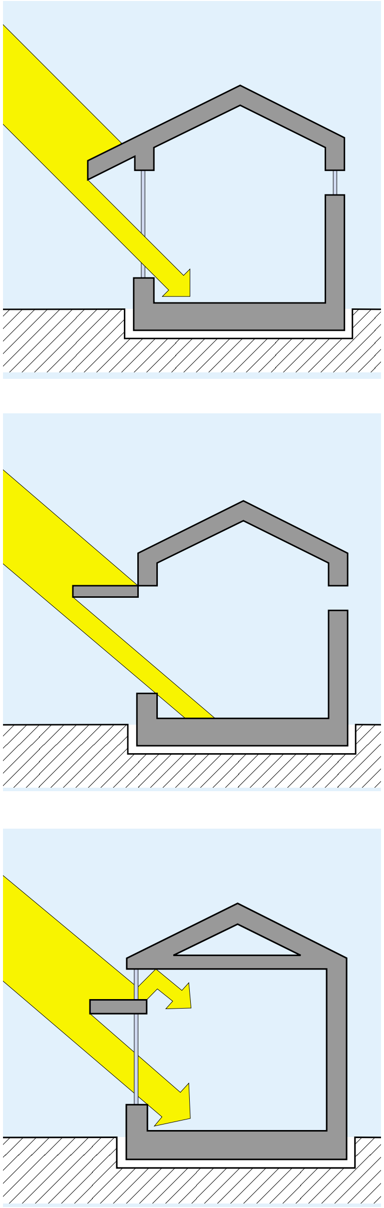
External shading devices (2)

Fixed Devices

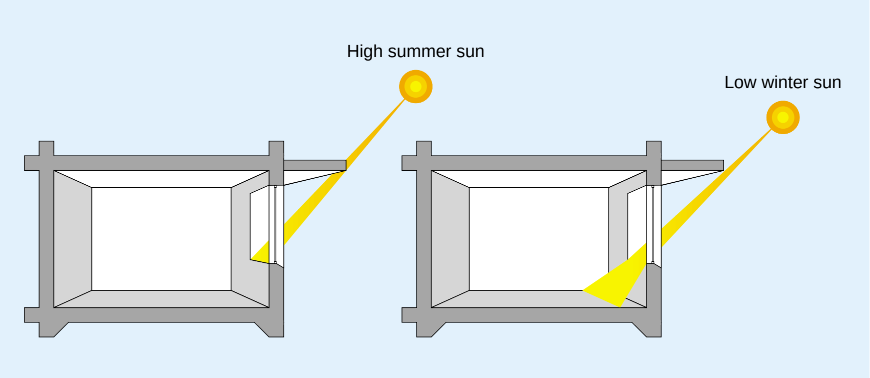
Fixed shading devices are usually external and highly visible and can provide important architectural opportunities. Typically they are in the form of horizontal overhangs, vertical fins or egg-crate (combined horizontal and vertical) devices. The recessed window is also a type of fixed shading device. They are relatively simple and inexpensive, and particularly effective at obstructing direct sunlight, but less effective against diffuse or reflected light.

The horizontal overhang is the most common form of fixed shading device and is the simplest device for controlling high angle direct solar radiation. In the northern hemisphere it is primarily used on the south façade. At lower latitudes, it tends to be used on the east and west facades. In warm climates, such as the Mediterranean, in which cooling is imperative, the overhang is often louvred to enable air to pass freely across the façade.

In fixed shading device design the orientation of the aperture is the main determinant. When correctly designed and used on the south-facing facade, the horizontal overhang can provide complete shading during midsummer and permit solar penetration in winter. To be most effective (i.e. to better control low-angled morning and afternoon sun) the overhang should extend sufficiently on both sides of the window aperture. The overhang length is determined by the width of the aperture and the latitude. The depth is determined by latitude, window height, and the vertical distance between the window and the overhang.

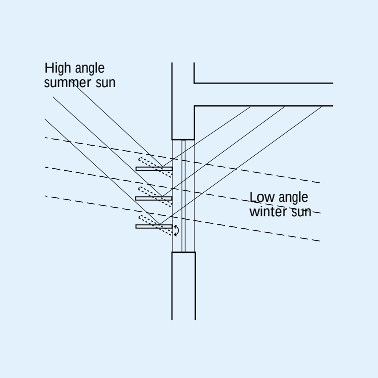


Fixed devices



Fixed horizontal device: summer and winter

Fixed devices do not generally provide effective protection from the low-angled sunlight of morning and afternoon, particularly on the east and west facades. Fixed vertical fins can give some protection, but tend to reduce internal illuminance. Carefully planned vegetation or moveable external devices give better control of the low-angled direct sunlight.

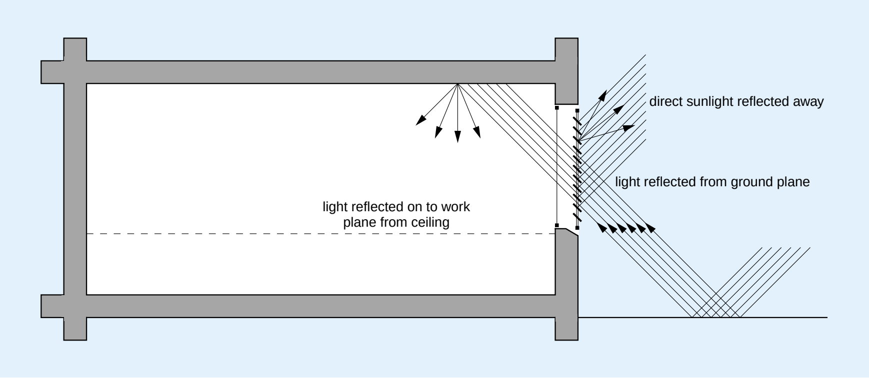


External louvres: high & low angle sun

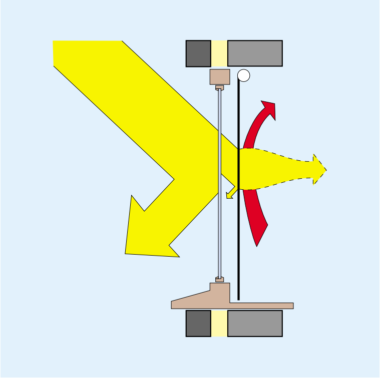
Adjustable Devices

Adjustable and moveable shading devices can be located externally, internally or between the panes of a double or triple glazed window. Adjustability is most often found in internal shading systems, where manipulation is readily achievable and relatively inexpensive. However, it can be applied to external systems in certain circumstances. An external adjustable device can be manipulated to exclude or admit sunlight when required, and is particularly effective in dealing with low-angled direct sunlight, diffuse and reflected light. Unlike fixed shading, it can be operated such that internal illuminance is not excessively reduced. It can be adapted for use in most European climates. However, its success depends on robust construction and correct use, and if automated, it can be expensive.

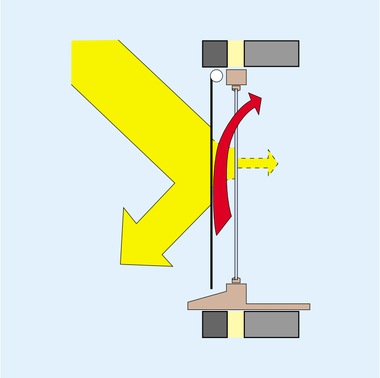
Adjustable external shading (Source: ERG)



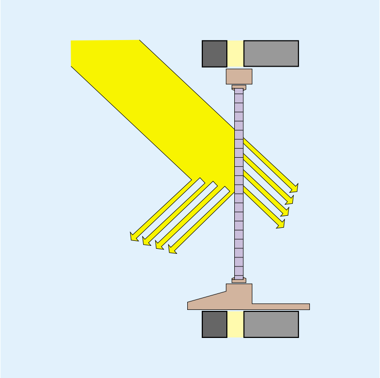
Adjustable external louvres



Internal retractable device



External retractable device



Mid-pane device: venetian blind

Automation of adjustable external shading, if it is to be energy efficient, depends mainly on climate and the frequency of adjustment. Fully automated, adjustable external shading devices can reduce solar heat gain through windows to 10% of that incident on the façade. The main concern with adjustable external shading systems, however, is durability: they require more maintenance and repair than fixed or internal systems.

Retractable Devices

Retractable shading devices may be retracted to the upper or side portion of the window, or totally removed. Internal blinds and curtains fall under this category, as do external devices such as fabric awnings, louvres and shutters. These devices avoid the compromise between adequate shading in summer and adequate sun access in winter. Their use may compromise ventilation requirements when full shading is required during periods of overheating. They can, however, be designed to minimise this effect.

Mid-Pane Devices

Mid-pane shading devices may be located between the panes of a double glazed unit or, in some commercial buildings, within a curtain wall. Such devices, when accompanied by effective ventilation to the outside, combine the advantages of external and internal shades. Heat gains are dissipated to the outside, but the shades are protected from the severity of the outdoor climate. Mid-pane devices are particularly effective in controlling glare.

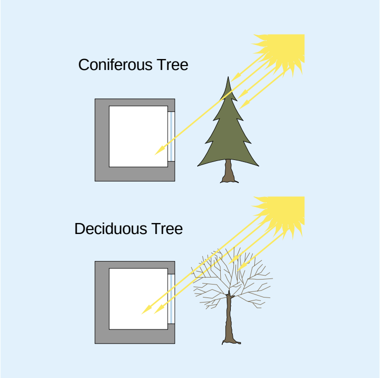
Typically, horizontal reflective louvres or venetian blinds are used. Both control glare but reflective louvres are more effective at preventing solar heat gain.

Vegetation

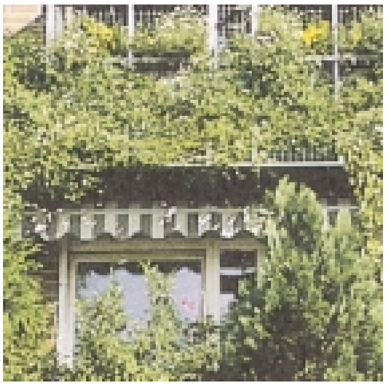
Strategic planting of trees, shrubs and vines about a building and on structures such as pergolas and beam overhangs can, along with urban form, help to modify the microclimate. When correctly applied, the need for internal and external shading devices can be greatly reduced. Selective planting can shade not only windows and other apertures but also whole facades and roofs, reducing conductive as well as radiative heat gains.

By using deciduous trees and vines shading is provided only when needed, in summer. Through the use of evergreens, it can be provided year-round. Vegetation can also be used to reduce ground reflection and, through evapotranspiration, the ambient air temperature. Evergreen shrubs and ground cover are useful for preventing or reducing reflection from roads, paved areas and buildings. Evergreens are also effectively used as wind barriers. Deciduous species are particularly suitable for Europe's temperate climates.

The shading effect of vegetation depends heavily on the plant type (trees, shrubs or vines), species, and age. These factors define the leaf type and the density of the vegetation. In the case of deciduous plants, the density changes from season to season. Givoni[4] records that vegetation affects the internal temperature and cooling load of buildings in various ways as follows:



Solar access to building related to distance of obstructions

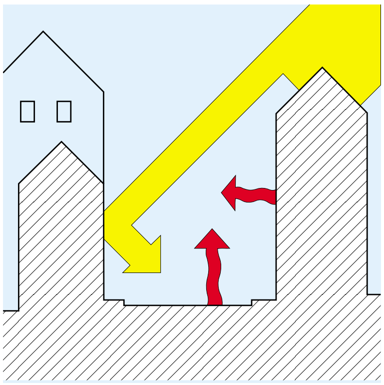


Shading through vine and tree planting (Source: KUKA Kronsberg Environmental Liaison Agency)

1 Tall trees and pergolas situated a short distance from walls and windows will provide shade without significantly reducing ventilation;
2 Vines on walls and high shrubs close to walls will provide shade but also reduce the wind speed next to the walls;
3 The air temperature adjacent to the building's external façade is decreased, thus reducing conductive and infiltration heat gains;
4 Vegetative ground cover around a building reduces reflected solar radiation and longwave radiation emitted toward the walls from the surrounding area, thus lowering the solar and longwave heat gain;
5 Vegetation around the condenser of a building's air conditioning unit can lower the ambient temperature, thereby improving the COP (co-efficient of performance) of the system, so that less electrical power is consumed for a given cooling energy delivered to the building;
6 Vegetation on the eastern and western sides of a building can provide effective protection from solar gain in summer.

During peak summer days the average temperature of walls shaded by trees or a combination of trees and shrubs can be reduced by up to 15^{0}K^{5}. Climbing vines can reduce the temperature by up to 12^{0}K. Givoni's research has found, however, that the insulating capacity of vegetation may, under certain conditions, negate the cooling effects of its shading function. Even in the Mediterranean region the average external surface temperature of a white wall is up to 2^{0}K lower than the average ambient air temperature. Shading the wall by vegetation may be counterproductive since the wall's longwave heat loss will be reduced. The colour of the wall, and the distance between the wall and the vegetation, are therefore of great importance.

Urban Morphology



Shading by neighbouring buildings

In regions experiencing hot summers, the built urban environment is often compact in layout. Streets are narrow and sometimes covered, partially or wholly, by fabric awnings and overhangs during the peak summer season, and shaded by neighbouring buildings at critical times. Sloping ground is also exploited to enhance mutual shading of buildings. The main purpose of such measures is to provide a comfortable outdoor and indoor environment. Such design, however, may lead to poor ventilation and so, like daylighting, ventilation should be considered together with shading. Urban design in cold climates like northern Europe, on the other hand, is influenced more by the need for heating in the winter months.

In the Mediterranean climate, there are two main climatic effects to be considered in building and urban design. First, high ambient air temperature and intense solar radiation during summer produces high heat stress. Second, direct and reflected solar radiation produces very high glare. Well conceived urban design can counter these negative influences to a large extent. The setback distance between buildings, generally represented by the public street, is of chief importance in such design, and may be calculated to provide overshadowing during the cooling season.

Shading through urban design, Portugal (Source: AJ Stack, ERG)

Shading can be achieved not only by optimising street width, but also through the use of courtyards. These can be designed to give both sunlight and shade in harmony with the seasons. Courtyards are a common feature of Mediterranean architecture and can be used to create an entire urban form.

Advanced Glazing Systems

All advanced glazing systems influence the passage of light and heat through glass in some way. Their performance is measured in terms of reflectance, absorptance, transmittance and emittance. Absorptance refers to the ability of an element to absorb solar radiation, reflectance its ability to reflect radiation. Emittance refers to the radiation emitted and is the same as absorptance for the same wavelength (temperature) of radiation. These properties relate to the surface qualities of an element and may apply to both transparent and opaque surfaces. Transmittance refers to the ability of a body to transmit radiation and is a function of thickness as well as surface qualities. It applies only to transparent or translucent elements.

Each of the above properties is quoted by manufacturers, calculated under standard conditions, (i.e. in which the solar radiation is at normal incidence to the glass surface). The transmittance of the glazing element is of foremost importance in calculating cooling load. It comprises three aspects: thermal transmittance, light transmittance and total solar transmittance. The thermal transmittance, (often referred to as the Solar Factor or the Total Transmission), is the longwave radiation emitted from objects and diffuse radiation deriving from the sky vault and the ground passing through the glazed element (U-value). The light transmittance refers to the visible component of the spectrum of the solar radiation passing through the glazed element, and defines the amount of daylight transmitted. The total solar transmittance refers to the direct component of the solar radiation and the longwave radiation absorbed and re-emitted inwards through the glazed element (g-value).

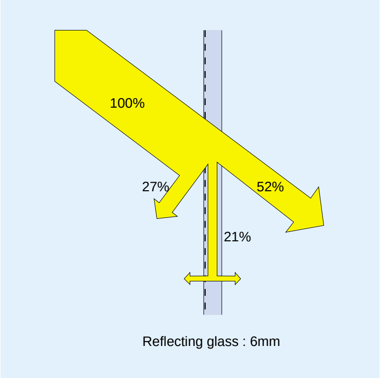

Glass louvre system: Gartner Design offices, Gundelfingen (Source: Gartner & Co.)

	Glazing type	Light Trans.	Total Trans.
1	6 mm float glass	.87	.83
2	bronze absorptive	.12	.32
3	blue reflective	.30	.39
4	green absorptive	.26	.37
5	green high performance	.35	.25

Light & Total Transmittances of various glass types

Advanced glazing systems are used mostly for insulation and shading purposes, but in some cases serve a daylighting function by redirecting sunlight in a similar way to light shelves. They may prove an adequate alternative when traditional shading devices are not an option or, in retrofitting, may improve a poor shading situation. They may involve special treatment of the glass during the manufacturing process, or easily applied external films and coatings. The latter are particularly applicable to retrofitting. Selective glazing has an external surface that responds to radiation from different parts of the spectrum in different ways. The ultraviolet, infrared and visible parts of the spectrum are each influenced separately according to heating and cooling needs. Selective glazing can be selective in transmittance, absorptance and reflectance. It includes tinted, reflective, low-emissivity, responsive and prismatic glass, and holographic film. Fritted glass and glass blocks can also serve a shading function. The technology of advanced glazing systems is developing rapidly with new developments in materials science but many advanced glass types are still at the prototype stage and are limited in their application. Photochromic glass, for example, is used extensively for sunglasses but hardly at all for building purposes.

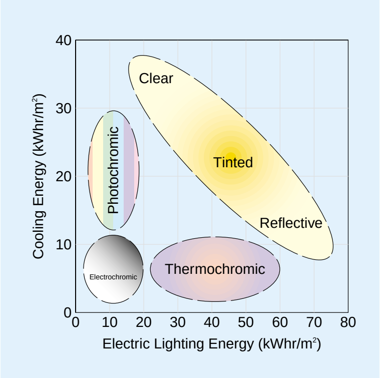
Tinted glazing, which was the first form of glazing developed for shading control, is able to marginally reduce penetration of solar heat gain. However, it tends to reduce daylight significantly. It also discolours the view through the glass.



Reflecting glass 6mm

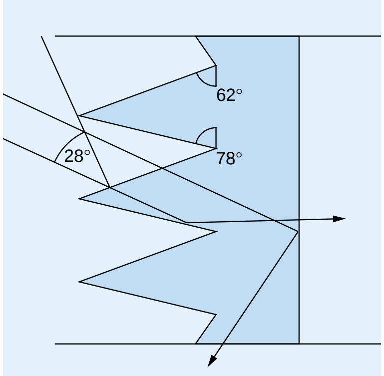
Reflective glazing effectively obstructs solar heat gain but also reduces visible light transmittance.

Low emissivity glazing (commonly referred to as ‘low-e’) can transmit up to 80% of the light falling on it, comparing favourably with single-glazed clear float glass (which transmits 85%). It is used primarily where heat loss from the building is an issue. Low-e glasses demonstrate high absorptance of solar wavelengths, particularly in the visible region, and low emittance of longwave infrared radiation.

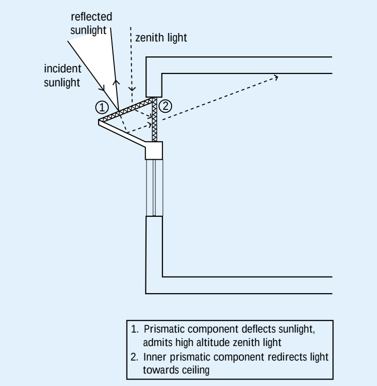


Chromogenic glass

Responsive glasses, or ‘chromogenic glasses’, (sometimes referred to as ‘smart windows’), are selective in transmittance. There are three basic types: those that respond to changes in temperature (thermochromic), those that respond to changes in light (photochromic), and those that change in response to an electric signal (electrochromic). Electrochromic glasses can be connected to a Building Energy Management System. Photochromic glasses can be used for solar control purposes (i.e. daylighting) but not for thermal control as they only react to radiation in the visible part of the spectrum. They cannot be made using the standard float glass process and are thus expensive.



Prismatic glass



(Source: Daylighting Design,
N. Baker, K.Steemers, 1998)

External device using prismatic component

Daylight Device	Light Transmittance
Low E double glazing	0.65
Double glazing plus	
• Internal light shelf	0.55
• Prismatic film	0.55
• Internal and external light shelves	0.40
• Coated Prismatic glazing	0.30
• Solar control mirrored louvres	0.30

Light transmittances for different daylight components

(Source: BRE Environmental Design Guide
for naturally ventilated and daylit offices,
D. Rennie, F. Parand, 1998)

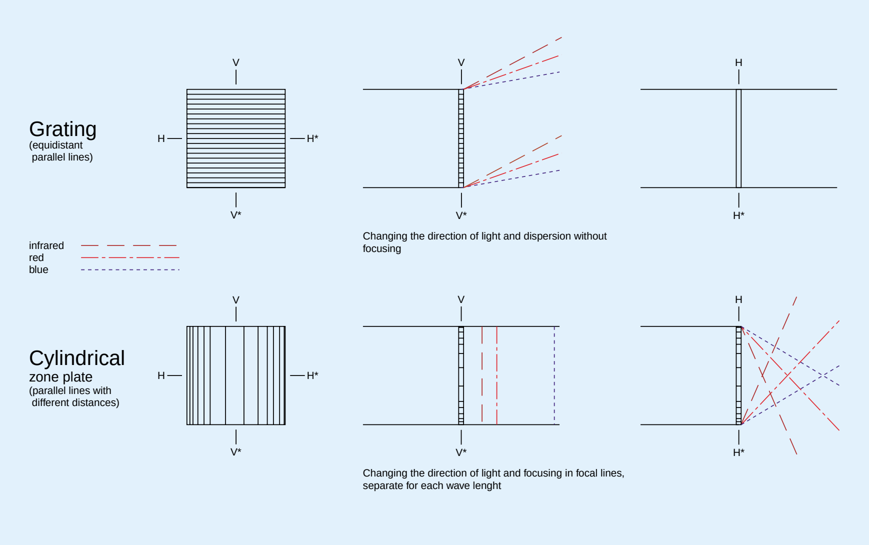
Light transmittances

Transparent louvre system: Gartner Design offices, Gundelfingen (Source: Gartner & Co.)

Prismatic glazing can refract as well as reflect light and thus can be used for daylighting, shading, or both. It is translucent rather than transparent, and is used mainly where daylighting (rather than provision of a view) is the main issue. It is thus most suitable for high level glazing. Its main function is redirection of incoming light to the ceiling or the rear of the room but it can also reduce glare, and is often incorporated into double glazed units. Currently the construction cost of prismatic glass is high but costs may fall as it becomes more widely available.

Holographic optical elements (HOE) diffract, rather than obstruct, incoming radiation and are thus mainly used for daylighting purposes. However, they can be designed for providing shading or to reflect light emanating from extreme angles, such as low angled sun on the West façade. Light diffraction in holographic optical elements is caused by gratings or zone plates embedded in the glass which only work for a chosen sun angle, allowing selective redirection of light.

Recent research has seen HOE applied to external venetian blinds and glass louvres. The two main shading applications involve directional selective shading. In one system, holographic elements in the glass localize direct solar radiation onto opaque strips on the glass. Diffuse light is transmitted but the view out is partially obstructed by the opaque strips. In another, transparent glass louvres are embedded with holographic film that can diffract direct radiation. Again, diffuse light is unobstructed but the transparent louvres maintain the view out.



Changing the direction of light and dispersion without focusing

Changing the direction of light and focusing in focal lines, separate for each wave lenght

Light redirection using HOE (Source: ILB, Cologne)

Due to their inability to work for more than a small range of angles, these systems need to track the sun to achieve optimal performance. They should therefore be mounted on an automated tracking device.

Fritted glass is capable of providing minor shading and light diffusion but can cause glare and prevent a view out.

Combined Daylight and Shading Systems

Light shelves, prismatic glazing and holographic louvres are advanced shading systems insofar as they redirect and redistribute light, thus serving a daylighting as well as a shading function. They are able to redirect sunlight deeper into a space, improving light uniformity. They can also control direct sunlight.

Littlefair[6] tested these devices to judge their performance under a range of conditions. The systems were fitted to the upper window area of a full-scale test room and tested for their ability to:

- increase light levels at the rear of the space;
- improve light uniformity throughout the space; and,
- control direct sunlight.

It was found that the prismatic glass and film can increase rear room illuminance, but only in clear sky conditions and at specific sun angles. All the systems tested improved light uniformity. Prismatic glass was the most effective at controlling unwanted direct sunlight. Only the light shelf was able to shade the lower part of the window.

Other Shading Technologies

Recent advances in materials technology have led to development of transparent insulation materials (TIM) in the form of honeycomb, capillary or aerogel materials. Aerogel (also known as Cloud Gel) is a porous silicate foam which reduces thermal transmision while admitting the visible range of the solar radiation spectrum. It can be inserted between two window panes, and changes from clear to opaque when heated to a pre-determined temperature. It is not totally clear, however, and thus hinders the view out.

There is a current trend towards using more sophisticated technologies that involve holographic or prismatic film and automated sun-tracking devices. Wall-mounted, automated glass louvres embedded with spectrally selective film is an example. Such systems are costly, durability is a concern and maintenance can be difficult. Simple devices, correctly designed, are usually at least as effective as sophisticated systems.

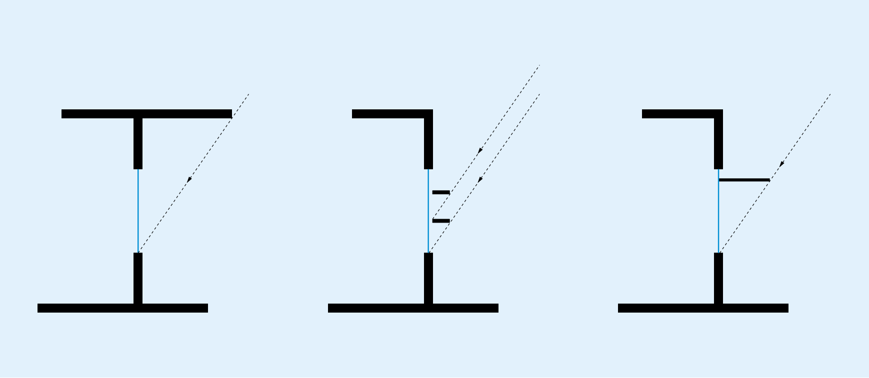
Designing Shading Systems

When designing an external shading system, the sun's movement and influence can be predicted using a number of methods. Laboratories typically use physical models such as the heliodon and the model-mounted sundial, but such methods are beyond the scope of many designers.

Computer software is readily available which ranges widely in nature, complexity and cost. 3D modelling programmes that include algorithms for the sun's movement throughout the year for most latitudes can be used for visualising the overshadowing impact of neighbouring buildings as well as designing shading devices.

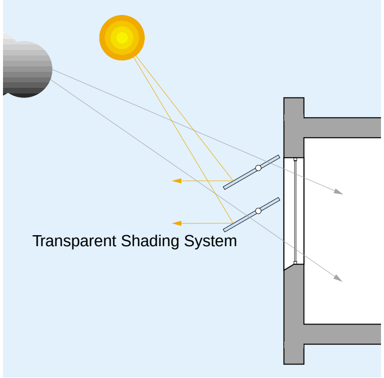
There are three types of manual sun path diagram: the equidistant chart, the orthographic projection and the stereographic projection. The stereographic projection is the most widely used. Shadow masks created using the stereographic projection are a very useful tool in designing shading devices and assessing shadow impact.

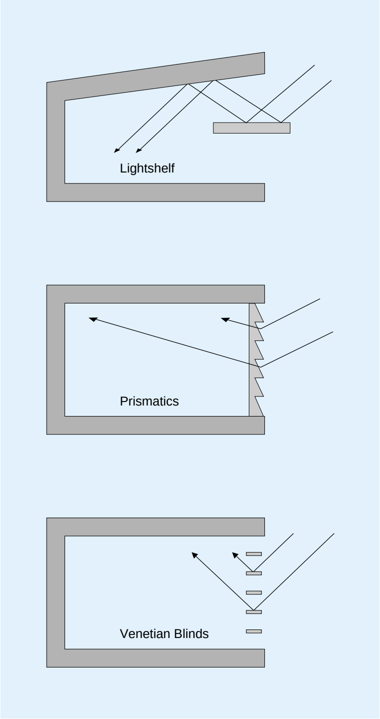
Szokolay[7] has written extensively on solar geometry and shading system design and has identified three basic steps to be taken in the design process:



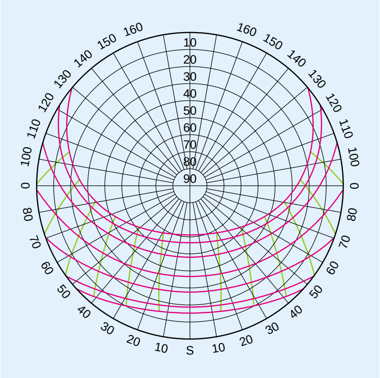
External horizontal devices with similar performance

1. Identify the periods when both seasonal and daily shading is required. Also consider the building type, available thermal mass and internal heat gains;

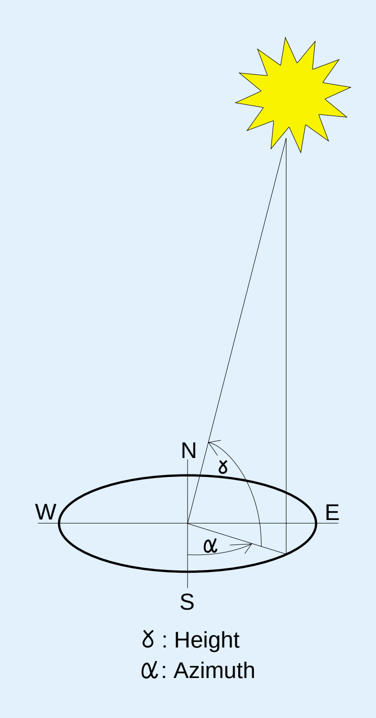




Light Redirection: light shelf, prismatic glass, venetian blind



Sun-path chart for 52° latitude: stereographic projection



Sun's position: Azimuth & Altitude

2. Calculate the performance required of the device by establishing the necessary horizontal and / or vertical shadow angles;

3. Design the shading device to meet the performance requirements.

Once the performance requirements are determined the designer can choose from a wide range of devices. Although individual devices vary in size and shape, the performance of each remains unchanged since the solar geometry remains the same. Thus, a wide range of devices will perform similarly under similar conditions, leaving the designer great freedom of choice.

To use sun-path diagrams effectively, a simple understanding of shadow angles, solar geometry and solar time is needed.

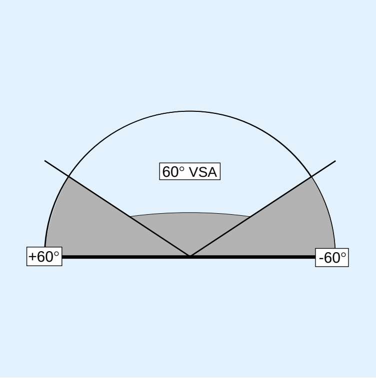
Solar Geometry

Regarding solar geometry, all that is required of the designer is to understand the sun's apparent movement (lococentric view), as opposed to the earth's orbit about the sun (heliocentric view). The heliocentric view explains the true orbital relationship between the sun and earth and considers the earth's elliptical orbit, its tilt, and the declination angle. The lococentric view is a simplified model in which the earth is assumed to be flat and the sky a hemispherical vault. The sun's position on this imaginary sky vault is defined in terms of the altitude angle and the azimuth angle, using solar time. The altitude angle is measured from the horizon (the zenith = 90°). The azimuth angle is measured in the horizontal plane from North (0°) through East (90°), South (180°) and West (270°).

Solar Time

Because of the human constructions of latitude, longitude and reference time zones, solar time does not equate directly with the local clock time of each time zone. Only at the reference longitude of each time zone do they coincide. The 360° circumference of the earth, in terms of time, represents 24 hours. One hour thus equals 15° longitude, or 4 minutes equals 1° longitude. Hence, reference longitude 120° is 8 hours ahead of Universal Time (often referred to as the Greenwich Mean Time). The solar time at this longitude coincides with normal local clock time. Longitude 124°, however, is four degrees beyond the reference longitude and the associated local clock time. The 4° difference means that the local clock time is 16 minutes ahead of solar time. The daily times given on sun-path diagrams refer to solar time.

Horizontal and Vertical Shadow Angles

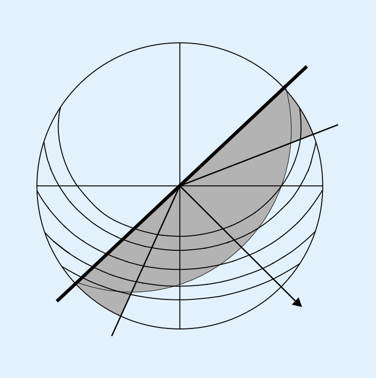


Solar protractor diagram with HSA and VSA values

The Horizontal Shadow Angle (HSA) refers to the difference in azimuth between the sun position and the orientation of the building face considered. It describes the performance of a vertical shading device.

The Vertical Shadow Angle (VSA) is measured on a plane perpendicular to the building face and describes the performance of a horizontal shading device.

The HSA and VSA values can be plotted on a solar protractor, which shows arcual lines for VSA values and radial lines for HSA values.



Sunpath diagram with solar protractor

The solar protractor is then superimposed over the relevant latitude sun-path diagram to read dates and hours of shading.

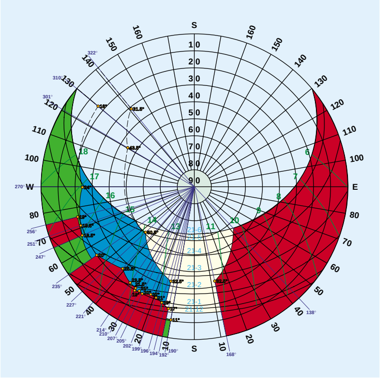
Overshadowing

The shadowing impact of neighbouring buildings can be assessed using sun-path diagrams. The PLEA Notes on Solar Geometry[7] provide a full description of the method. The basic steps are:

1. Receipt of all necessary information such as Dimensioned Plans, Sections and Elevations for all existing and proposed buildings. Site plan with all necessary levels;

2. Selection of critical points in surrounding environment at which potential overshadowing is to be calculated;
3. Plotting of sun's path and azimuth angles for each chosen point on site plan using a solar protractor;
4. Measurement of distances between chosen points and proposed and existing buildings;
5. Calculation of altitude angles of all proposed and existing buildings in relation to chosen points;
6. Plotting of calculated altitude and azimuth angles on relevant sun-path diagram;
7. Completion of sun-path diagram.

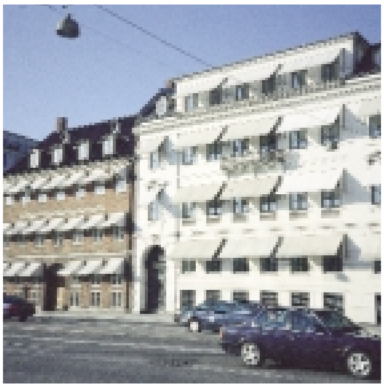
Computer software is available for assessing overshadowing impact of neighbouring buildings. The output is usually in the form of two-dimensional images of the site in plan set against a stereographic projection for the relevant latitute. Such software is limited, however, by a lack of modelling ability, and the output images can be of low quality.



Example completed sun-path chart for overshadowing

Retrofitting Shading Systems

Shading systems can often be retrofitted into existing buildings to advantage, particularly as part of an overall energy retrofit programme. Existing buildings with excessive glazing and poor insulation against solar heat gain stand to benefit most from such an approach. Because of the wide variety and range of shading systems available, a device can generally be found to suit a particular situation. Most types of shading system, internal and external, can be used in retrofitting. The most common are internal devices such as blinds and curtains, and holographic and prismatic films and coatings. Although most effective when integrated into the overall design, external devices can also be applied to existing buildings. They have been used in many instances to improve the thermal performance of over-glazed buildings.



Retrofit: retractable fabric awnings (Source: J Goulding, ERG)

Evaluation of Shading Systems

At present there is no standard method for the evaluation of shading systems. The wide range and diversity of devices on offer is undoubtedly a reason for this. Various methods with different approaches are used for evaluating performance, based on calculation of solar gain to the space, or internal light levels.

The shading coefficient is a highly useful concept for evaluation purposes. It is the ratio of the total solar radiation entering through the combination glass-shading element to that entering a single unshaded glass window. It should be considered as an approximate value, as the position of the sun, and the proportion of the direct and diffuse solar radiation incident on the shading system, changes throughout the day.

Computer Visualisation

Shading systems can also be tested for their impact on daylighting and internal illuminance. Raytracing and radiosity rendering are two inexpensive computer methods that can be used to calculate internal illuminance. They use global illumination algorithms that calculate the transfer of light between surfaces in a space.

- Raytracing. This computer method calculates illuminance by tracing the light rays backwards from the eye, through each pixel on the monitor, and into the computer model. It can accurately account for direct illumination, shadows, specular reflections and refraction. However, it does not account well for indirect illumination, which it defines in terms of an arbitrary "ambient light" value. Raytracing is view-dependent: the calculation process must be repeated when the view is changed.

- Radiosity. This is an iterative process that calculates the luminance of surface points in the space and accounts for indirect illumination. All surfaces are assumed Lambertian (ideal diffuse) and thus reflect light evenly in all directions. The luminous flux of each surface is determined by Lambert's cosine law. Radiosity is view-independent: the geometry of the model contains the light data and thus can be viewed from any angle.

Manual Methods

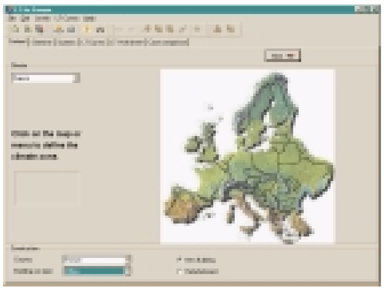
The LT Method (Lighting and Thermal), developed initially in 1989 by The Martin Centre for Architectural and Urban Studies, University of Cambridge for the EC Architectural Ideas Competition 'Working in the City', is a strategic energy design tool that allows the designer to predict energy consumption for a proposed building at the early design stage. It is sensitive to parameters such as building plan and section, orientation and glazing ratio, and provides an output of annual primary energy use and CO^2 production for the end uses of heating, lighting and cooling. A more recent development is the prediction of overheating risk in naturally ventilated buildings.

To date, seven variations of the LT Method have been developed for specific building types and climates. The LT Method 3.0 was developed in 1994 specifically for office and retail buildings in southern Europe. It takes into account the effect of shading on the thermal performance of the building under analysis. Two distinct shading device categories are defined:-

Type A
(1) Moveable shading which is only in place when there is a cooling load; or,
(2) Fixed shading which is so designed that it does not reduce the daylighting at the back of the room and still permits useful solar gains in winter.

Type B
Fixed shading which reduces solar gain in summer, daylight, and solar gain in winter, by an equal and fixed fraction.

The effect of the above shading types on heating, lighting and cooling is determined. The effect of shading due to adjacent buildings is also calculated but overshadowing effect should be determined using other analytical tools such as sunpath diagrams.



LT Europe interface

The EU-funded LT Europe project aims to establish the use of the LT Method on a pan-European basis, and in the form of a computer interface. One of the declared objectives of the LT Europe project is to adequately assess the use of daylight from sunny skies and the effect of shading devices.

The interface is a major step in the development of LT since although previous versions have relied on computer models to generate data, the actual interface has been on paper (i.e. graphs and tables). The new computer interface maintains the transparency and educative quality of the paper version in structure and appearance, but is far more powerful. It is planned to launch a pilot version at the Passive and Low Energy Architecture conference (PLEA 2000) to be held in Cambridge in July 2000.

Tsangrassoulis[9] et al. developed a method for assessing shading systems based on daylight coefficients. From these coefficients the internal illuminance of a space under various sky conditions can be calculated. The method has been validated with measurements taken from a PASSYS test cell, an instrumented room for building component testing. In brief, the daylight coefficient is defined as the ratio between the luminance of a patch of sky, and the illuminance in the space due to light from that patch. The sky vault can be divided into zones of altitude and azimuth and a daylight coefficient assigned to each zone. The total illuminance at a particular point in the space can then be calculated using a simple formula. The method can account for specular, diffuse, combined specular/diffuse surfaces, and reflective and diffusing glass. It compares well with raytracing and radiosity methods.

Salazar[10] developed in 1995 a method for evaluating shading devices which gives qualitative comparisons between various shading options, and allows for quick and accurate assessment of the most suitable solution. Some years earlier, the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) developed a system for evaluating the efficiency of shading devices. This method was able to evaluate rectangular windows with vertical and horizontal shading devices but more complex window designs and shading devices could not be tested. Salazar's method allows one to predict the performance of any type of shading device for any latitude at any time of the year. Internal comfort levels can be determined and a cost-benefit analysis calculated.

Conclusions

Ludwig-Erhard-Haus, Berlin-Charlottenburg (Source: Gartner & Co.)

- Shading devices should be able to moderate or control direct, diffuse and reflected solar radiation, and glare, whilst ensuring that daylighting and natural ventilation are not excessively reduced.

- Shading devices may be designed to protect opaque as well as transparent surfaces.

- Shading devices that both protect against solar radiation and redistribute daylight can reduce cooling loads and the use of artificial lighting.

- For visual comfort, good daylight distribution is important.

- Fixed shading devices are effective in excluding summer sun but admit low angled winter sun. They can reduce internal illuminance in cloudy conditions. They give minimal control of diffuse and reflected light.

- Internal devices should be considered in terms of daylighting and glare control, since they can control diffuse and reflected light.

- External adjustable shading can provide shading without reducing internal light levels, and is effective in controlling low angled direct sunlight, diffuse and reflected light, and glare. It must be robust enough to resist wind damage.

- Retractable shading devices may reduce ventilation when deployed to provide full shading during the cooling season.

- Mid-pane shading devices provide effective glare control, and are protected from weathering.

- Vegetation can shade whole facades and roofs, reducing conductive as well as radiative heat gains. Evergreen species can be used to reduce reflection from water bodies, roads, paved areas and buildings.

- The shading effect of vegetation depends strongly on the type, the species, and the age of the plant.

- Advanced glazing should not normally be considered as a complete shading solution, but can improve a building's shading performance when used in conjunction with other devices. Window films are highly applicable in a retrofit situation.

- Simple devices, correctly designed, are often as effective as hi-tech systems.

- A wide range of devices will meet similar performance requirements.

Beyeler Foundation Museum, Riehen, SWITZERLAND

CREDITS

Year built: 1997
Building function: museum building
Floor area: 2,200m^2
No. floors: one storey

Climate
Latitude: 47°30’N
Longitude: 07°36’E
July mean sunshine duration: 750 hours
January mean sunshine duration: 90 hours
July mean solar radiation: 5797 Wh/m^2
January mean solar radiation: 832 Wh/m^2

Client: Beyeler Foundation
Architect: Renzo Piano Building Workshop
Consulting Engineers: Ove Arup and Partners (structural, services, façade)

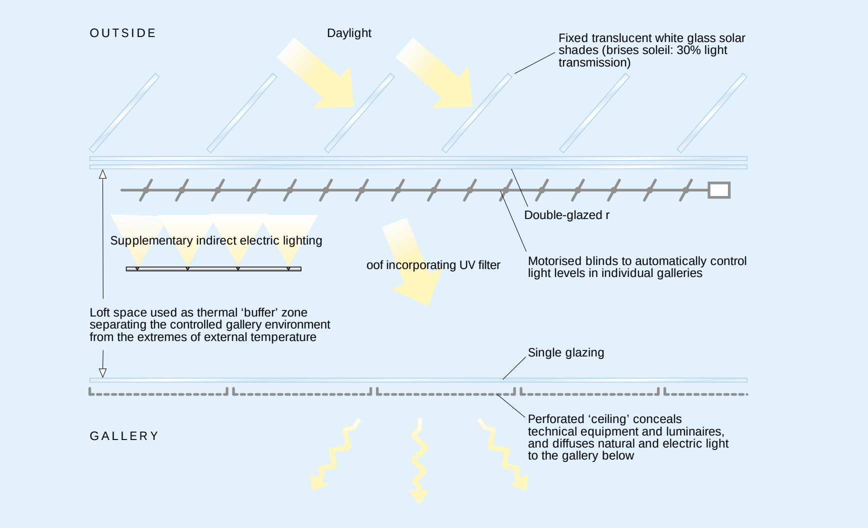
Shading Strategy: UV-resistant double-glazed roof, inclined fritted glass brises soleil, motorised adjustable louvres, perforated metal ceiling panels.

The Beyeler Foundation Museum has an active shading system utilising a number of shading and daylighting devices. The roof is of particular interest, being multi-layered and comprising inclined fritted glass brises soleil, a flat clear double-glazed roof, motorised adjustable louvres, and a perforated metal ceiling. These elements allow for good daylighting in overcast conditions and good solar control in sunny conditions. A steel roof structure supports the glass ceiling, the internal louvres, the double glazing and the posts that hold the brises soleil. The building comprises four monumental parallel walls (long axis east-west) and glazed end walls. The light roof structure provides a large overhang around the building perimeter.

The fritted glass brises soleil, which have 30% light transmission, are designed to block direct solar access and admit diffuse light from the sky vault. The double-glazed roof beneath the brises soleil is weather resistant and reflects potentially damaging ultraviolet light. The motorised aluminium louvres immediately below the double-glazed roof control the amount of incoming light and are operated via a computerised management system. When the museum is closed the louvres are closed to prevent unwanted light penetration. During summer the louvres and external brises soleil together can prevent up to 98% of incident solar radiation from entering the display areas.

The perforated metal panels situated below the motorised louvres serve two functions: to screen the complex roof structure above, and to provide even light distribution in the spaces below.

Source: Ove Arup & Partners



Josef Gartner & Co Design Offices, Gundelfingen, GERMANY

CREDITS

Year built: June 1997
Building function: open-plan design offices
No. floors: two storeys

Climate
Latitude: 49°N
Longitude: 11°E
July mean sunshine duration: 760 hours
January mean sunshine duration: 140 hours
July mean solar radiation: 5464 Wh/m^2
January mean solar radiation: 978 Wh/m^2

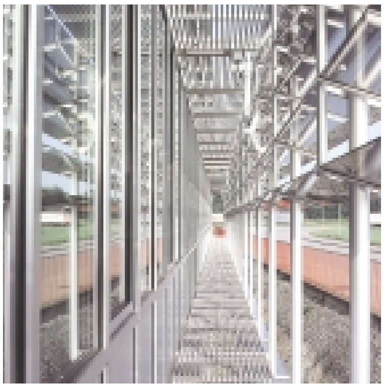
Client: Josef Gartner & Son, Gundelfingen, Germany.
Architect: Kurt Ackermann und Partner.
Engineers: Bernhard Behringer, Walter Muller (structural); Buro Dr. Karl Pitscheider (mechanical); Karl Gertis, Walter E. Fuchs (environmental engineering)

Shading Strategy: external motorised louvres, retractable louvre blinds, infra-red resistant glazed curtain wall, manually-operated internal fabric blinds.

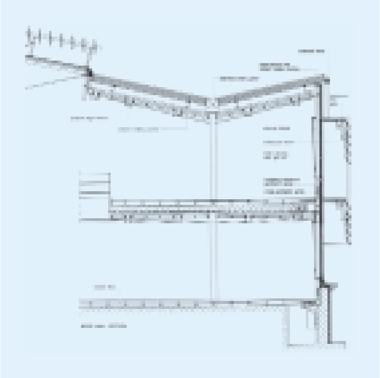
These offices employ some state-of-the-art high-tech solar control devices to achieve a comfortable indoor environment. External motorised louvres, retractable louvre blinds, curtain walling comprising infrared-reflecting layers, and internal blinds, are used for solar radiation control. External motorised louvres of heat-strengthened reflective glass are used on the walls and roof. Approximately 14 percent of incident light is transmitted and thus the louvres are able to block shortwave radiation while still allowing unobstructed views to the outside. When tilted horizontally they are able reflect the diffuse light of overcast days onto the ceiling and thus have a daylighting function.

The clerestory glazing above the motorised louvres is protected by retractable louvre blinds and the atrium is protected by an overhead louvre system. This motorised overhead system is composed of broad blades and is thus able to provide effective shading when the blades are in a vertical position. A computerised building management system (BMS) is used. The BMS adjusts the angle of external louvres and blinds for daylighting or shading as required according to information on sun angle and intensity gathered from light sensors.

The curtain walling system is composed of triple-glazing with two layers of infrared reflecting glass. Argon gas is used between the glazing elements. Tubular steel sections support the glazing elements and include a water-carrying element for radiant heating and cooling. Glare protection is provided by interior fabric blinds



Source: Gartner & Co.



Source: Gartner & Co.

LNEC - Laboratorio Nacional de Engenharia Civil, Main Building, Lisbon, PORTUGAL

Shading Strategy: retractable external awnings, manually-operated internal venetian fabric blinds.

LNEC is a public institution engaged in civil engineering research and is situated in a dense urban environment in the northern part of Lisbon. Built in 1950, it comprises three storeys and has rooms facing south and north off central corridors. The main façade faces south. There are also wings facing east and west. Recent retrofitting has used traditional shading strategies: retractable external awnings on the south façade and internal venetian blinds provide effective solar and glare control.

The tilted external awnings are manually operated by the maintenance department of LNEC twice annually. At the beginning of the cold season, they are retracted to allow for direct solar penetration. At the end of the cold season, they are extended for shading. Internal venetian blinds are used for controlling glare and daylight levels, and are manually operated by the occupants. The blinds also prevent direct solar access through the sides of the external awnings. The awnings attenuate diffuse skylight by 70%.

CREDITS

Building function: multi-purpose building
Year built: 1950
Floor area: 7,000m^2
No. floors: three storeys (plus a basement)

Climate
Latitude: 38°46’N
Longitude: 09°08’W
Altitude: 100m
Summer mean temperature: 22.6°C
Winter mean temperature: 10.5°C
Summer average cloud cover (in tenths): 3
Winter average cloud cover (in tenths): 6
July solar radiation: 7535 Wh/m^2
January solar radiation: 1991 Wh/m^2

Client: Laboratorio Nacional de Engenharia Civil, Lisbon, Portugal.
Architect: Porfirio Pardal Monteiro

Source: LNEC

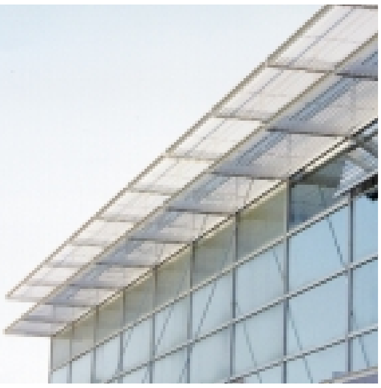
Source: LNEC

CREDITS

Year built: 1997
Building function: Aquatic displays and laboratories
No. floors: five levels

Climate
Latitude: 38°46'N
Longitude: 09°08'W
Altitude: 100m
July mean temperature: 22.6°C
January mean temperature: 10.5°C
July average cloud cover (in tenths): 3
January average cloud cover (in tenths): 6
July solar radiation: 7535 Wh/m^2
January solar radiation: 1991 Wh/m^2

Promoter: Parque Expo '98/IDEA
Architect: Cambridge Seven Associates
Consulting Engineers: Ove Arup and Partners (structural, services, fire safety, façade, geotech)
Associate Engineers: Antonio da Fonseca (AFA)



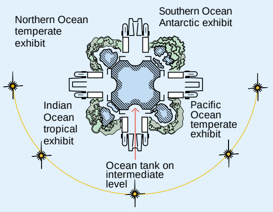
Source: Ove Arup & Partners

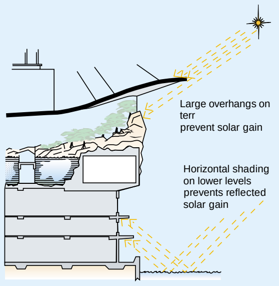
The Lisbon Oceanographic Centre. Lisbon, PORTUGAL

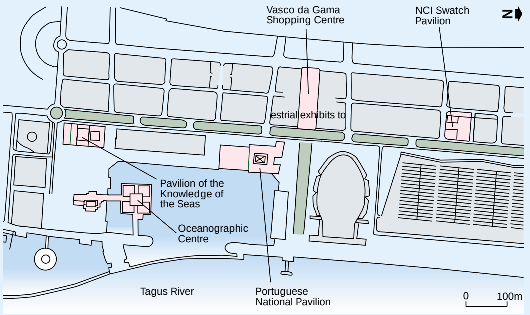
Shading Strategy: fixed glazed roof overhang, fixed external horizontal shading devices.

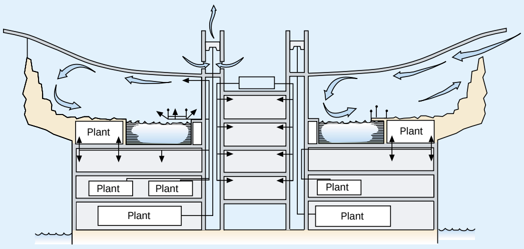
The Lisbon Oceanographic Centre is the second largest aquarium in the world and comprises four main areas: Northern Ocean temperate exhibit, Southern Ocean Antarctic exhibit, Pacific Ocean temperate exhibit, and Indian Ocean tropical exhibit. Building orientation, facade characteristics and roof performance were studied to provide the best internal conditions. Protection against solar gain was a major consideration in the design. Large fixed overhangs and horizontal shading devices are employed to control direct and reflected solar radiation. A 4m wide glazed louvred overhang is used to protect against direct solar radiation. The roof glazing is varied to provide the required average shading co-efficient. Horizontal shading devices with a low-reflectivity underside are used on the lower levels for protection against reflected radiation.

The Southern Ocean exhibit, in which internal conditions need to be maintained at between 6°C and 18°C on a seasonal basis, is oriented to the north-east to reduce the effect of solar radiation. The walls achieve an overall shading co-efficient of 0.5, and the roof 0.25. The Northern Ocean exhibit requires the same internal conditions as the Southern Ocean exhibit and is oriented to the north-west to reduce solar penetration. Again, overall shading co-efficients for the walls and roof are 0.5 and 0.25 respectively. The Pacific Ocean temperate exhibit also requires internal conditions of between 6°C and 18°C and is oriented to the south-east. An overall shading co-efficient of 1.0 for the walls and 0.39 for the roof has been achieved. The Indian Ocean exhibit requires internal conditions between 20°C and 32°C seasonally and an overall shading co-efficient of 1.0 for the walls and 0.39 for the roof has been achieved.









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NOTICE TO THE READER

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The overall objective of the European Union's energy policy is to help ensure a sustainable energy system for Europe's citizens and businesses, by supporting and promoting secure energy supplies of high service quality at competitive prices and in an environmentally compatible way. The European Commission Directorate-General Energy & Transport initiates, coordinates and manages energy policy actions at transnational level in the fields of solid fuels, oil and gas, electricity, nuclear energy, renewable energy sources and the efficient use of energy. The most important actions concern maintaining and enhancing security of energy supply and international cooperation, strengthening the integrity of energy markets and promoting sustainable development in the energy field.

A central policy instrument is support and promotion of energy research, technological development and demonstration (RTD), principally through the ENERGIE sub-programme (jointly managed with the Directorate-General Research) within the theme "Energy, Environment and Sustainable Development" under the European Union's Fifth Framework Programme for RTD. This contributes to sustainable development by focusing on key activities crucial for social well-being and economic competitiveness in Europe.

Other programmes managed by Directorate-General Energy & Transport, such as SAVE, ALTENER and SYNERGY, focus on accelerating the market uptake of cleaner and more efficient energy systems through legal, administrative, promotional and structural change measures on a trans-regional basis. As part of the wider Energy Framework Programme, they logically complement and reinforce the impacts of ENERGIE.

The internet website address for the Fifth Framework Programme is
http://www.cordis.lu/fp5/home.html

Further information on Directorate-General Energy & Transport activities is available at the internet website address
http://europa.eu.int/en/comm/dg17/dg17home.htm

This maxibrochure is available for downloading as a .pdf file at the internet website address
http://erg.ucd.ie/erg_downloads.html

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