



Solar Shading

How to integrate solar shading
in sustainable buildings

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Federation of European Heating, Ventilation and Air-conditioning Associations

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**How to integrate solar shading in
sustainable buildings**

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REHVA –

Federation of European Heating, Ventilation and Air-Conditioning Associations

REHVA, now almost 50 years old, is an organization of European professionals in the field of building services (heating, ventilation and air-conditioning). REHVA represents more than 100 000 experts from 28 European countries.

REHVA's main activity is to develop and disseminate economical, energy efficient and healthy technology for mechanical services of buildings. The work is supervised by the board of directors. REHVA Guidebook projects are coordinated by the Technology and Research Committee of REHVA.

Several task forces are currently working on REHVA Guidebooks, such as: Indoor Environment in Museums, Indoor Environmental Investigations, Indoor Environment and Energy Efficiency in Schools, New Air Distribution Systems, Radiant Heating, and many others.

Solar radiation is an important issue in all building projects as it has such a significant impact on the indoor environment and affects the design of HVAC systems. Selection of solar shading should always be one of the first steps in the design of HVAC systems, as the demand for power and the energy consumption are greatly influenced by solar shading. Shading makes it possible to prevent extra solar heat from entering the building and to avoid the need for additional cooling to remove this heat, which costs precious energy. In winter time, however, the free heat from the sun is very welcome to reduce the building's heating cost.

The integration of solar shading in building HVAC-systems is more and more important in the future to optimise the investment and operation costs of buildings.

This guidebook gives solid background information on the physics of solar radiation and its behaviour in windows equipped with solar shading systems. The major focus of the book is on the effect of solar shading on the use of energy for cooling, heating and lighting. Practical guidance is offered for the selection, installation and operation of solar shading systems as well as information on future trends in integration of HVAC-systems and solar control.

This guidebook is developed as a common project between REHVA and ES-SO. It is a good example of how two different disciplines working together can produce something new for the benefit of the whole building industry and the building users.

The REHVA Board would like to express its sincere gratitude to ES-SO and the working group for this invaluable work. REHVA would also like to express its gratitude to the companies that indirectly supported the work by allowing and encouraging their experts to participate in this work.

Olli Seppänen

Secretary General

Chair of the Technology and Research Committee (TRC)

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This book has been written by a group of people from the solar shading industry, assisted by experts from REHVA for a number of subjects. The working group had numerous discussions and meetings between October 2008 and April 2010. The following experts were involved:

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Foreword

This book is about solar shading and its influence on the energy balance and energy consumption of a building. As buildings account for almost 40% of total primary energy use in Europe, pressure has grown to make them more energy-efficient. The savings potential is huge: many existing buildings today consume more than 250 kWh/m².a, whereas state-of-the-art technology in modern buildings shows figures well below 100 kWh/m².a. Several countries are working on legislation limiting maximum energy use to 50 kWh/m².a by the year 2015 or shortly after that. At the same time, passive house technology is gaining market share and the Recast EPBD, as adopted by the European authorities, says that all new constructions should be ‘nearly zero energy’ from 2019 onwards.

Solar shading is a term we use to cover all methods of controlling the entry of solar light and energy, ranging from shade trees over fixed awnings to fully automated blinds and shutters. Outdoor weather conditions – light and heat – can change constantly in the course of a single day. That is why, in the context of this book, the emphasis will be on automated solar shading systems (blinds, awnings, shutters, etc) because only an automatically controlled system will be able to adapt to these rapidly changing outdoor conditions.

Controlling the entry of solar heat and light will have a considerable effect on the energy needs of a building, as we will demonstrate. However, solar shading is

but one element of the building’s envelope, along with glazing, window frames, walls, roofs and floors.

The selection of the best solar shading system must be made in the early design stage of the building process in order for automated solar shading to help reduce energy consumption. Many factors must be taken into account, such as the outdoor climate and the immediate environment, but also the orientation of the building, the user profile and many others. Building physics will show how each of these factors have their effect. Building simulation software may quantify these effects.

Solar shading must be installed by professionals; experience shows that in the installation stage, mistakes must be prevented to secure the expected results. Another subject is maintenance: sometimes owners consider solar shading systems, especially when they are external, like the bricks and concrete of the building: you just don’t look after them. But systems with moving parts need to be taken care of by regular maintenance.

These and other aspects will be discussed in this book. We hope you will find it of interest.

Dick Dolmans
Secretary General
ES-SO – European Solar-Shading
Organization

Absorptance

The ratio of absorbed to incident radiation. Usually denoted by a letter A or α . A subscript e denotes *energetic* (full solar spectrum). Subscript v denotes *visual*.

ACH – air changes per hour

The number of room volumes of outdoor air supplied to the room per hour.

BMS

A Building Management System is a computer-based system that controls and monitors a building's mechanical and electrical installations, fire alarms and security systems.

Cooling demand

The integrated cooling load over a total year in kWh or MJ. This is often expressed in terms of energy per square meter per annum (year): kWh/m².a.

Cooling load

This is the instantaneous cooling rate required to keep the building “in balance” at a specific temperature level (e.g. a design temperature of 25.0°C). Expressed in W or W/m². Note: this is in thermal terms, regardless of the efficiencies (COP) of the cooling system.

Candela (cd)

Unit of luminous intensity, 1 cd = 1 lm/sr or 1 lumen per steradian.

Candela per square meter (cd/m²)

Unit of luminance: the amount of visible light in a given direction, the measure of brightness.

Diffuse radiation

Solar radiation received indirectly as a result of scattering due to clouds, fog, haze, dust, or other obstructions in the atmosphere or on the ground.

Emissivity

Emissivity is a number between 0 and 1 giving the fraction of radiated power emitted by a substance, compared to the power emitted by an ideal black body radiator at the same temperature.

Energy (J)

One Joule (J) is the work done, or energy expended, by a force of one Newton moving one meter along the direction of the force. This quantity is also denoted as a Newton-meter with the symbol Nm.

Energy use (kWh)

A unit or measure of electricity supply or consumption of one thousand watts acting over a period of one hour. The kWh is a unit of energy. 1 kWh = 3600 kJ = 3412 Btu. The energy delivered by electric utilities is usually expressed and charged for in kWh.

EPBD

The Energy Performance of Buildings Directive, an EU Directive of late 2002 aiming at improving the energy performance of buildings, strengthened and accelerated in 2009 by the ‘Recast EPBD’.

g-value

A number between 0 and 1 which represents the sum of primary transmittance and secondary transmittance to a room. The secondary transmittance is the ratio between solar radiation and the part of the solar energy absorbed in the window/solar shade materials, which reaches the room through convection or as (thermal) radiation. (See also: equation 3.1). The g-value is also referred to as the total solar energy transmittance or solar factor. In North America it is referred to as the solar heat gain coefficient (SHGC).

Illuminance (lx)

The total luminous flux, incident on a surface, per unit area. Expressed in $lx = lm/m^2$.

Incident solar energy (W/m^2)

The amount of solar radiation striking a surface per unit of time and area, expressed as W/m^2 . Also referred to as irradiance.

Heating load

The instantaneous heating rate required to keep the building “in balance” at a specific minimum comfort temperature level e.g. a design temperature of $21.0^{\circ}C$. (Without taking into account the effectiveness of the heating system). Expressed in W or W/m^2 .

Internal heat gain

Heat originating from persons, computers, artificial lighting and any other sources, which add heat to the room. Given in W or W/m^2 .

Lumen (lm)

Lumen (lm) is the SI unit for luminous flux. This is the radiative flux within the range of 380-780 nm, weighted by the relative sensitivity of the eye, the so-called photopic luminosity function. Lumens can be viewed as ‘weighted watts’.

Long wave infrared radiation

Part of the electromagnetic spectrum with a wavelength between 8000 and 15000 nm, corresponding to the radiation of objects at room temperature. Normal glazing is not transparent to this radiation.

Luminance

Luminance is measured in cd/m^2 and is a property of extended (direct and indirect) light sources. Luminance is defined as the luminous power per unit area per unit solid angle. This is the luminous flux in lumen emitted by a small patch in a certain direction within a certain solid angle.

Luminous efficacy

The ratio of the luminous flux of a light source to the total power. Depending on context, the power can be either the radiant flux of the source’s output, or it can be the total electric power consumed by the source. For example, a typical incandescent light bulb

may have a luminous efficacy of 12 lm/W. Average natural daylight has a luminous efficacy of about 100 lm/W.

Lux (lx)

The SI unit for illuminance. This is the luminous flux in lm per m². 1 lx = 1 lm/m². klx denotes 1000 lx.

Nanometer (nm)

Used for expressing wavelengths. One nanometer is 1.10⁻⁹ m or one billionth of a meter. A human hair is over 100,000 nm thick.

Near Infrared or Short Wave Infrared

Part of the electromagnetic spectrum of sunlight with a wavelength between 780 and 2500 nm. Normal glazing is transparent to this radiation.

Openness Factor or OF

The openness factor of a fabric is the ratio of the area of the open spaces between the fibres to the total area. It is usually expressed as a percentage. Standard EN 14500 states that it may be approximated as the value of normal-direct visible transmittance.

Operative Temperature

The operative temperature is the uniform temperature of a radiant black body enclosure in which an occupant would exchange the same amount of heat as in the actual non-uniform environment (ISO 7730).

PMV

Predicted Mean Vote is an index that predicts the mean value of the votes of a large group of persons on a 7-point thermal sensation scale.

Power (W)

Watt is the SI unit of power, equal to one joule of energy per second. It measures a rate of energy conversion.

PPD

Predicted Percentage of Dissatisfied predicts the percentage of a large group of people likely to feel either too warm or too cold.

Reflectance

The ratio of reflected to incident radiation. Usually denoted by a letter R or ρ . A subscript *e* denotes *energetic* (full solar spectrum). Subscript *v* denotes *visual*.

R-Value

The inverse of the U-value, or the thermal resistance coefficient, expressed in Km²/W. The bigger the number, the better the material's insulating properties.

Shading coefficient (SC)

A measure of the ability of a window, or window with solar shading device, to transmit solar heat, relative to that ability for 3 mm clear, single glass. Is being phased out in favour of the g-value (in the US: solar heat gain coefficient or SHGC), and is approximately equal to the g-value multiplied by 1.15.

Solar Heat Gain Coefficient

The fraction of solar radiation admitted through a window, or window with solar shading device, both directly transmitted, and absorbed and subsequently released inward. The lower the number, the better the window is at blocking heat gain. Has replaced the shading coefficient as the standard indicator of a window's shading ability. In Europe this is the g-value.

Solar transmittance

A number between 0 and 1 representing the ratio of the directly transmitted solar radiation to the incident solar radiation.

Steradian (sr)

Unit of solid angle. The solid angle is the angle in three-dimensional space that an object subtends at a point. It is a measure of how big that object appears to an observer looking from that point.

Transmittance

The ratio of transmitted to incident energy. Usually denoted by a letter T or τ . A subscript *e* denotes *energetic*, i.e. solar transmittance (full solar spectrum). Subscript *v* denotes *visual*.

U-value

The U-value describes how well a building material transports heat (through all three modes of heat transfer). It measures the rate of heat transfer through a material per unit of area per unit of temperature difference between the two surfaces of the material. The unit is W/m²K. It is the measure in W of how much heat flows through 1 m² of a medium in an attempt to reach thermal equilibrium when there is a 1 K temperature difference between the two sides. Also termed the thermal transmittance.

Ventilation

The supply of fresh outside air to a room, expressed in ach, l/s or l/s m².

W

Watt – SI-unit of power. 1 W = 1 J/s.

2 SOLAR RADIATION

Summary

In the built environment, solar radiation is one of the dominant energy fluxes. For a building, the solar energy flux is highly dynamic. Yet a building must be capable of providing a stable indoor environment under all circumstances. This chapter provides basic background information on the nature, magnitude and variability of solar radiation.

2.1 The sun

Our sun produces an enormous amount of energy: 3.85×10^{26} Joules per second (W). Of that, the amount that reaches the earth is about 1.74×10^{17} W (or 174 PW or petawatts). Comparing this to the annual energy consumption of all mankind, which is about 5×10^{20} J, it follows that the earth (at the top of the atmosphere) receives this amount of energy in about three quarters of an hour. In other words, if we could harness the sun's energy only partially, our worries in that area would be over.

On average, at the top of the atmosphere the solar irradiance measured in a plane perpendicular to the solar rays is 1366 W/m^2 . At sea level it is obviously much less due to atmospheric absorption

and scattering. Under optimal conditions it may reach values of the order of 1000 W/m^2 .

2.2 The solar spectrum

Figure 2.1 gives the solar spectrum as measured by a satellite at the top of the atmosphere (red line) and the spectrum at sea level (blue line). Upon passage through the atmosphere, solar radiation is subject to absorption by several atmospheric gases. The atmosphere predominantly absorbs blue light which is then re-emitted in all directions, explaining the blue colour of the diffuse sky. In addition to gas molecules, radiation may also be scattered by molecules and particles of different types, including aerosols of water, dust and smoke.

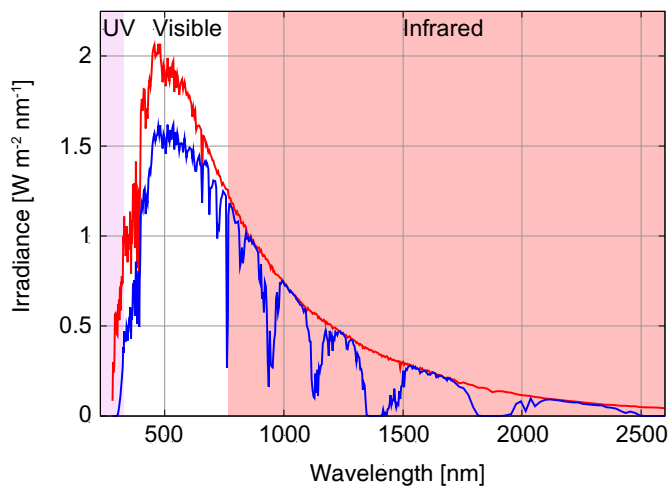


Figure 2.1 The solar spectrum at the top of the atmosphere (red), and at sea level (blue). [ASTM]

As can be seen in Figure 2.1, the solar spectrum at sea level extends from about 320 nm in the ultraviolet to 2500 nm in the infrared. Outside that range, the solar irradiance is negligible. Visible light ranges from 380 nm (violet) to 780 nm (red).

At sea level, about 53% of the spectral power lies within the visible range, 5% lies in the ultraviolet and the remaining 42% lies in the infrared. This distribution is air mass dependent and therefore varies with the height of the sun.

The solar radiation in the infrared range 780 – 2500 nm is often referred to as short wave infrared. This radiation is to be distinguished from long wave or thermal infrared radiation. The latter is emitted by all objects in our everyday environment. This radiation extends from about 5,000 nm beyond 25,000 nm and is strongest at wavelengths of about 10,000 nm or 10 μm . Whereas normal glass is transparent to short wave infrared, it is opaque to long wave infrared. So, solar energy that enters a room through a window and is absorbed by objects inside the room, cannot escape as thermal radiation through the windows. Heat in the room builds up: the greenhouse effect.

2.3 Solar angles

The amount of solar energy incident on a window depends on solar angles. These angles also determine whether or not direct solar energy even reaches the window. For example, in the summer, eaves

or overhangs can block the sun from entering south facing windows.

Because the axis of the earth's rotation is tilted 23.5° relative to the plane of its orbit around the sun, solar angles for a specific location change every day. On 21 June at solar noon, the sun is straight overhead at the tropic of Cancer. On 21 December the same is true at the tropic of Capricorn.

Figure 2.3 shows the angles of incidence on a south-facing window for a building at latitude of 40° North. Notice how much more solar energy is incident on the south-facing window in winter than in summer. This is ideal to passively heat the home. The bottom part of the diagram shows the breadth of solar exposure as degrees of earth rotation, along with the directional starting and ending points of the sun's arc in the sky. This effect is also shown in Figure 2.2.

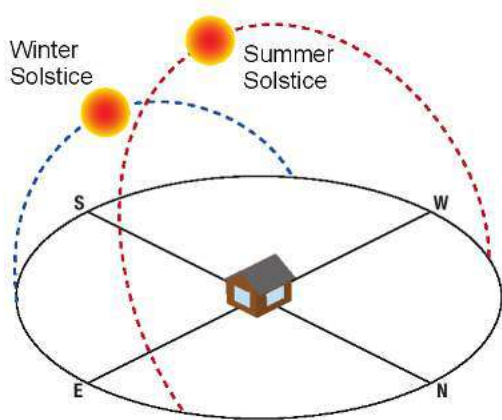


Figure 2.2 The solar paths for the winter and summer solstices.

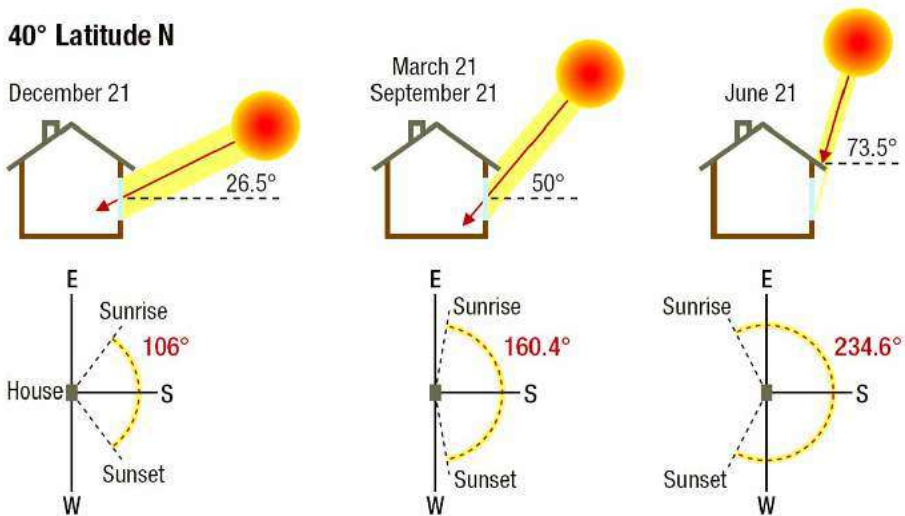


Figure 2.3 Top: Solar angles for a south oriented window. Below: Breadth of solar exposure.

2.4 Solar irradiance

Solar irradiance on an arbitrarily oriented surface under clear sky conditions consists of three components:

- direct radiation from the sun,
- diffuse radiation from the sky, and
- reflected radiation from the ground and other surrounding objects.

On a horizontal surface, the third component is zero and the direct radiation is normally by far the strongest component. Only at sunrise and sunset this may not be the case.

Figure 2.4 shows examples of the radiation intensity on vertical surfaces in various directions on cloudless days in summer (21 June) and winter (21 December) at a latitude of 50° N. These charts give us a fairly good impression of the maximum amount of solar power per square meter that can be expected on the different façades. Irradiance will normally be less under less favourable conditions,

such as clouds and atmospheric pollution. Note that at other latitudes these graphs will be different. In Europe the general pattern is the same. In particular, for more northern latitudes the winter curves will generally be lower. For more southern latitudes the reverse is true.

In practical situations – even under perfect clear sky conditions – irradiance will usually be less than indicated in Figure 2.4 due to the modelling assumptions. In computing the diffuse sky component for instance, the implicit assumption is that the surface sees exactly half of the sky hemisphere. In practical situations, part of the sky will be blocked by neighbouring buildings.

Irradiance on a north facing façade is indeed fairly flat. This is why northern light is preferred by most painters. In summer, early in the morning and late in the afternoon, there is a limited amount of direct solar irradiance. Irradiance in winter is limited at all times.

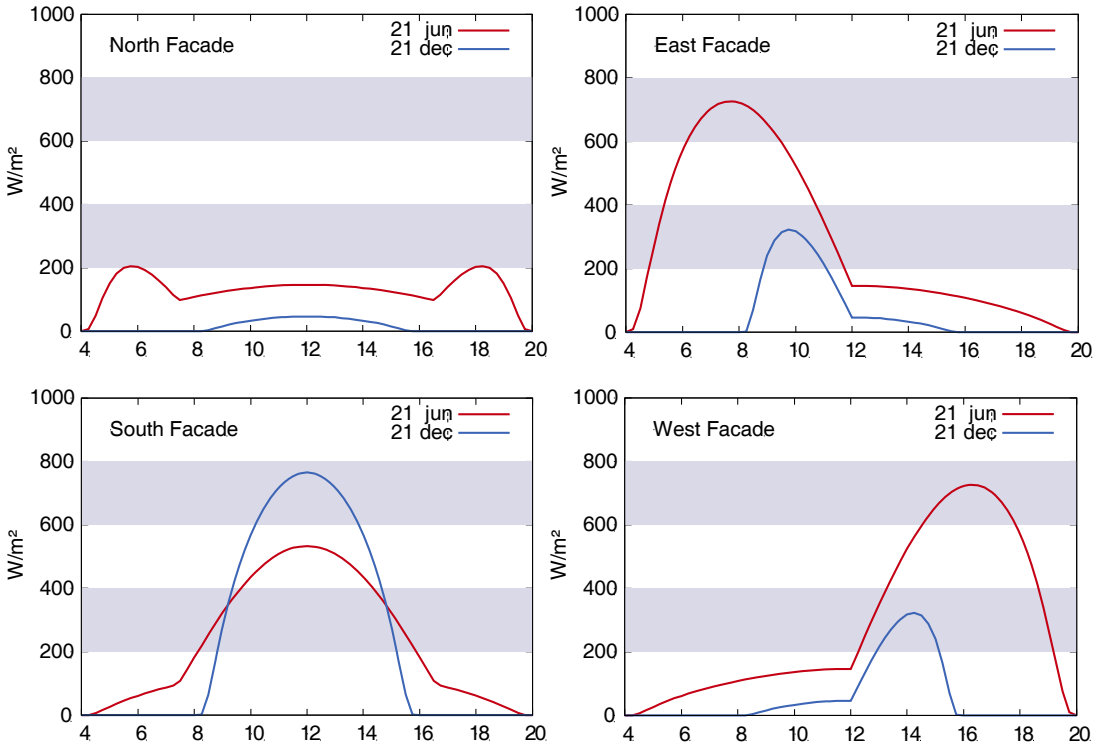


Figure 2.4 Top row: Irradiance in W/m^2 on vertical surfaces oriented north and east, respectively. Bottom row: Irradiance on vertical surfaces oriented south and west, respectively. Horizontal axis: local solar time in hours. Graphs computed for 50° latitude north, using the ASHRAE clear sky model and a ground reflectivity of 0.2.

For the east facing façade in summer, we see strong irradiance until solar noon. Here, direct solar irradiance is the main component. After solar noon, there is only diffuse sky and reflected ground irradiance. This graph clearly shows that two hours after sunrise, irradiance reaches quite significant levels. A practical consequence is that an east façade fitted with external solar shading will show the best results when automated. Most offices will not have personnel lowering the screens for the entire building at 7:00 am.

In the graph for the south facing façade, we see the effect that irradiance on a vertical

surface in winter can be higher than in summer. This is the case for latitudes below about 56° N. In summer the irradiance on a south oriented surface early in the morning and late in the afternoon is limited and is mainly due to diffuse sky irradiance.

For the west facing façade, we see a similar pattern as for the east facing façade. This time strong irradiance occurs during the afternoon. In summer, the west façade is normally the most demanding from a solar shading perspective, because the ambient air will normally be warm and the building will have received solar energy during the whole day.

3 EFFECT OF WINDOWS ON THE INDOOR ENVIRONMENT

Summary

Windows have a significant impact on indoor environmental quality. Indoor environmental quality can be characterized by four main dimensions: thermal comfort, visual comfort, acoustic comfort and indoor air quality. The first two dimensions are strongly influenced by windows, because windows bring in light and heat. In this chapter we focus on these two dimensions and review the quite significant correlations between good indoor environmental quality and worker productivity.

As windows bring in natural daylight, they are also the pivotal elements in daylighting strategies. Such strategies can be very effective in reducing the use of electric energy.

The last section of this chapter compares the economic effectiveness of seemingly minor increases in productivity with the value of energy savings.

3.1 Thermal Comfort

Often the thermal conditions in a room are characterised with the term ‘room temperature’. However, the thermal sensation of the body reacts to the combination of the room air temperature and the temperatures of the surrounding surfaces. The combined effect is often expressed as the operative temperature. In practice it is close to the average of air temperature and mean radiant temperature. The latter can be approximated by an average of air temperature and room surface temperatures (exact definitions and methods are given in ISO 7730). The interior surface temperature of windows may differ significantly from the room air temperature and the temperature of other surfaces. Exterior solar shading has an important impact on the window surface temperature, and may significantly improve thermal conditions, particularly in summer.

Temperature has several effects on the occupants of a building:

- Temperature has an effect on the performance of office tasks (Figure 3.1). Too high or low temperatures deterio-

rate work performance. In routine type work, the best temperature range appears to be between 20-24°C, with an optimum of 22°C. [Sepp 2006a]

- High indoor temperatures increase the prevalence of sick building syndrome (SBS) symptoms [Sepp 2006b] and perceived indoor air quality deteriorates.
- High temperatures in classrooms are harmful to performance of schoolwork. In a controlled Danish study the performance of school tasks was found to be better at a temperature of 20°C than 25°C. [Warg 2006a, Warg 2006b]
- Low temperatures decrease the dexterity of hands and may reduce the performance of manual performance.
- Low temperature increases the sensitivity to air movement and draught.
- High temperatures of the air also increase the sensation of dryness of the air.

Solar radiation has effects on thermal comfort in both general and local thermal conditions.

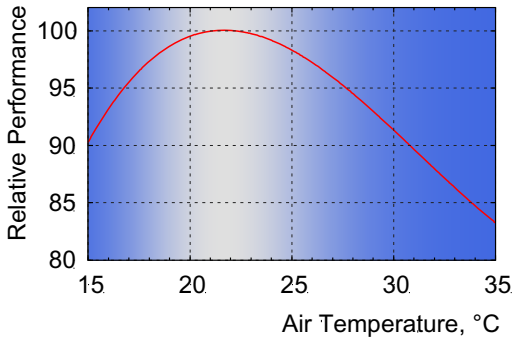


Figure 3.1 Normalised performance versus temperature in the office environment. The relationship is based on 148 data points from studies made in Northern Europe and North America, details in [Sepp 2006b].

The thermal sensation of the body as a whole (general thermal comfort) can be predicted by calculating the predicted mean vote (PMV) index introduced in ISO 7730:2005. The predicted percentage dissatisfied (PPD) index, obtained from the PMV index, provides information on thermal discomfort (thermal dissatisfaction) by predicting the percentage of people likely to feel either too hot or too cold for a given thermal environment. The criterion for an excellent PPD-index is 6% (EN 15251:2007). PPD levels for good and basic comfort are set to 10% and 15%, respectively.

Because solar loads are predominantly confined to areas close to the window, there can be a significant difference between loads close to the window and in internal areas. In open-plan offices, this could lead to several degrees of temperature difference between perimeter and interior areas.

A high temperature of window surfaces increases the radiant load and will generally lead to local discomfort. High temperatures of the interior window pane may

arise under different circumstances. The problem is especially severe in the case of:

- Single pane glazing with or without solar shading;
- Tinted or heat absorbing single glazing;
- Only a single pane of glass between the solar shading and the room.

Section 4.3.1 presents results on window surface temperatures. There it is shown that without shading the temperature of an interior pane of a south oriented window in Amsterdam may well exceed a temperature of 35°C during approximately 350 h in a year.

High window temperatures will also affect the air distribution in a room. In some situations, the convective flow from a warm window can turn a jet down. This can in turn lead to high local air velocities and an increased risk of draught. A model for local discomfort that predicts the percentage of dissatisfied due to draught was introduced by Fanger et al. (1988). An index called draught rating (DR) index was derived as a function of mean air velocity, air temperature and turbulence intensity. A draught rating (DR) lower than 15% is recommended in the standards (EN ISO 7730: 2005, CR 1752: 2001).

3.2 Visual Comfort

There is no doubt that people prefer daylight to electric lighting as their primary source of light. Visual contact with the outside world is also generally recognised as an important factor influencing people's emotional states. Despite these positive aspects of windows and daylight, situations causing visual discomfort can easily arise in a day lit office. Occasionally, light

is just too bright or the contrasts are too large. To fully harvest the benefits of daylight, it needs to be regulated.

Luminance is the physical quantity corresponding to what people call ‘brightness’. As a practical criterion for good visual comfort the 1:3:10 rule is often applied. Good visual comfort is experienced when the luminance within the central field of view is no more than 3 times the luminance of the visual task, and no less than one third of it. Luminance within the peripheral field of view should be within 0.1 and 10 times the luminance level of the visual task. The idea is illustrated in Figure 3.2.

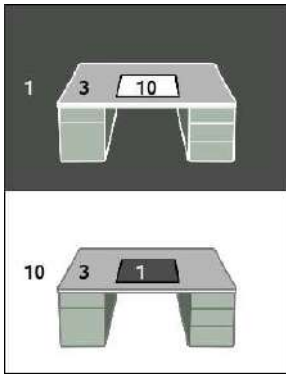


Figure 3.2 Luminance ratios for good visual comfort. In case of artificial lighting (above) and in case of broad daylight (below).

Discomfort glare is caused by high luminance ratios within the field of view. Severe glare may disrupt work and may even cause physiological disorders. Glare is usually caused by direct sunlight falling on objects in the office or high exterior luminance values within the field of view. Glare can also occur when using a computer display. The luminance of the reflection of the surroundings may be higher than the luminance of the computer screen. Without solar shading to attenuate and diffuse direct sunlight, the

conditions for good visual comfort are often violated (Figure 3.3).

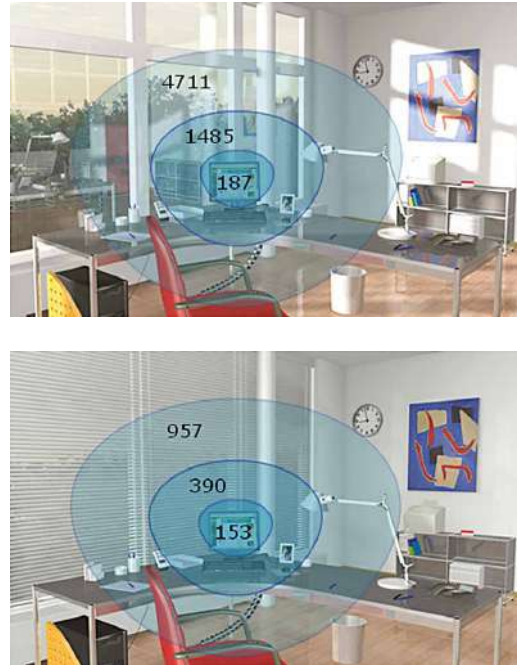


Figure 3.3 Luminance values in an office without (top) and with solar shading (below). Solar shading significantly reduces the luminance ratios, well within the bounds for good visual comfort. [Photos: Somfy]

Visual comfort is also affected by colour rendition. Colour rendition is determined by the spectral composition of the illuminating light source. Unfiltered natural daylight gives by far the best colour rendition.

Contact with the outdoors is an important aspect of visual comfort. Obviously, when lowered, solar shading will at least partially obstruct a view to the outdoors. The degree of obstruction is determined by the openness of the shading. Slatted devices may offer a view through, depending on the slat angle. Smaller slat widths are generally preferred. Screen fabrics will generally have an openness factor of several percent. This usually gives a reasonable

view of the outdoors. Fabrics with a dark interior and a low light transmittance through the fibres are to be preferred from this perspective. In this case, the luminance of the screen itself will be relatively low in comparison with the luminance of the exterior scene visible through the openings in the fabric.

The following is a summary of scientific findings on the influence of the use of daylight on factors related to worker and student productivity.

- By maximizing the use of daylight without glare and providing daylight-responsive lighting controls, a median productivity benefit of 3.75% was found by Carnegie Mellon University. [CMU 2004]
- On average, major health complaints are between 20% and 25% lower for persons close to an exterior window, compared to those that work in the interior core without access to view and daylight. [Hart 1999, Hart 1994]
- Access to windows and daylight resulted in a 15% reduced absenteeism. [Thay 1995]
- Office workers were found to perform 10% to 25% better on tests of mental function and memory recall when they had the best possible view versus those with no view. [Hesh 2003a]
- Direct sun penetration into classrooms, especially through unshaded east or south facing windows, is associated with negative student performance, likely causing both glare and thermal discomfort. [Hesh 2003b]
- Students with adequate natural daylight in their classrooms showed 20% faster progress in math tests and 26% in reading tests during one year. [Hesh 1999]

From the above it may be concluded that natural daylight has a significant and positive influence on occupant health, well-being and productivity. However, adaptive control of daylight is needed to guarantee the conditions of good visual comfort at all times.

3.2.1 Predicting visual comfort

As shown above, daylight is essential for the health, well being and productivity of individuals. Therefore, making sure in an early design stage that there is enough natural – and free – daylight will increase occupant satisfaction and work productivity.

Natural daylight, however, varies enormously in the course of a day or a year: on a bright and sunny summer day, there may be as much as 80,000 or even 100,000 lux, but only minutes later, clouds may reduce this to a fifth or a tenth of that figure. Only a dynamic shading system will allow to control this and to keep the amount of light within comfortable limits and avoid the undesirable side-effects of light: glare, annoying reflections and blinding.

Building physics simulation programs can help in an early design stage to predict how light conditions will be in a given location. Based on orientation, quality and quantity of glass, computer-generated images can be obtained, like the ones shown in Figure 3.4, either human sensitive or false colour, to show both illuminance (lux) and luminance values (cd/m^2 , brightness and contrast), for various views. Physical ray tracing techniques were used to accurately compute the luminance of each polygon in the scene below, in this case around 20,000 in total.

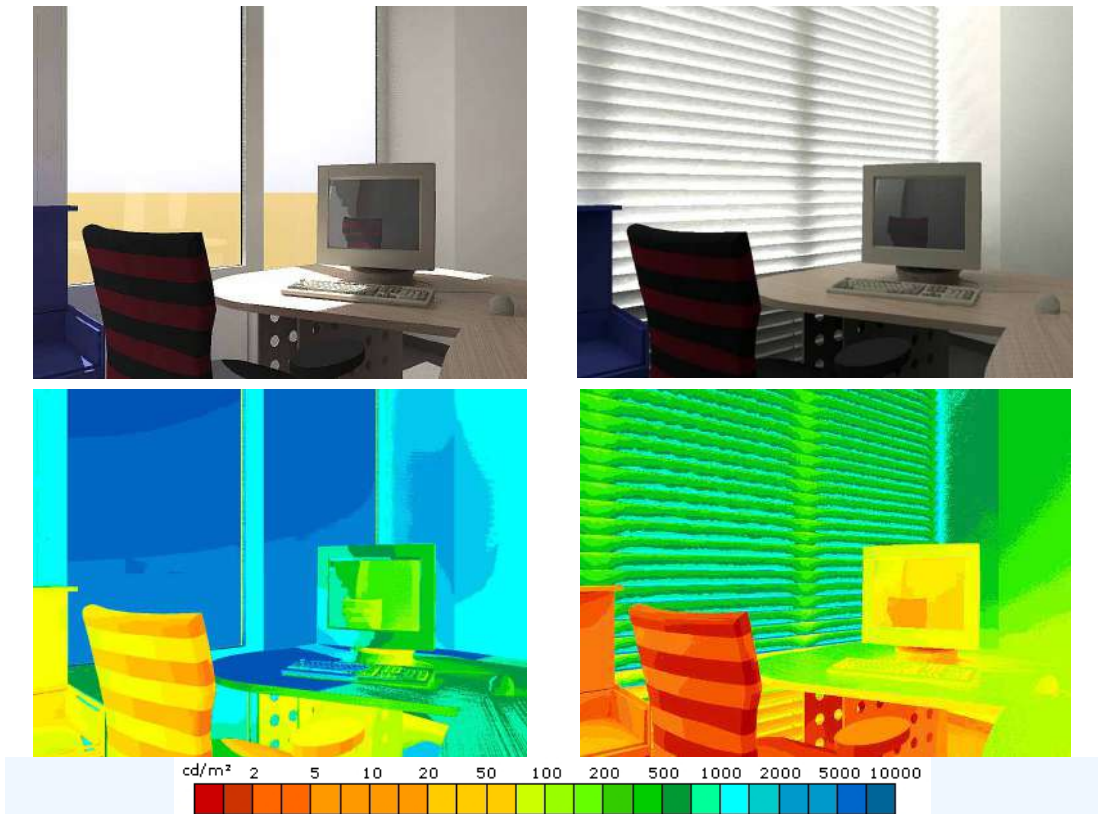


Figure 3.4 Top: human visible images for an office without shading (left) and an office equipped with a Venetian blind. Bottom: Luminance coded in false colours for the same offices. Without shading, the luminance ratio between the window and the computer screen is 45, whereas the ratio between office desk and computer screen is 22. With shading these ratios are reduced to 5 and 1.2, respectively. Without shading the luminance of the computer screen is only 1.2 times the luminance of the reflections of the room. With shading this factor increases to 2.8. [Photos: Hunter Douglas, Helioscreen]

3.3 Acoustics

Interior solar shading can have a limited, yet positive effect on room acoustics. This is especially true for devices made from woven or non-woven fabrics. These products may add acoustic absorption to a room and will reduce reverberation time.

When closed, exterior roller shutters may significantly reduce the transmission of exterior sound to the interior. One of the prime factors influencing the acoustic performance is the distance between the

shutter and the glazing. Distances above 10 cm are to be preferred.

3.4 Indoor air quality

Building design and operation influence the indoor air quality, and thus indirectly affect health and productivity. The mechanisms by which indoor air quality affects health and performance are not yet thoroughly known. Poor indoor air quality is related to allergic and asthma symptoms, airborne respiratory infections, odour and irritation. Several studies show

the effects of indoor air quality on the performance of office work [Warg 1999, Warg 2000]. The most widespread indoor causes and sources for these health impacts are: occupant activities, building materials, equipment and furnishing, pollutants from the outdoors and badly maintained ventilation systems.

Solar radiation and solar shading are linked to indoor air quality mainly through thermal effects. Solar radiation through unprotected window surfaces raises the room air temperature as well as the temperature of building structures and the window surface.

Perceived air quality is related to productivity. Increasing dissatisfaction with air quality means reduced productivity. Studies [Fang 2004] have shown that the dissatisfaction with air quality increases with higher room air temperatures. Preventing high room temperatures with solar shading therefore improves the perceived air quality and productivity.

One of the main indoor sources of air pollutants are the building materials. They emit various chemicals to the room air, depending on their composition. The emission rate from materials increases with temperature. Preventing high temperatures decreases these emissions and improves the air quality. Solar shading itself may also emit various substances. This is an important aspect to consider when selecting shading fabrics. There are various certification programs for products with low chemical emissions, such as Greenguard.

The temperature of the interior surface of a window will increase with the level of

incident solar radiation. A surface at a higher temperature than room air will cause convective air flows in the room. These flows may distract the air distribution in the room and spread the pollutants in a harmful way. In addition these air currents may change the flow pattern in the room and cause draught.

Solar shading can have an adverse effect on indoor air quality when inappropriately applied in combination with provisions for natural ventilation. This may be the case when an exterior screen covers ventilation openings. That may result in a decreased supply of fresh air.

3.5 Daylighting

High performance daylighting entails both the integration of solar control and occupancy- and daylight-responsive lighting controls, but also glare control by daylight redirection and diffusion. The use of daylight reduces the need for artificial lighting. Less artificial lighting translates into reduced cooling loads. Daylight carries relatively little heat per quantity of visible light. This is usually expressed by the luminous efficacy in lumen per watt. There is no artificial full spectrum source of light that approaches the luminous efficacy of daylight.

Solar shading is an important enabler of daylighting as it regulates the flow of both direct solar radiation and diffuse radiation. Illuminance levels by direct sunlight in summer may be as high as 100,000 lx. Inside an office one seldom needs more than 1000 lx. Direct sunlight or directly lit patches in the field of view of an occupant can cause glare. Attenuating and diffusing the incoming light re-

duces the chances of glare and may also bring light deeper into the space. This is an important function that is especially well performed by interior solar shading.

There are quite a few well-documented studies on the actual savings from daylighting.

- An often quoted case is Lockheed Building 157, a five story 53,400 sq.m building in Sunnyvale, which was designed for daylighting, using tall exterior windows, light shelves, and sloped ceilings to provide enough high-quality daylight to reduce the building's artificial lighting use by 75%. [Thay 1995]
- Gurtekin, Hartkopf and Loftness of Carnegie Mellon University report an average of 52% lighting energy savings due to high performance daylighting systems. Their analysis was based on six case studies. [Gurt 2004]
- Lee and Selkowitz report similar savings in a 9-month monitored field

study in New York for south orientations. Automation proved particularly important: “The large savings and good reliability can be attributed to the automatic management of the interior shades.” [Lee 2006]

Quite significant percentages! Especially if you recognize that in a typical office building on the order of 30-40 percent of electric energy is spent on lighting. [Warg 2006]

3.6 The impact of productivity

In sections 3.1 and 3.2 we saw that good indoor environmental quality typically has a positive effect of several percent on productivity. One may ask: “What is the significance of one percent productivity increase?” In general, this impact is strongly underestimated. Figure 3.5 gives a partial decomposition of operating expense for a typical office building.

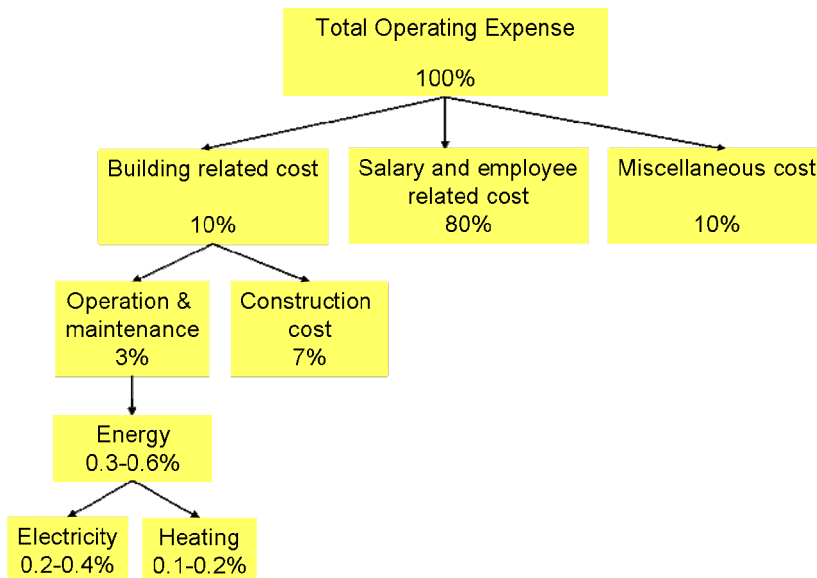


Figure 3.5 Decomposition of the operating expense in a typical office building. Data from [Warg 2006].

In the average office building, over 80% of the total operating expense are salaries and personnel related costs. Approximately 10% of the operating expense are building related costs. About 30% thereof is for operation and maintenance. The other 70% are for amortisation of building costs. The costs for energy generally lie in the range of 0.3% to 0.6%.

Productivity increases have an impact on the 80% for salary and employee related costs. A productivity increase of 1% translates into 0.8% of the total operating ex-

pense. As can be seen in Figure 3.5, this may be more than the total cost for energy. Along the same lines, a 1% increase in productivity would easily outweigh a 5% increase in initial building costs.

REHVA Guidebook no. 6 “Indoor Climate and Productivity in Offices” [Warg 2006] presents a quantitative model that allows one to assess the trade-offs between investments and productivity. From the above, it may be clear that relatively minor productivity increases have a large economic impact.

Summary

In this chapter we look at the physical characteristics of window systems. First, we look at the physical quantities characterising a window. These quantities are then linked to the thermal and spectral properties of glass. Finally, we look at the energy flows through a combination of glazing and a shading device.

4.1 Glass

Glass has been used for hundreds of years to allow daylight into our buildings, while providing weather protection. During the past 50 years there have been significant developments in glazing. Float glass was developed during the fifties of the last century. In this process molten glass is poured onto a bed of molten tin at a temperature of 1,000 C. During the 1960s double glazing was developed. This resulted in about twice the insulation value of single glazing, hence half the U-value. A further development was the use of gasses with lower thermal conductivity in the cavity between the two panes, notably Argon and Krypton. The application of special coatings such as low emissivity coatings and spectrally selective coatings are of more recent dates. Today, there is a large choice in glazing. This allows tuning the building's physical properties to the particular situation at hand.

There are three quantities that are of particular importance when characterizing glass:

- The **thermal transmittance** or U-value expressed in W/m^2K describes how well a glazing unit transports heat as the result of a temperature difference between the outdoors and the indoors.
- The **light transmittance** T_v or τ_v gives the percentage of visible light that is transmitted through the glazing unit.

- The **g-value**, the total solar energy transmittance, sometimes called solar factor or solar heat gain coefficient (SHGC), gives the percentage of the incident solar energy that eventually reaches the interior as heat.

The transmission of radiation through any glazing unit is determined by the spectral characteristics of the constituent glass layers.

The norm EN-410 describes how to calculate the light transmittance and g-value from spectral data. The computer program WIS [WIS 2006] computes all three quantities from the thermal and spectral properties of the components. WIS implements most of ISO 15099 "Thermal Performance of Windows, Doors and Shading Devices - Detailed Calculations." The calculation of the U-value which WIS performs is defined in EN 673.

Below, we briefly review the characteristics of common types of glazing. Table 4.1 lists the characteristics of some common glazing types.

4.1.1 Standard double glazing

Standard double glazing consists of two float glass panes separated by a closed cavity of between 6 and 16 mm. Glass is a fairly good conductor of heat. The thermal insulation of a double glazing unit derives for the larger part from the insulation of

thin boundary layers of air at each glass surface. The U-value of double glazing with an air filled cavity is about half the value of single glass: 2.8 W/m²K. Filling the cavity with Argon or Krypton reduces the U-value by a further 0.2 to 0.3 W/m²K.

Figure 4.1-a shows the wavelength dependent transmittance (T), reflectance (R) and absorptance (A) of 4-12-4 double glazing.

Table 4.1 Representative characteristics of common glazing types.

Type	U [W/m ² K]	g _{glass}	τ _v
Single clear 6mm	5.7	0.86	0.89
Double clear 4-12-4	2.8	0.76	0.81
Double clear low-e 4-12-4 Air	1.5	0.66	0.77
Double clear low-e 4-12-4 Argon	1.3	0.66	0.77
Solar control glass 6-16-6 Argon	1.1	0.34	0.59
Triple clear 4-6-4-6-4 Argon	1.9	0.67	0.73
Triple clear low-e 4-12-4-12-4 Argon	0.6	0.60	0.74

4.1.2 Low-e glazing

One of the most important innovations in glazing has been the development of the low-e coating. Low-e stands for low emissivity. A low-e coating consists of a very thin layer of metal oxide, usually tin or silver, that is applied under vacuum conditions. Such a coating has an effect on both the optical and the thermal properties of a glazing unit.

The thermal effect derives from the low emissivity of such a layer. Whereas the emissivity of normal glass is about 0.84, a low-e coating may have an emissivity of as low as 0.03. A low-e coating may be

applied at either position 2 or 3 of the integrated glazing unit¹. The low-e coating reduces the radiative energy transfer from the inner pane to the outer pane by a factor of more than 20. Because radiative energy transfer is the dominant transport mechanism in an integrated glazing unit, the U-value is almost halved: from 2.8 W/m²K to 1.5 W/m²K. Using argon in the cavity instead of air, further lowers the U-value to about 1.1 W/m²K.

The low-e coating also has an effect on the optical properties of the glazing unit. Figure 4.1-b shows the spectral properties of low-e double glazing. Comparing this to Figure 4.1-a, we see that the transmittance for the visible wavelengths is about the same, whereas in the infrared it is reduced relative to the uncoated glazing. Reflectance is increased in the infrared. In the case shown, this results in a lower g-value: 0.66 compared to 0.76 for the uncoated glazing.

Low-e coatings exist in different chemical compositions with different optical and emissive properties. Indium-doped tin oxides have emissivities of ~0.15 and high solar transmittance. This is usually applied at position 2. Silver solar control coatings may have emissivities in the range 0.03 – 0.1 and are usually also located on position 2.

4.1.3 Heat absorbing glazing

Heat absorbing glazing is obtained when metal oxides are added to the glass. Such glazing typically has very high absorptance in the near infrared, and can reach

¹ Positions are counted from the exterior to the interior. Position 1 is the exterior surface of the outermost pane, position 2 the inner surface of the exterior pane etc.

very high temperatures. This has a detrimental effect on the performance of air distribution under mid-season and peak load conditions. An imbalance between radiative temperatures and air temperatures can be produced, resulting in thermal discomfort. In this sense, heat absorbing glazing is a troublesome solution from the 1970s, that has largely been abandoned in favour of reflective glazing or exterior shading.

4.1.4 Solar control glazing

The name solar control glass is given to a wide range of double glazing. All of these combine a reasonable visible transmittance

with a low g-value. These characteristics can be achieved in various ways.

1. Using a heat absorbing outer pane;
2. Using a spectrally selective coating at position 2;
3. Using a spectrally selective low-e coating at position 3;
4. Using an outer pane with high infrared reflectivity.

Figure 4.1-d shows the spectral properties of solar control glass with high near infrared reflectance. For this glass, the visual transmittance coefficient $\tau_v = 0.59$ and the g-value is $g = 0.34$. Using argon in a 16 mm cavity, the U-value is $1.1 \text{ W/m}^2\text{K}$.

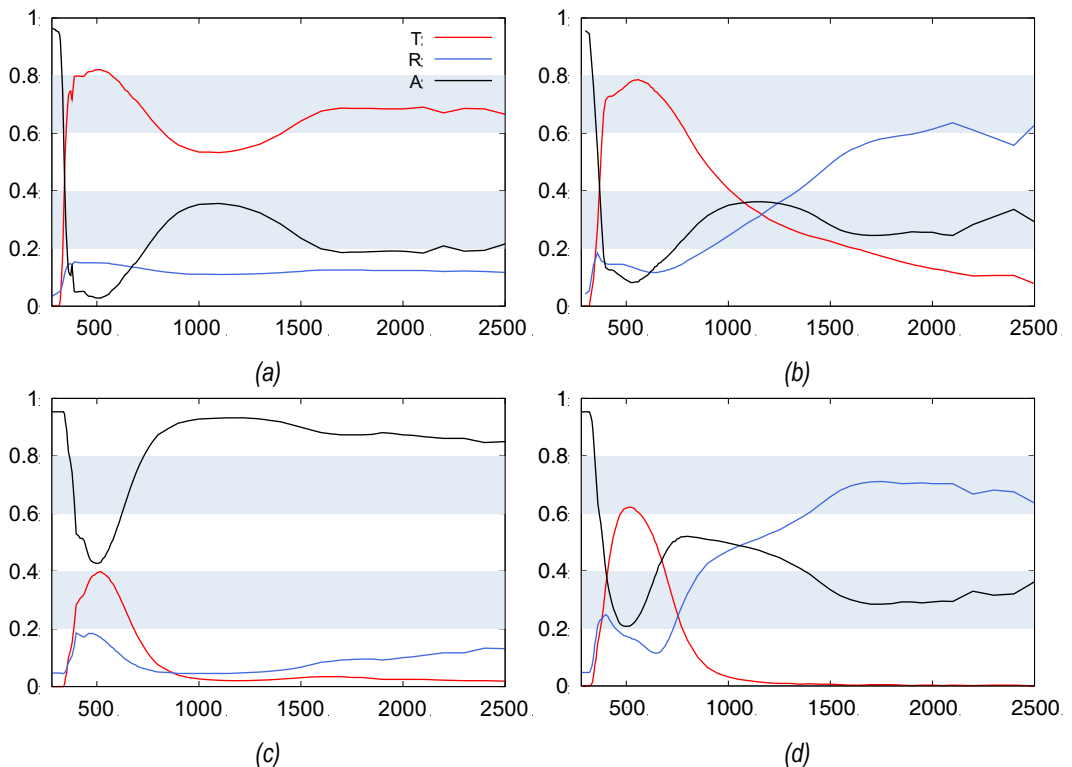


Figure 4.1 Transmittance (T), reflectance (R) and absorptance (A) as a function of wavelength in nm of standard double glazing (a), low-e double glazing (b), heat absorbing glazing (c) and solar control glazing (d).

4.2 Energy flows

Figure 4.2 shows the most important energy flows through a combination of an exterior screen and a double glazing unit. The yellow arrows represent short wave solar radiation. At each of the layers a certain percentage is transmitted, reflected or absorbed. The straight orange arrows indicate absorption. The absorbed energy is initially converted to internal energy of the screen and glass, causing the temperature of the materials to rise. Part of this energy is lost to the environment by thermal (long wave) radiation (red arrows) and convection (wavy orange arrows). At the screen, a little breeze easily carries away the convected heat. The glass is not transparent to the long wave radiation emitted by the screen. A small part is reflected. The larger part is absorbed by the glass, as the emissivity of uncoated glass (0.84) is equal to the absorptance for long wave infrared. The outer pane is effectively heated by absorption of the short wave solar radiation,

convective heat transfer from the screen and thermal radiation from the screen. By conduction part of the energy is transported to the other side of the pane. There it can be transferred through the cavity to the interior pane by radiation or conduction (convection does not normally occur in the cavity.) In case of a low e-coating on the interior pane, long wave radiation is predominantly reflected back to the outer pane. In the end, the interior pane transports three energy flows to the room:

1. the directly transmitted short wave radiation q_t
2. long wave radiation emitted by the interior pane q_{ri}
3. heat convected from the interior pane q_{ci}

If the incident irradiation is denoted by q_i , the g-value is given by:

$$g = \frac{q_t + q_{ci} + q_{ri}}{q_i} \quad (4.1)$$

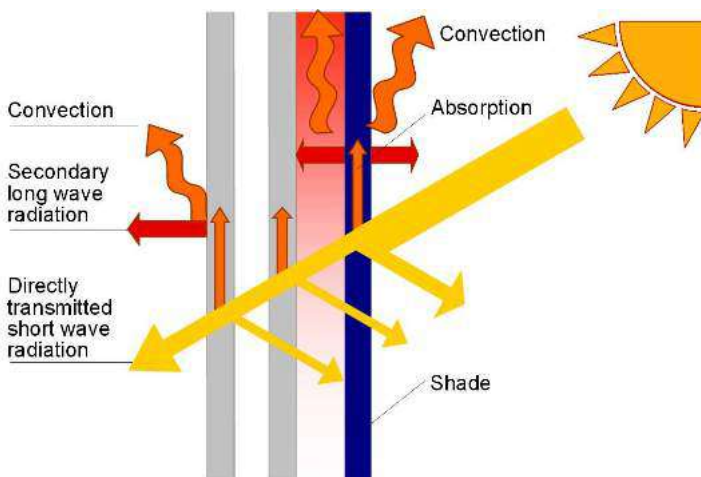


Figure 4.2 Energy flows through a combination of a double glazing unit and an exterior shading device. Only the most important flows are shown.

The last two contributions ensure that the g-value is always higher than the solar transmittance. In EN 410 $(q_{ri} + q_{ci})/q_i$ is termed the secondary internal heat transfer factor.

A few aspects of the g-value are worth mentioning:

1. The g-value depends on the angle of incidence of the solar radiation.
2. For Venetian blinds the g-value is strongly dependent on the slat angle, and the angle of incidence (both vertically and azimuthally.)
3. The g-value given in specifications of products are defined at normal incidence. For Venetian blinds the g-values are given for a closed blind.

All of these need to be taken into account when making detailed calculations.

Figure 4.3 shows the most important energy flows through a combination of a double glazing unit and an interior screen. In this case, the primary flow of short

wave radiation readily passes the glazing. Unless it is reflected by the screen, the energy is in the interior. Because the glass is not transparent to the long wave infrared radiation emitted by the screen, the heat is effectively trapped in the room (the greenhouse effect.) Of course, when the air between screen and window heats up there will be a certain flow of energy to the exterior due to the temperature difference between this air and the outside air. The magnitude of this energy flow is determined by the U-value of the glazing and small when compared to the direct and secondary energy flows.

Interior shading can only be effective for heat control if it is either highly reflective or when it has a high insulation value and is equipped with efficient edge seals. In the latter case, heat is trapped in the closed cavity between window and shade. The temperatures in this cavity may rise to high values and may even cause glass to break from thermal stress. This effect can be alleviated if the hot air is ventilated to the outdoors.

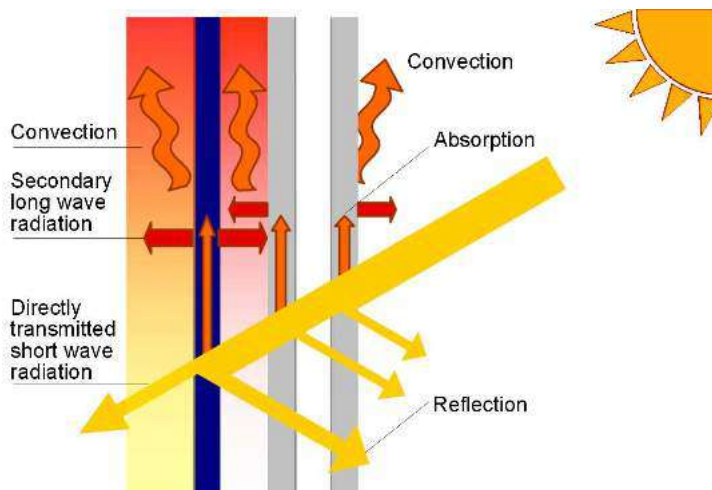


Figure 4.3 Energy flows through a double glazing unit and interior solar shading. Only the most important flows are shown.

4.2.1 Convection loads

The quality of a solar shading solution from the perspective of heat control is further determined by the proportion of heat that is transported to the interior by convection. If the larger part of the energy absorbed by the shading is transferred to the room as thermal radiation, this is preferable because this radiation is most likely to be absorbed by the thermal mass of the building. By this mechanism, the temperature of the room will only slowly build up because the thermal mass requires a lot of energy to heat up. If the larger part is transferred by convection, which is sensible heat, the temperature in the room will immediately rise.

The convection factor CF is a number between 0 and 1 which represents the part of the energy transferred to the room by convection and can be defined in terms of the energy flows introduced in section 4.2 as:

$$CF = \frac{q_{ci}}{q_i + q_{ci} + q_{ri}} \quad (4.2)$$

Similarly, one can define a radiative fraction RF and a direct fraction DF by replacing q_{ci} in the nominator of (4.2) by q_{ri} and q_t , respectively.

For a particular combination of glazing and solar shading, the computer program WIS will compute the magnitude of the radiative and convective heat fluxes. Figure 4.4 shows typical results.

Comparing interior to exterior shading, it is clear that exterior shading potentially has much better shading characteristics than interior shading in terms of g -values. There are however some very good inte-

rior products on the market. When comparing such a product to an exterior or inter-pane solution, the convection factor may be another factor to consider². Let us assume both the exterior and the interior product give a g -value of 0.2, and the convection factors are 0.05 and 0.25 for the exterior and interior product respectively. For the exterior product $0.05 \times 0.2 = 1\%$ of the solar heat would enter the space convectively. For the interior product this would be $0.25 \times 0.2 = 5\%$.

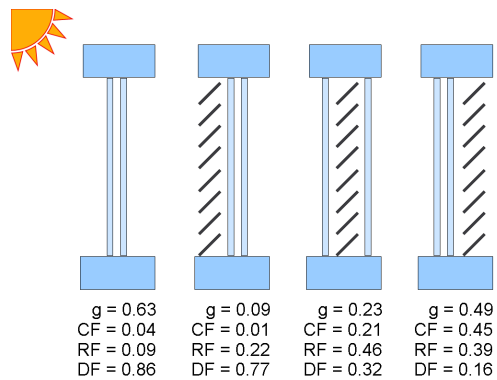


Figure 4.4 Typical g -values for the same Venetian blind with a slat angle of 65° in different window configurations. CF denotes the convective fraction as given by eq. 4.2, RF the radiative fraction and DF the direct fraction. Note that these values may differ significantly for other shadings. Screens generally have lower convective fractions.

4.3 Effect of high solar load on the room airflow pattern

Mixed ventilation is the most common ventilation strategy in buildings. In order to reach low air velocities in the occupied zone, low air flow rates should be used. Thus, to cover the requested cooling load in case of an all-air system, the tempera-

² The simplified formulas of EN 13363-1 which relate the g -value to the optical and thermal properties of the blind material and glazing, are also useful when making such comparisons.

ture difference between supply and exhaust air is typically about 10 K.

Windows have a significant influence on the total cooling load in the perimeter area. In that area, the total sensible cooling load typically ranges from 50 up to 120 W/m². The required cooling capacity is strongly dependent on the orientation and the shading strategy. It should be noted that the geographical location plays a less significant role than one would think: the maximum cooling demand is almost the same in Southern as in Northern Europe if glazing, orientation and shading are the same. This is exemplified in Figure 4.5.

Air distribution in rooms is the result of a complex interaction of ventilation flow from the room unit with the convection flow generated by heat sources, occupants, warm/cold window surfaces and office equipment. The airflow distribution de-

pends on several factors, including arrangement of supply units, supplied airflow rate and momentum flux, lay out of workplaces, strength and location of heat sources, etc. The airflow pattern changes a lot when heat gains increase in the room space.

In case of relatively low thermal loads in the range of 15-30 W/m², mechanical ventilation dominates air distribution in the room space. In case of higher heat gains, the buoyancy forces start to dominate the airflow pattern. Sometimes, the convection flow may be strong enough to turn the jet. In those cases, a room air temperature gradient between perimeter and central areas may develop. Also, the dropping airflow rate increases the risk of draught in certain parts of the occupied zone. Additionally, the location of the maximum velocity changes according to the heat gain condition.

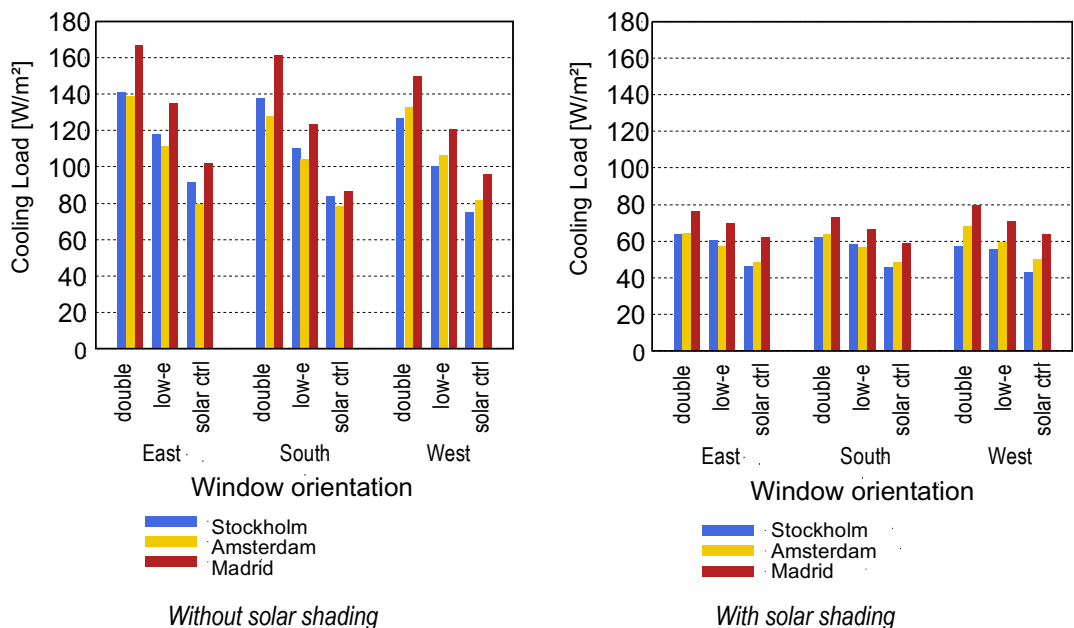


Figure 4.5 Peak cooling loads in perimeter zones for model offices in Stockholm, Amsterdam and Madrid with different orientations and different glazing types. See Table 5.1 for details of these offices.

Under heating conditions, cold window surfaces create thermal plumes and high air velocities close to the floor. This will be especially significant for poor windows with a high U-value. The problem gets more severe when there is no heating available underneath the window, or when the room controller has closed the valve of the heating element (room air set point is exceeded even though the window surface is cold). With cold window surfaces, the draught risk increases when the supply jet is directed to the window. In that case, it may accelerate the dropping convection flow and increase the air velocity at ankle level.

4.3.1 Surface temperature and effect on the operative temperature

The operative temperature is defined as the uniform temperature of an imaginary

radiant black body enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non uniform space.

In practice, operative temperature is often determined as the average of mean radiant temperature and mean air temperature.

Figure 4.6 shows the surface temperature of interior window panes under peak load conditions for model offices in Stockholm, Amsterdam and Madrid. As can be seen in the left graph, without shading, surface temperatures range between 35 and 42°C, with the low-e glazing reaching the highest temperatures. The right graph shows the temperatures in case of solar shading. Clearly, peak temperatures are several degrees lower and mostly below 32°C.

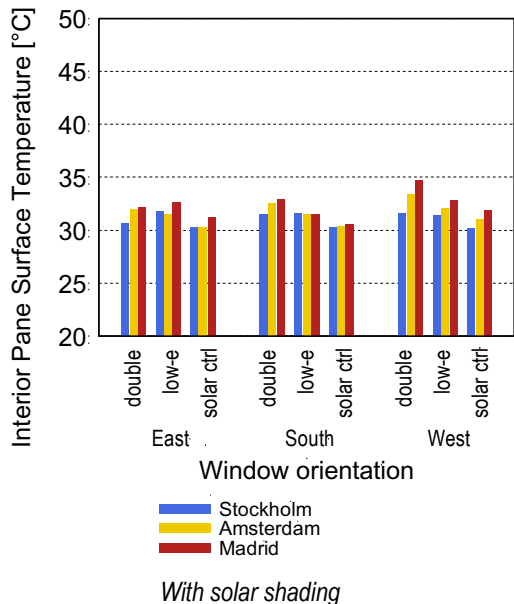
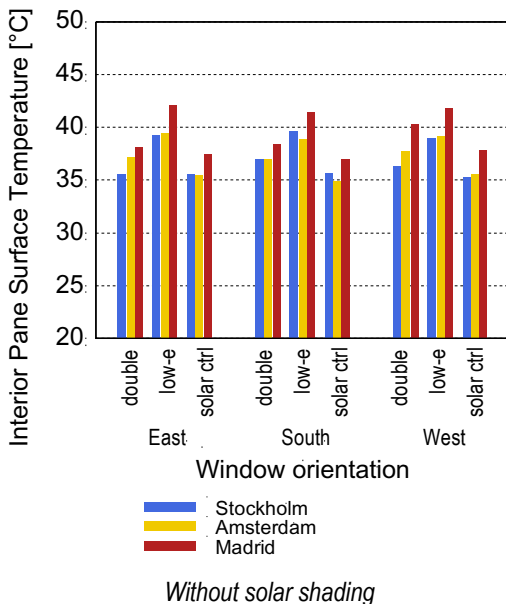


Figure 4.6 Surface temperature of the interior window pane under peak load conditions for offices in Stockholm, Amsterdam and Madrid. See Table 5.1 for details of these offices and the glazing. The shading season runs from 1-1 through 31-12.

Figure 4.7 and Figure 4.8 show the surface temperature of the interior pane of a south oriented low-e glazing unit in Amsterdam. From these figures it is clear that the shading reduces the temperature significantly, by more than 5 degrees during approxi-

mately 400 hours. Interestingly, in the case of the shaded window the highest temperatures occur in February-March and October-November which was outside the shading season, which in this case was chosen from 15 March to 15 October.

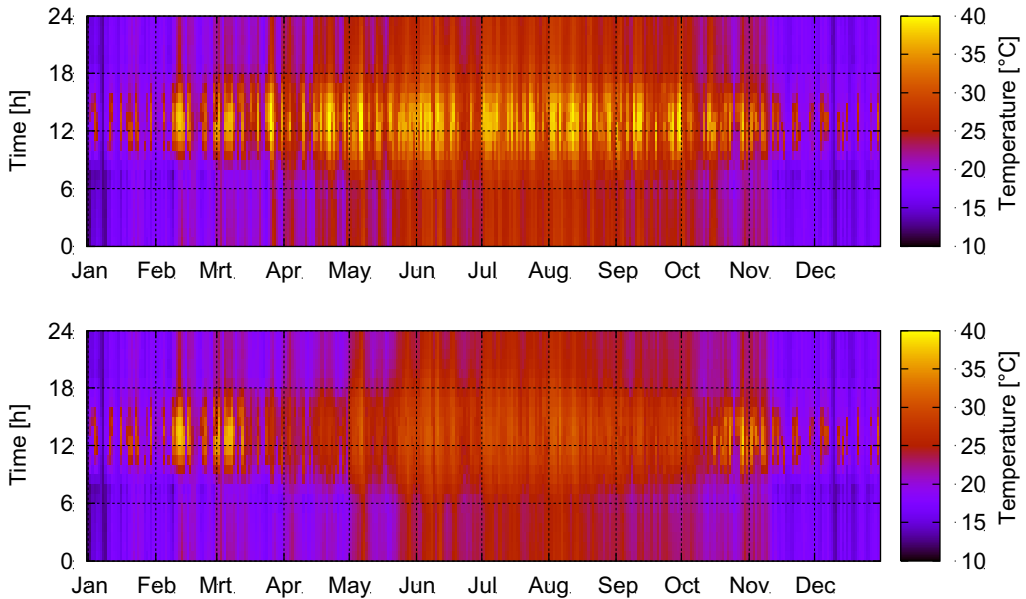


Figure 4.7 Distribution of surface temperatures for the interior pane of a south oriented low-e glazing unit in Amsterdam. Each day of the year is shown as a vertical column of pixels. Top panel without solar shading, bottom panel with an exterior Venetian blind operating between 15 March and 15 October. Even in February and November surface temperatures above 35°C occur. [Figures: Hunter Douglas]

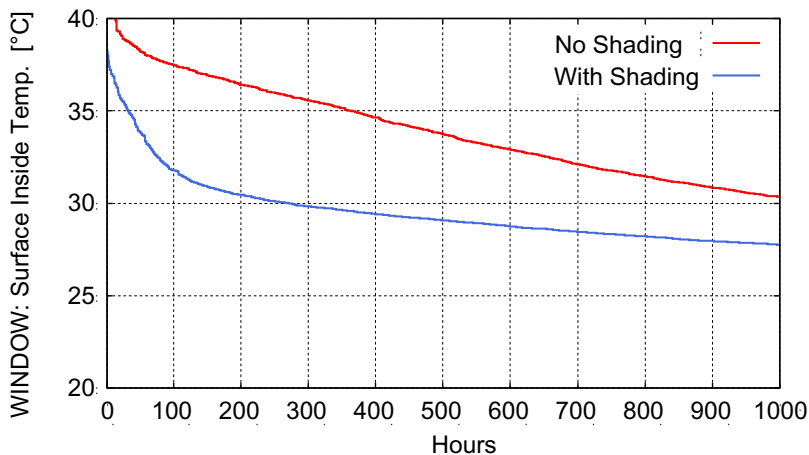


Figure 4.8 Distribution of surface temperatures for the interior pane of a south oriented low-e glazing unit in Amsterdam. Same data as in Figure 4.7.

In case of double glazing, exterior shading will generally reduce the temperature of the interior window pane, as can be seen in Figure 4.7. The temperature of the exterior pane can be higher than without shading. This is the result of radiative and convective heat transfer between the shade and the exterior pane. In case of single glazing, exterior shading will often actually increase the temperature of the window pane.

The effect of the radiant temperature asymmetry of the warm window should be taken into account and the effect on thermal comfort should be analysed during the design phase of a building.

Interior shading will in general increase the operative temperature because the surface temperature of the shading will in general be higher than that of an unshaded interior window pane. This will usually be unwanted in summer, in winter the effect can be desirable (passive heating).

4.3.2 Influence of solar shading on light needs

Energy consumption for artificial lighting can be substantial and amount to 40% of the electric energy consumption in a typical office building. Daylight-responsive lighting can lead to significant reductions in energy use. Ideally such lighting is continuously dimmable and adds just the amount of luminous flux to reach a prescribed illuminance level, usually 500 lx. In practice, daylight-responsive lighting is often supplemented by an occupancy sensor.

As solar shading reduces the flux of solar radiation entering a room, at the same time it reduces the amount of light coming in. The question arises whether the energy

saved by reducing the cooling demand is offset by an increased demand for artificial lighting. Experience shows that a properly configured automated shading system need not increase the energy demand for lighting.

Lund University in Sweden [Bulo 2007] studied the influence of solar shading, in combination with artificial light, on the overall energy consumption of an office room. The solar shading (25 mm interior Venetian blind) was connected to an energy control system and the room was fitted with an artificial light above the desk. A light sensor was installed in the lamp and directed to read the illuminance of the desk below. Connected to an automated dimmer, a minimum illuminance level of 500 lux was maintained. Without any wiring between light and solar shading systems, the light level was dimmed continuously according to the actual need, at any given time during the day. The solar shading operated according to the set energy parameters. Between overcast days and sunny days, the savings on electricity for the light ranged from 39% to 89% during May.

Daylight autonomy is defined as the percentage of time during which daylight is adequate to fulfil human lighting needs. The target illuminance and hours of operation are flexible, but are usually chosen as 500 lx and between 8:00 h and 18:00 h.

Solar shading in general influences the daylight autonomy of a room. This is especially true for locations further away from the window. This is shown in Figure 4.9, where the daylight illumination of a window fitted with solar control glazing is compared to the daylight illumination of a clear low-e window fitted with an automated external

Venetian blind. The Venetian blind is lowered when the vertical solar irradiance on the façade exceeds 200 W/m^2 . For reference point 1, the shading does not reduce the number of hours that daylight illuminance falls below 500 lx when compared to the unshaded solar control glazing. In fact, the number of hours that daylight supplies 500 lx is greater, because the low-e window has higher visual transmittance than the solar control glazing. For reference point 2 there is a slight decrease of 200 h during which daylight illuminance falls below 500 lx due to the shading, when compared to the solar control glazing. At 450 lx the distributions cross, and the low-e glazing gives a higher daylight illuminance in reference point 2.

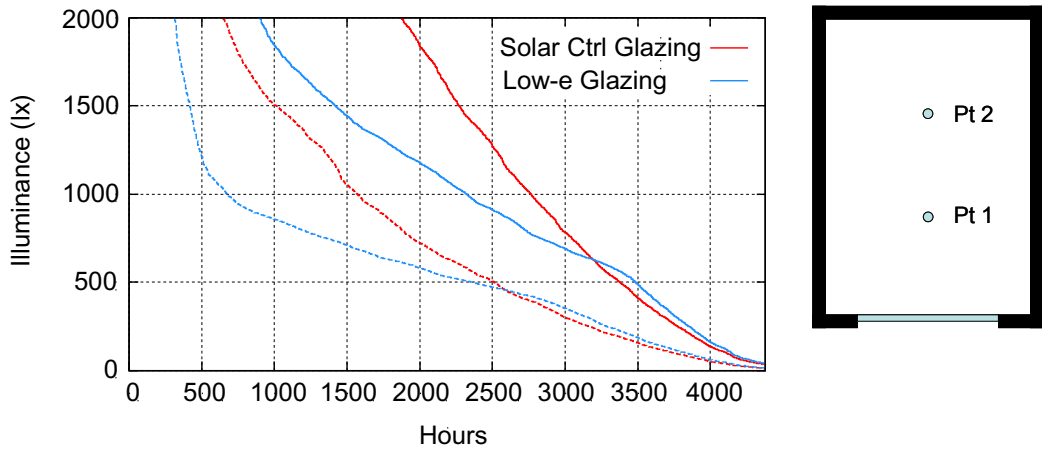


Figure 4.9 Plot of the daylight illuminance distribution for a south facing office in Amsterdam, see Table 5.1 for details. The solid lines represent point 1 which lies at one third of the depth of the room, the dotted lines represent point 2, situated at two thirds of the depth of the room, see right panel.

5 ENERGY EFFECTS OF SOLAR SHADING

Summary

Assessing the effects of solar shading on a building and its installations is virtually impossible without computer simulation. In this chapter we show energy simulations for offices in Stockholm, Amsterdam and Madrid. We analyse the energy requirement for heating, cooling and lighting. Quantitative results on the reduction of energy use and the reduction in required cooling capacities are presented.

5.1 The energetic effects of solar shading

In this section we present simulation results for model offices in three different locations in Europe: Stockholm, Amsterdam and Madrid. For each of these locations we calculated the annual energy use for lighting, heating and cooling through full dynamic simulation for one year. For each location we compare the outcomes of the model office without and with solar shading. The simulations were run for three different glazing types.

Artificial lighting is daylight-dependent and controlled by two lux meters, each controlling half the room. If the daylight illumination at the sensor exceeds 500 lx, artificial lighting is switched off. If daylight falls below 500 lx, additional illumination is provided through a continuously dimmable light. Note that this lighting concept is in fact very efficient.

For the shading we used an exterior Venetian blind. This blind is operated automatically and controlled by a seasonal schedule: in winter the shading is always raised in Stockholm and Amsterdam (see Table 5.1.) The shading is lowered whenever:

1. The interior air temperature exceeds a set point of 22°C, and at the same time
2. The sum of direct and diffuse irradiance exceeds a threshold value of 200 W/m².

This strategy avoids shutting out valuable solar energy for passive heating during the transition season³. The slat angles are continuously adjusted such that they always block the direct solar radiation. Table 5.1 gives an overview of the building's physical characteristics for the model office. The simulations were performed using EnergyPlusTM.

To compute the primary energy consumption, we used the efficiencies⁴ in Table 5.2.

The primary energy per square meter was computed as:

$$E_{\text{prim}} = \frac{1}{A} \left(\frac{E_{\text{light}}}{\eta_e} + \frac{E_{\text{cool}}}{\eta_e \eta_c \text{COP}} + \frac{E_{\text{heat}}}{\eta_h} \right) \quad (5.1)$$

where A denotes the area of the office.

³ Note that this is not entirely realistic in view of glare, due to low solar height. From an energy perspective, glare in winter is best controlled with interior blinds. They allow control of glare, while their relatively high g-value also allows passive heating.

⁴ These efficiencies will vary per country and installation. These figures are representative for the Netherlands

Table 5.1 Characteristics of the model office.

Characteristic	Schedule	Value	Unit
Locations		Stockholm Amsterdam Madrid	
Façade width (x)		3.6	m
Height (z)		3.0	m
Depth (y)		5.0	m
Glazing percentage		60	%
Glass 1: Std.double glazing 4-12-4 Ar filled g = 0.75, Tv = 0.8, U = 2.9 W/m ² K			
Glass 2: Low-e glazing 4-16-4 Ar filled g = 0.64, Tv = 0.8, U = 1.2 W/m ² K			
Glass 3: Solar control glazing 6-16-6 Ar filled g = 0.32, Tv = 0.60, U = 1.1 W/m ² K			
Walls medium, adiabatic			
Floor, Ceiling: medium, adiabatic			
Façade: U-value sun, wind exposed		0.3	W/m ² K
Ventilation rate, no heat recovery	6 – 20 h	1.5	dm ³ /m ² s
Infiltration rate	0 – 24 h	0.1	ACH
Lighting, daylight responsive continuously dimmable max. power:	8 – 18 h	12	W/m ²
Minimum illumination at point (x,y,z) = (1.8, 1.6, 0.8) controlling 50% of the lighting	8 – 18 h	500	lx
Minimum illumination at point (x,y,z) = (1.8, 3.3, 0.8) controlling 50% of the lighting	8 – 18 h	500	lx
Internal loads people	8 – 18 h	10	W/m ²
Internal loads equipment	8 – 18 h	15	W/m ²
Shading: Exterior Venetian Blind 60mm (light grey) Slat angle control: block beam solar	All year		
Set point for shading (total irradiance on façade) I > set point: shading down I < set point: shading up	Stockholm Amsterdam Madrid	15/3 – 15/10 15/3 – 15/10 1/1 – 31/12	200 W/m ²
Thermostat settings air temperature for cooling	8 – 18 h Otherwise	25 30	°C
Thermostat settings air temperature for heating	8 – 18 h Otherwise	21 15	°C
Mechanical cooling COP		3	W _{th} / W _e

5.2 Stockholm

Figure 5.1 shows the annual energy requirement as a function of orientation for the model office in Stockholm. The top row shows the results for double glazing (type 1), the middle row for low-e glazing (type 2) and the bottom row for solar control glazing (type 3). The left column

shows the results without shading, the right column with shading.

Table 5.2 Assumed efficiencies.

	Symbol	Value
Heating (natural gas)	η_h	85%
Electricity	η_e	39%
System efficiency for cooling	η_c	70%

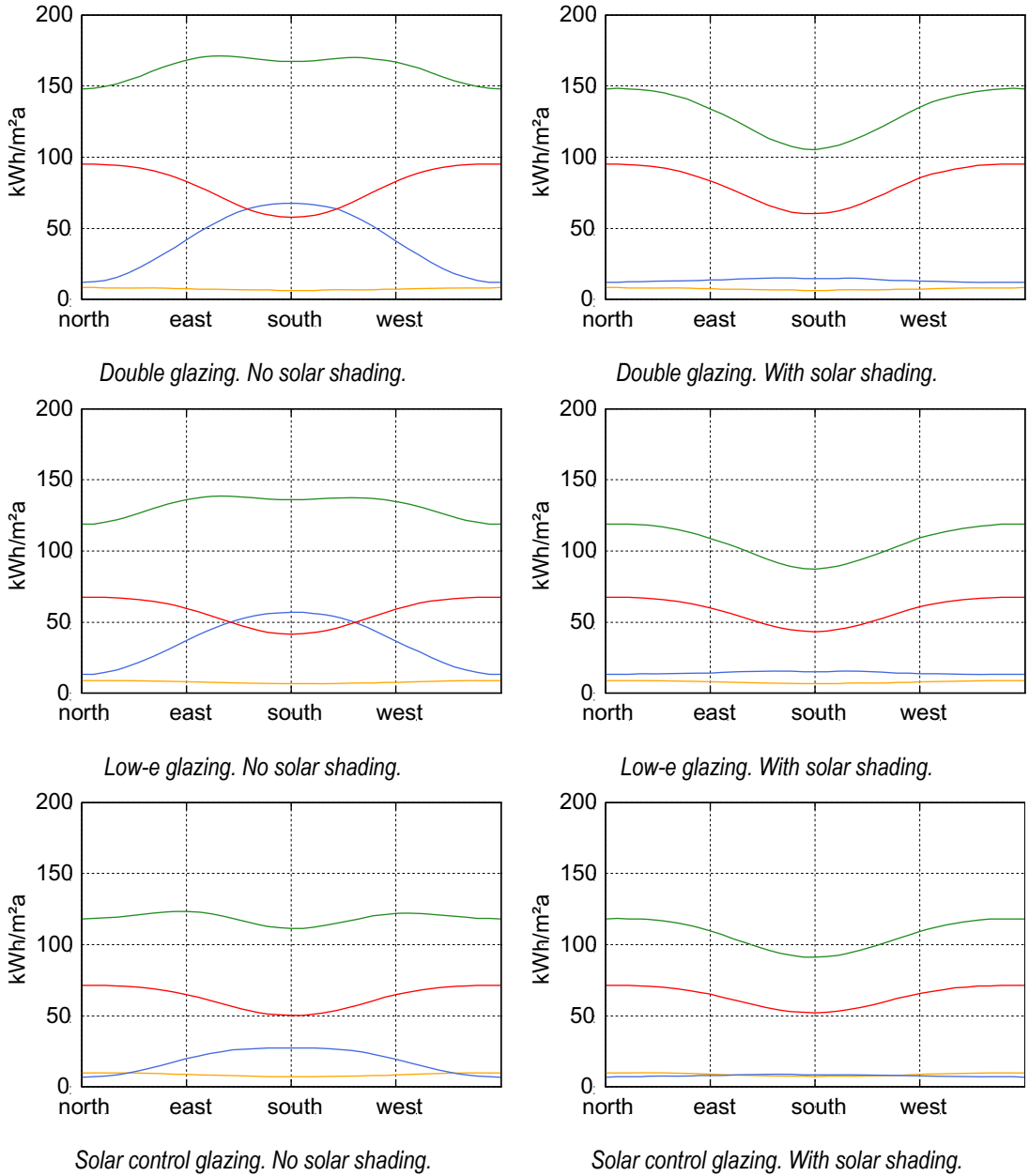


Figure 5.1 The annual energy balance for the model office in Stockholm. The red line represents the heat supplied to the room by the heating system, the blue line the heat removed from the room by the HVAC system. The yellow line represents the electric energy needed for lighting. The green line represents the total primary energy for heating cooling and lighting (eq. 5.1.).

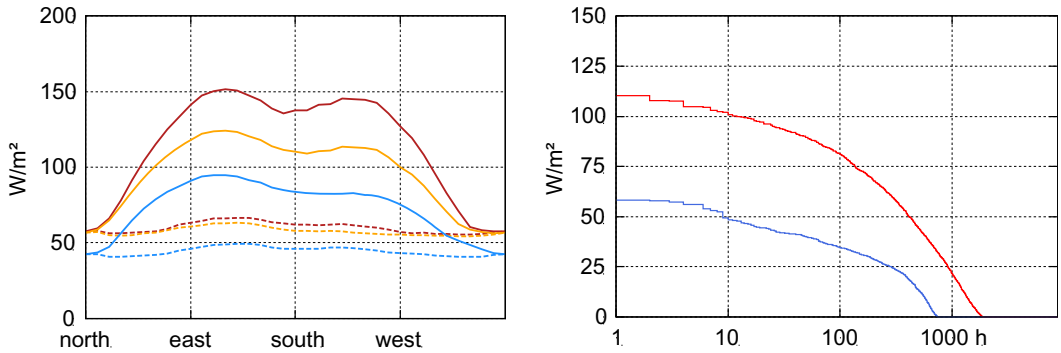


Figure 5.2 Left: Cooling load as a function of window orientation. Solid lines represent the situation without shading, the dotted lines represent cooling loads with solar shading. Red represents double glazing, orange low-e glazing and blue solar control glazing. Right: cooling rate distribution for low-e glazing (type 2) for a south orientation. Red represents the situation without shading, blue with shading.

The energy requirement is clearly dominated by heating. On south orientations the heating energy is significantly lower for all glazing types than for north orientations, due to passive solar heating in winter. In summer, there is considerable solar heat gain on south orientations, resulting in a significant energy demand for cooling. Clearly this effect is stronger for glazing with higher g-values. Converting heating, cooling and lighting to primary energy demand shows that without solar shading there is actually an advantage for north orientations for type 1 and 2 glazing.

The situation becomes markedly different when exterior solar shading is applied, as shown in the right column of Figure 5.1. The annual energy demand for cooling is drastically reduced by over 70% on south orientations. Solar shading results in slight increases in the energy demand for

heating and lighting. This is due to the fact that the shading intercepts solar energy that would have contributed to daylighting and passive solar heating. However, the control strategy is quite effective. Note that the primary energy requirement in absolute terms is lowest for the low-e glazing combined with solar shading.

The right graph in Figure 5.3 shows that for south orientations the primary energy requirement for low-e glazing is reduced by 30% through the use of solar shading. The left graph in Figure 5.3 shows the reduction in cooling load as a function of orientation for different levels of allowed temperature exceedance. From this figure it is clear that for a wide span of orientations from east through south to west, cooling rates are more than halved due to the solar shading.

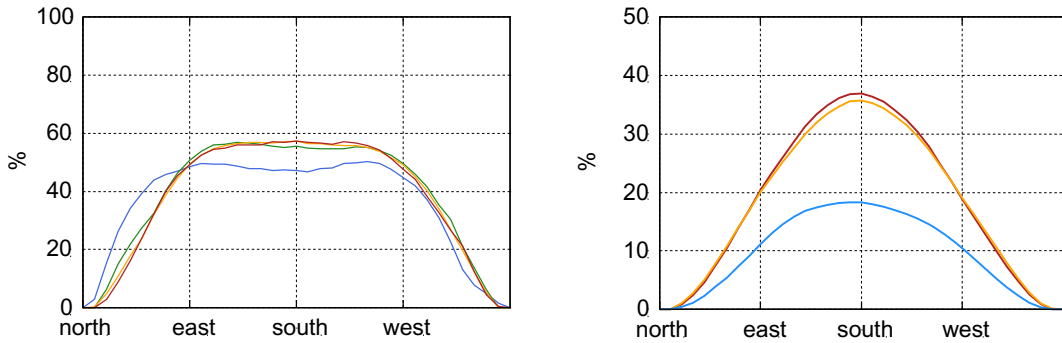


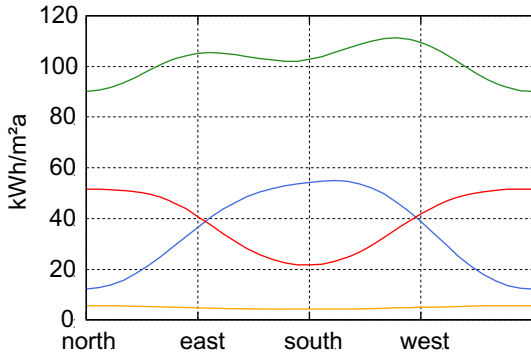
Figure 5.3
 Left: Cooling load reduction for low-e glazing (type 2) through shading for different levels of temperature exceedance. Blue: no exceedance, air temperature 0 h above 25°C, green: 50 h above 25°C, orange: 100 h above 25°C, red: 150 h above 25°C.
 Right: Reduction in primary energy use for heating, cooling and lighting through shading, when compared to the energy use without shading, for double glazing (red line), low-e glazing (orange line) and solar control glazing (blue line).

5.3 Amsterdam

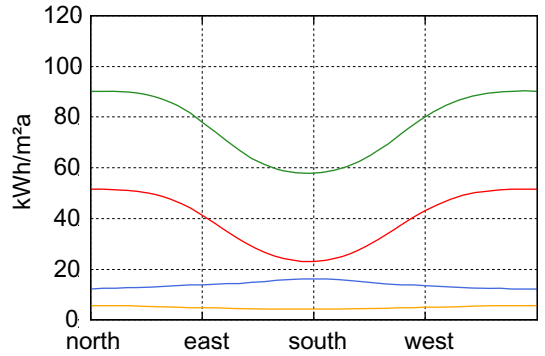
Figure 5.4 shows the energy requirement as a function of orientation for the model office in Amsterdam. The energy requirements for heating and cooling are more or less balanced. On south orientations the heating energy is significantly lower than for north orientations, due to passive solar heating in winter. In summer, there is a considerable solar heat gain on south orientations, resulting in a significant energy demand for cooling. Converting heating, cooling and lighting to primary energy shows that without shading there is an advantage for north orientations for type 1 and 2 glazing. Compared to Stockholm, the primary energy requirement in Amsterdam is significantly less.

The right column in Figure 5.4 shows the energy demand with solar shading. We see the same pattern as for Stockholm. Once again, in absolute terms the energy demand is lowest for an office equipped with clear low-e glazing and solar shading on a south orientation.

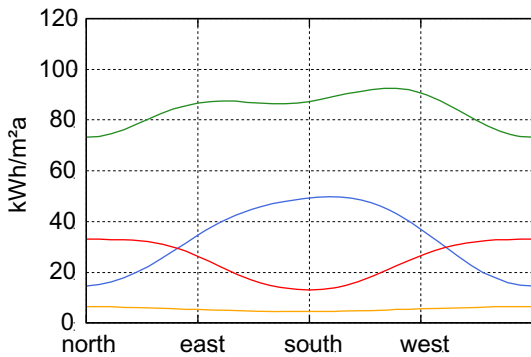
The right graph in Figure 5.6 shows that for south orientations the primary energy requirement for low-e glazing is reduced by 40% through the use of solar shading. The left graph in Figure 5.6 shows the reduction in cooling load as a function of orientation for different levels of allowed temperature exceedance. From this figure it is clear that for a wide span of orientations from east through south to west, cooling rates are about halved due to the solar shading.



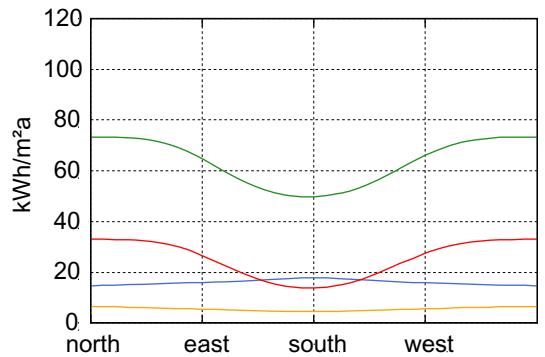
Double glazing. No solar shading.



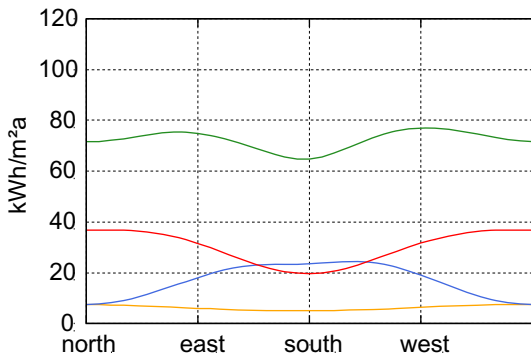
Double glazing. With solar shading.



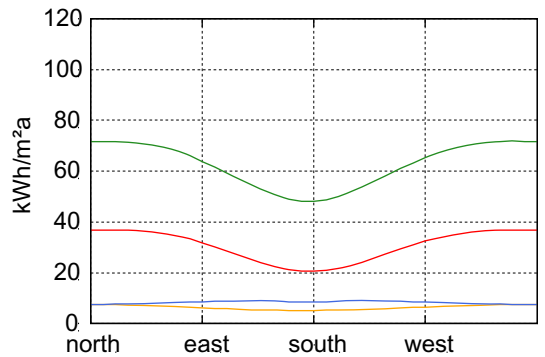
Low-e glazing. No solar shading.



Low-e glazing. With solar shading.



Solar control glazing. No solar shading.



Solar control glazing. With solar shading.

Figure 5.4 The annual energy balance for the model office in Amsterdam. The red line represents the heat supplied to the room by the heating system, the blue line the heat removed from the room by the HVAC system. The yellow line represents the electric energy needed for lighting. The green line represents the total primary energy for heating cooling and lighting (eq. 5.1.).

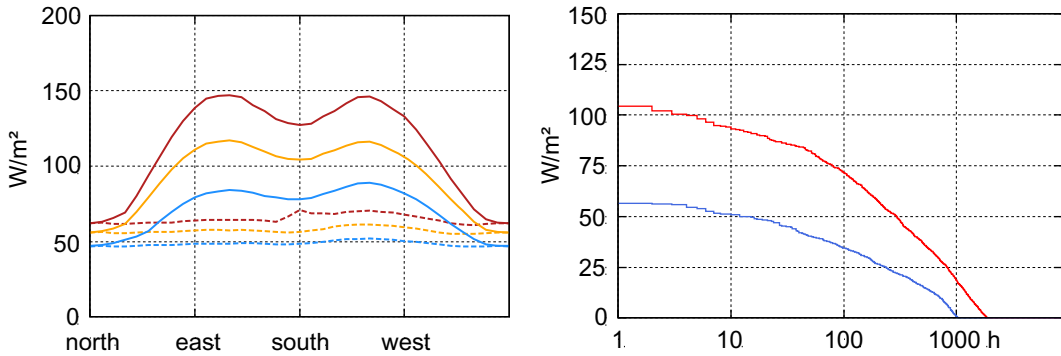


Figure 5.5 Left: Cooling load as a function of window orientation. Solid lines represent the situation without shading, the dotted lines represent cooling loads with solar shading. Red represents double glazing, orange low-e glazing and blue solar control glazing. Right: cooling rate distribution for low-e glazing (type 2) for a south orientation. Red represents the situation without shading, blue with shading.

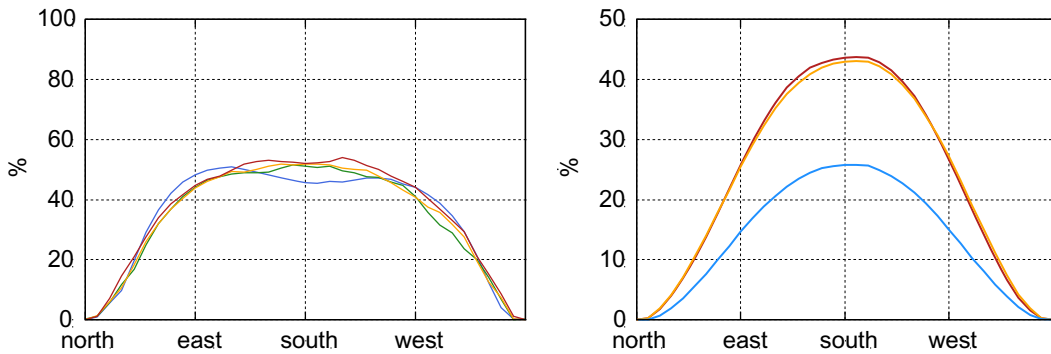


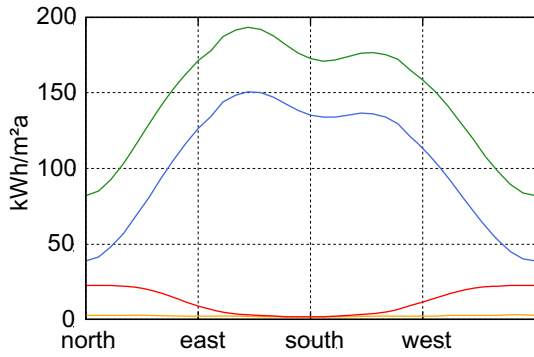
Figure 5.6 Left: Cooling load reduction for low-e glazing (type 2) through shading for different levels of temperature exceedance. Blue: no exceedance, air temperature 0 h above 25°C, green: 50 h above 25°C, orange: 100 h above 25°C, red: 150 h above 25°C. Right: Reduction in primary energy use for heating, cooling and lighting through shading, when compared to the energy use without shading, for double glazing (red line), low-e glazing (orange line) and solar control glazing (blue line).

5.4 Madrid

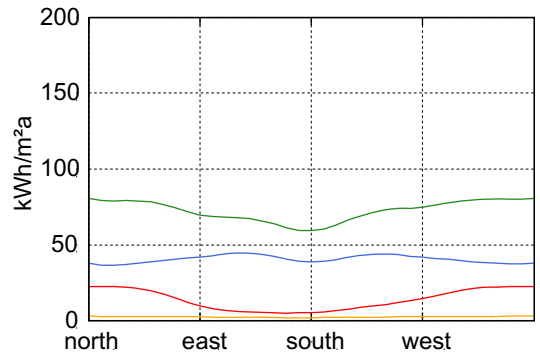
Figure 5.7 shows the energy requirement as a function of orientation for the model office in Madrid. This case, the energy requirement is clearly dominated by cooling. On south orientations heating is almost negligible, due to passive solar heating in winter. In summer, there is a considerable solar heat gain on south orientations, resulting in a significant energy demand for cooling. For the particular

climate year used in the simulation, there appears to be a bias towards south-east orientations. Without shading, there is a clear advantage for north orientations for all glazing types.

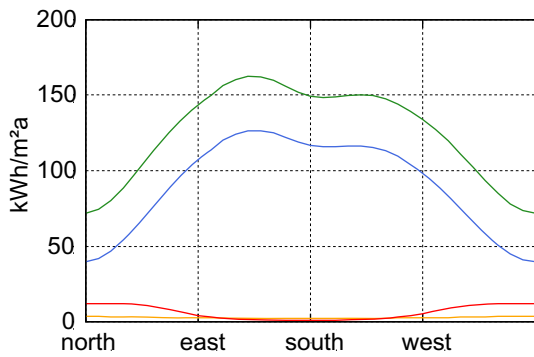
Solar shading drastically reduces the primary energy requirement for off-north orientations. In this case the lowest primary energy requirement is attained for a combination of solar control glazing and exterior solar shading.



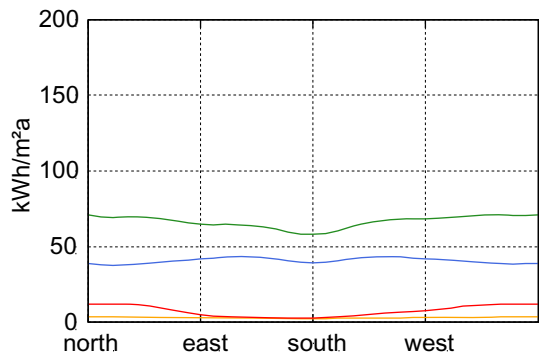
Double glazing. No solar shading.



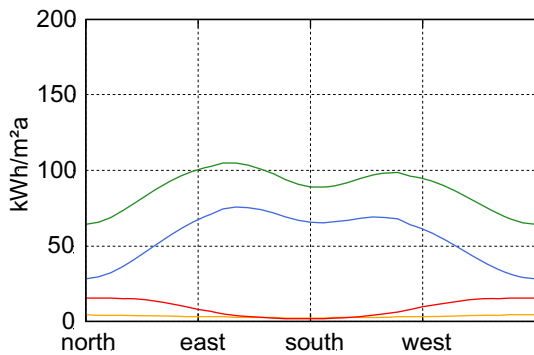
Double glazing. With solar shading.



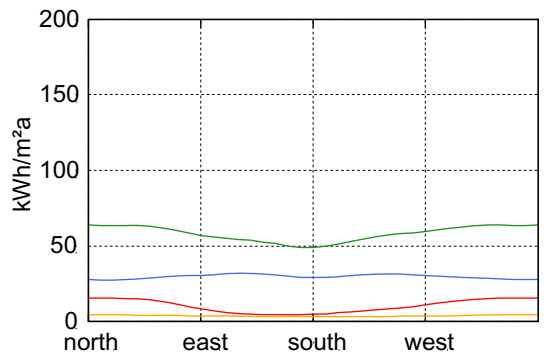
Low-e glazing. No solar shading.



Low-e glazing. With solar shading.



Solar control glazing. No solar shading.



Solar control glazing. With solar shading.

Figure 5.7 The annual energy balance for the model office in Madrid. The red line represents the heat supplied to the room by the heating system, the blue line the heat removed from the room by the HVAC system. The yellow line represents the electric energy needed for lighting. The green line represents the total primary energy for heating cooling and lighting (eq. 5.1.).

During the heating season, the solar shading occasionally intercepts solar energy that otherwise would have contributed to daylighting and passive solar heating. This causes increases in the energy demand for heating and lighting. Heating more than doubles, although the increase in terms of absolute magnitude is relatively small compared to the total demand. However, the control strategy is quite effective because for southern orientations cooling loads are once again halved and the pri-

mary energy requirement is reduced by over 50% (See: Figure 5.9).

Combining solar control glazing with solar shading is a somewhat unusual choice. Normally, solar control glazing is viewed as an alternative to exterior shading. In this case, the primary energy requirement for an office fitted with solar control glazing and solar shading is in fact about 30% lower than for the same office fitted with solar control glazing only.

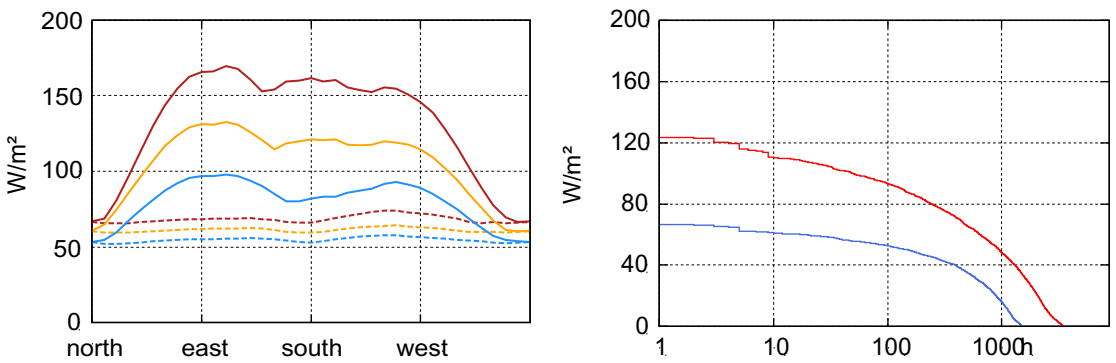


Figure 5.8 Left: Cooling load for the model office in Madrid as a function of window orientation. Solid lines represent the situation without shading, the dotted lines represent cooling loads with solar shading. Red represents double glazing, orange low-e glazing and blue solar control glazing. Right: cooling rate distribution for low-e glazing (type 2) for a south orientation. Red represents the situation without shading, blue with shading.

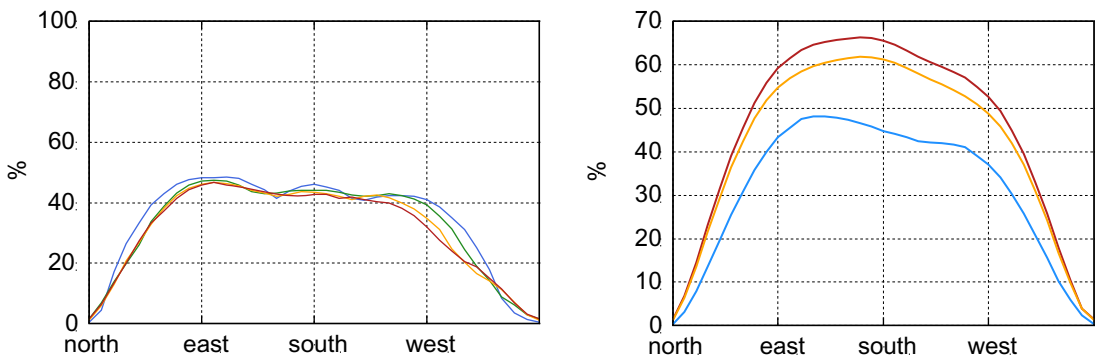


Figure 5.9 Left: Cooling load reduction for low-e glazing (type 2) through shading for different levels of temperature exceedance. Blue: no exceedance, air temperature 0 h above 25°C, green: 50 h above 25°C, orange: 100 h above 25°C, red: 150 h above 25°C. Right: Reduction in primary energy use for heating, cooling and lighting through shading, when compared to the energy use without shading, for double glazing (red line), low-e glazing (orange line) and solar control glazing (blue line).

5.5 Cost benefit analysis of solar shading

When assessing the costs and benefits of solar shading, we have to consider several scenarios. The outcome for these scenarios may vary greatly.

The first distinction is between scenarios where design of the solution for solar shading, glazing, artificial lighting and HVAC is approached integrally and scenarios where glazing and the HVAC installation are a given, e.g. retrofits of existing buildings. In the first case, solar shading will generally have an impact on the capacity of the HVAC installation, the associated investment costs and the costs for energy during the exploitation phase. In the second case, solar shading will only have an impact on the energy cost.

Another aspect to consider is the environmental footprint of the building. An investment in solar shading saves energy and therefore reduces the environmental footprint of the building over its entire life cycle (assuming the reduction bears on energy derived from fossil sources.) This in itself may be a reason to choose for this solution.

5.5.1 Newly developed building

Based on the efficiencies given in Table 5.2 we may calculate the cost for heating and cooling. The Table 5.3 gives average energy prices for the three locations in 2009.

Both HVAC installations and solar shading come in many designs and qualities. Comparing cost in general is therefore not easy and individual cases may deviate considerably from the following results.

The cost for the HVAC installation is parameterized as:

$$C_{HVAC}(P) = A_R(aP + b), \quad (5.2)$$

where the parameters are given in Table 5.4.

Table 5.3 Energy prices.

Energy type	Stockholm	Amsterdam	Madrid	Unit
Electricity	0.120	0.100	0.066	€/kWh
Natural gas		0.350		€/m ³
Calorific value natural gas		8.780		kWh/m ³
Cooling	0.058	0.048	0.032	€/kWhth
Heating	0.070	0.050	0.030	€/kWhth

Table 5.4 HVAC cost parameters.

Parameter		Value	Unit
C_{HVAC}	Investment cost		€
A_R	Area of the room	18	m ²
a	Regression parameter	0.7	€ W ⁻¹
P	Max. cooling load		W _{th} m ⁻²
b	Regression parameter	38.1	€ m ⁻²

The parameters in Table 5.4 were derived from a cost calculation for a chilled beam installation [Kos 2010].

The investment cost for the solar shading is parameterised similarly as:

$$C_{SS}(A_W) = pA_W + q, \quad (5.3)$$

where the parameters are given in Table 5.5.

Table 5.5 Shading cost parameters.

Parameter		Value	Unit
C_{SS}	Investment cost		€
A_W	Area of the window		m ²
p	Regression parameter	31.2	€ m ⁻²
q	Regression parameter	424.0	€

The costs in Table 5.5 were derived from a project consisting of Venetian blinds and includes costs for motorisation and control

as well as costs for installation of the blinds. For the glazing we have the cost presented in Table 5.6 [Arc 2009].

Table 5.6 Glazing cost parameters.

Parameter		Value
C_{SCG}	Cost of solar control glazing	122 € m ⁻²
C_{Low-e}	Cost of low-e glazing	68 € m ⁻²

Based on these cost models, we have calculated the investment cost and recurring energy cost for Stockholm, Amsterdam and

Madrid, based on the results presented in sections 5.2 to 5.4. As can be seen in Figure 5.2, Figure 5.5 and Figure 5.8, the maximum cooling load varies with orientation. To derive more general results, we averaged angular results over the range east to west (over south). This procedure was applied to the cooling loads, investment costs and annual energy uses for heating, cooling and lighting. The results are given in Table 5.7 for the 18 m² office with a glazing percentage of 60%, as defined in Table 5.1.

Table 5.7 Investment cost and recurring energy cost for Stockholm, Amsterdam and Madrid.

Stockholm	Solar control glazing			Low-e glazing with solar shading			
Investment cost	Quantity	Unit	Cost €	Quantity	Unit	Cost €	Delta €
HVAC	1548	W	1769	1064	W	1431	338
Solar shading	6.48	m ²		6.48	m ²	626	- 626
Glazing	6.48	m ²	791	6.48	m ²	441	350
Total investment			2560			2498	62
Recurring cost	Quantity	Unit	Cost €	Quantity	Unit	Cost €	Delta €
Electricity for lighting	141	kWh	17	133	kWh	16	1
Cooling	451	kWh _{th}	26	270	kWh _{th}	16	10
Heating	1017	kWh _{th}	71	921	kWh _{th}	64	7
Total recurring per year			114			96	18
Simple payback period (years)							0
Amsterdam	Solar control glazing			Low-e glazing with solar shading			
Investment cost	Quantity	Unit	Cost €	Quantity	Unit	Cost €	Delta €
HVAC	1490	W	1729	1053	W	1423	306
Solar shading	6.48	m ²		6.48	m ²	626	- 626
Glazing	6.48	m ²	791	6.48	m ²	441	350
Total investment			2519			2490	30
Recurring cost	Quantity	Unit	Cost €	Quantity	Unit	Cost €	Delta €
Electricity for lighting	99	kWh	10	91	kWh	9	1
Cooling	404	kWh _{th}	20	292	kWh _{th}	14	6
Heating	447	kWh _{th}	22	372	kWh _{th}	19	3
Total recurring per year			52			42	10
Simple payback period (years)							0
Madrid	Solar control glazing			Low-e glazing with solar shading			
Investment cost	Quantity	Unit	Cost €	Quantity	Unit	Cost €	Delta €
HVAC	1714	W	1885	1255	W	1564	321
Solar shading	6.48	m ²		6.48	m ²	626	- 626
Glazing	6.48	m ²	791	6.48	m ²	441	350
Total investment			2676			2631	45
Recurring cost	Quantity	Unit	Cost €	Quantity	Unit	Cost €	Delta €
Electricity for lighting	52	kWh	3	50	kWh	3	0
Cooling	1242	kWh _{th}	40	756	kWh _{th}	24	24
Heating	78	kWh _{th}	2	80	kWh _{th}	2	0
Total recurring per year			46			30	16
Simple payback period (years)							0

Analysis

For all three cities considered in this guidebook a simple payback period of zero results, because in all cases the investment with solar shading is lower than the investment without solar shading. However, from the numbers in the above tables it is clear that energy savings are two orders of magnitude smaller than the investment costs. Therefore, computing payback periods is extremely sensitive to variations in costs for HVAC, glazing and solar shading. In other words: computing payback periods is an ill-conditioned problem.

Obviously it is too restricted to judge the benefit of solar shading only on an investment cost and recurring energy cost basis. For a fair comparison, functionally equivalent solutions should be compared. This is broader than just looking at the energy for heating, cooling and lighting required to maintain a certain prescribed indoor climate in terms of air temperature and illuminance. As shown in chapter 3, solar shading has a significant influence on indoor environmental quality in the thermal and visual domains. Therefore, comparing a solution consisting of a certain glazing type and a certain HVAC installation to a solution consisting of another glazing type fitted with exterior shading and a smaller HVAC installation, is like comparing apples and oranges. In the visual domain, the first solution is dysfunctional since it lacks the capability to prevent glare. Despite this fact, we've chosen to make this 'unfair' comparison, because specifying a functionally more equivalent solution adds another term with debatable parameters to a comparison, in an already ill-conditioned problem.

Figure 5.10 shows the extra investment cost in case of exterior shading as a function of glazing percentage, for the office defined by Table 5.1 This graph shows that for low glazing percentages, the extra investment is on the order of 5%, whereas for high glazing percentages there is a lower cost of the same magnitude. Interestingly, the case for Stockholm appears to be the most favourable, whereas the moderate conditions of Amsterdam present the least favourable case.

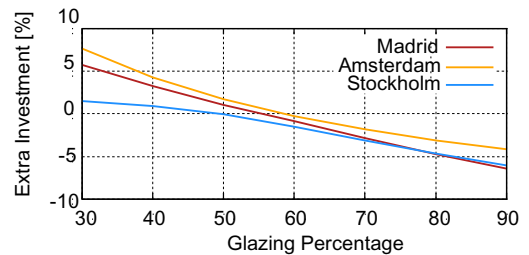


Figure 5.10 Top: The extra investment (averaged over all orientations from east to west) as a function of glazing percentage of the model office with solar shading. Base case is the investment for HVAC and solar control glazing. This is compared to the investment for a smaller HVAC installation combined with low-glazing and an exterior automated blind.

5.5.2 Renovation of existing building

The financial case for solar shading in case of a renovation can be entirely different from the one presented in the previous section.

In case of a building that in its pre-renovation state did not have mechanical cooling, the case for solar shading may be favourable if there are structural constraints that prohibit certain installation concepts. Passive cooling by shading can be a very cost effective solution. On the other hand, architectural regulations may prohibit the application of exterior shading.

If HVAC and glazing are all replaced in the renovation, the case is essentially the same as in the previous section. In case ductwork is re-used, the case for solar shading may even be more favourable because the cost of the cooling machine is relatively more important in that case.

If the HVAC equipment and/or the glazing are not replaced it is clear from the cost data in the previous section that payback from reduced energy cost will be too long for normal business practices. In that case, solar shading can derive its justification from comfort considerations.

If the renovation project will not have mechanical cooling, solar shading may be an important means to assure summer comfort. Like in the previous case, payback can only come from improved comfort and productivity.

5.5.3 Including productivity gains from improved comfort

In addition to the impact on the costs for capital expenditure and energy, we may also include the effects of improved indoor environmental quality and increased productivity. In general, these effects are largely underestimated. Even small increases in productivity have large financial effects, as explained in section 3.6.

The main comfort aspects of solar shading are visual and thermal comfort. In case of visual comfort, glare prevention is

most directly linked to work performance, especially in the case of computer work. In case of an air-conditioned building, the main thermal comfort benefit from solar shading is reduced window surface temperatures. In case of non-conditioned buildings or buildings with limited cooling capacity (top-cooling), there is an additional effect on air temperature.

Although there is plenty of qualitative evidence on the positive effects of windows and daylight, there are very few quantitative results relating glare and productivity. However, glare can be a serious impediment to working with a computer screen. Without any shading (interior or exterior) glare occurs relatively often, even on north oriented façades.

Few has been published on the relation between productivity and radiative temperatures and the asymmetries that may exist. It appears not to be unreasonable to expect dependencies of similar strength as depicted in Figure 3.1. Figure 4.8 may give an idea of the duration of such effects.

All in all, it appears not to be unreasonable to expect productivity effects on the order of a few percent. A productivity gain of 1% would bring a benefit of 500 € in a company where a revenue of 50,000 € is associated with an average office worker. If these benefits are included into the analysis of section 5.5.1, payback periods for all glazing percentages are less than 1 year.

6 HOW TO CHOOSE A SOLAR SHADING SOLUTION

Summary

There are many products that come under the tab 'solar shading'. They can be internal or external, fixed or mobile, automated or manual, textile-based or metal, and there are many other variables. The market offers a wide choice of different designs and working principles, so it may appear to be difficult to suggest that there is a list of selection criteria. Obviously, each application will have its own properties depending on the climate, the type of building, the size and shape of the windows, the aesthetics, the preference of the designer or architect ... or the end-user's taste. The purpose of this short overview is to provide some of the selection criteria, based on the functional properties (what practical results do I expect from the solar shading system?), whereby we will only consider mobile shading systems, as these offer the best potential for providing a dynamic solution to the rapidly changing levels of incoming solar heat and light.

6.1 Selection criteria

The three major functional benefits expected from solar shading are related to energy saving and improved indoor comfort:

- To reduce the need for artificial cooling in summer (passive cooling);
- To reduce the need for heating in winter (passive heating);
- To improve visual comfort (avoid glare) and maintain contact to the outside in all seasons.

Solar shading also has an effect on the insulating capacity of the window. The thermal resistance (R-value) will improve slightly, particularly with sealed internal solar shading devices, as several studies have shown. But often users – and also architects – will consider aspects like aesthetics, ease of operation, fashion and other more emotional motives for a choice. These motives may even prevail in many cases. The purpose of this chapter is to demonstrate the functional benefits of solar shading and to provide arguments to take these benefits into consideration.

An obvious first selection criterion would be to choose between the three possible

positions of the solar shading device: external, internal or intermediate (the latter one only for double skin façades). If only the three functional benefits, listed above, were considered in the selection process, we might offer this schematic table:

Type	Cooling	Heating	Visual comfort
External	+++	+	+
Intermediate	++	+	++
Internal	+	-	++








Double-skin façades are not necessarily the most common, so the intermediate position of the shading device – an ideal position – remains somewhat of an exception. If all the benefits are to be harvested in the other 'normal' buildings, the conclusion is that both internal and external shading would be required at the same time. External primarily for heat control, internal mostly for light control – although external systems obviously can also be designed to help improve the visual comfort. Several scientific studies, from Fraunhofer Institut für Bauphysik among others, come to that same conclusion: ideally, a window has both internal and external shading.

6.2 The choice of available products

ES-SO's website provides a survey of the most popular currently available solar shading systems. There are many

more on the market but this overview comprises the most popular products.

*An overview of the most popular **exterior solar shading systems**.*

<p>External roller blind</p>		<p>Rolls down vertically along the window, solar shading agent is a fabric (most often fiberglass screen, polyester or acrylic), with head box for the protection of the fabric and side guide rails or cables for reliable performance</p>
<p>External Venetian blind</p>		<p>Horizontal aluminium slats can be raised or lowered, then adjusted to any angle to regulate the entrance of daylight. Head box and side rails or cables. Slat widths vary from 50 mm to 150 mm.</p>
<p>Drop-arm awning</p>		<p>'Drop-arm' or 'fall-arm' indicates an arm projecting forward when lowered. Equipped with a fabric and a head box for retracting the fabric.</p>
<p>Folding arm awning</p>		<p>Suitable for shop windows and patios, the folding arm awning is equipped with two or more folding arms, allowing to stretch the fabric (mostly acrylic) to extend up to 3 m or more. Often these awnings have closed cassettes to protect the fabric when retracted.</p>
<p>Sliding arm awning</p>		<p>Often referred to as 'marquiselette', this is a combination of the external vertical blind and the drop-arm awning, with the fabric dropping vertically, then projecting forward. Suits in particular high, narrow windows.</p>
<p>Conservatory awning</p>		<p>Designed to reduce the energy impact of the sun on all-glass conservatories by externally covering the sloped roof and sometimes the front end of conservatories. Exists in various shapes and sizes. Equipped with solar shading fabric .</p>
<p>Roller shutter</p>		<p>Basically, a number of horizontal slats in aluminium or plastic, hinged together and rolling down or up. For windows, but also for doors, and even vans and trucks. Offers an improvement of the thermal resistance of the window.</p>

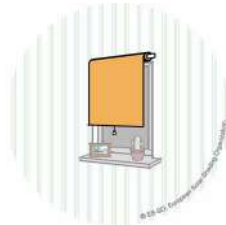
An overview of the most popular **interior** solar shading systems.

Venetian blind



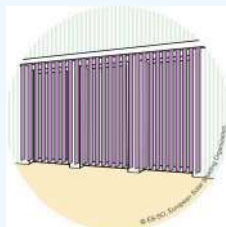
The quintessential interior blind, composed of slats of aluminium, wood or plastic that adjust by rotating from an open position to a closed position by allowing slats to overlap. Mostly operated with cord or wand, also available in motorized version. Slats can be perforated.

Roller blind



Rolls down vertically along the window on the inside or between the inner and outer wall of a double skin façade. Great variety of fabrics, including metallized fabrics for better reflection of the solar energy.

Vertical blind



System consisting of a number of vertical louvers, mostly made of fabric, more rarely of plastic or aluminium, moving to one side or to both sides. For large windows and sliding glass doors. Popular in the office environment.

Pleated blinds



Especially suitable for irregular window shapes, these blinds are equipped with a pleated fabric that rolls down the window. Very flexible, pleated blinds can be used for trapezoid or half-round window shapes, with a choice of control options.

Roman blinds



When lowered, these blinds (also named Roman shades) look like one flat panel, while opening them will bring the folds under one another. Exists in a great variety of fabrics, including darkening fabrics.

Curtains or draperies



The classic solution for creating privacy and decorating or darkening a room. Could be considered a solar shading solution, although it will seldom be automated to bring the benefits of a mobile solar shading system.

6.3 Products rated on the basis of functions and benefits

It is not easy to summarize and categorize all the benefits in one table. We have tried to rate the various products accord-

ing to their capacity to contribute to the various benefits and functions, for a rough, first orientation.

Rating ++ excellent + good o moderate - not capable n.r. not relevant		Passive Cooling	Passive Heating	Reduction of heat loss (winter)	Thermal comfort	Visual comfort	Contact to the exterior	Preferred facade orientation	Wind resistance	Life expectancy	Typical g-value	Typical τ_v	Convection factor
External retractable	Venetian blinds	++	++	-	++	o	o	ESW	+	+	0,10	0,10	0,04
	Screens	++	++	o	++	++	+	ESW	o	+	0,15	0,10	0,10
	Roller shutters	++	++	+	++	o	o	ESW	++	+	0,10	0,02	0,15
	Awnings	+	++	-	++	+	+	ESW	o	+	0,17	0,12	0,15
	Daylight Saving Awnings	++	++	-	++	+	o	ESW	+	+	0,12	0,05	0,18
External non retractable	Horizontal solarfins, louvers static	o	o	n.r.	+	-	+	S	++	++			
	Horizontal solarfins, louvers dynamic	++	+	n.r.	++	o	+	S	++	++			
	Vertical solarfins, louvers static	-	o	n.r.	o	-	+	EW	++	++			
	Vertical solarfins, louvers dynamic	++	+	n.r.	++	o	+	EW	++	++			
Intermediate	Venetian blinds, non ventilated gap	+	++	n.r.	+	++	+	ESW	n.r.	++	0,23	0,10	0,21
	Venetian blinds, ventilated gap	++	++	n.r.	++	++	+	ESW	n.r.	++		0,10	
	Venetian blinds		++	n.r.									
Interior retractable	Interior Venetian blinds	o	++	-	o	++	o	NESW	n.r.	+	0,45	0,12	0,50
	Metalized screens	+	++	o	+	++	+	ESW	n.r.	+			
	Screens	o	++	o	o	++	+	NESW	n.r.	+			
	Honeycomb shades	+	++	++	+	+	-	NESW	n.r.	+	0,25		
Static	Solar protection glazing	+	-	n.r.	+	-	++	ESW	n.r.	++	0,34		0,04
	Sun protection foils	+	-	n.r.	+	-	++	ESW	n.r.	+	0,35		0,04

6.4 Things to consider in the choice

Obviously, there is not a single formula for the thought process leading to the choice of a solar shading system. There are too many variables to take into account. Let us try however to indicate a few guiding questions that should be considered in all cases:

- The *climate*: the geographic location will determine the climate data, hence the solar energy intensity. Climate data are available for virtually every spot on earth. They will include outdoor temperatures and the incident solar energy.
- The *orientation* of the building: this will affect the choice of the shading system because, obviously, a south façade in Berlin will not have the same solar incidence as the north façade of the same building.
- The prevailing *wind conditions*: this may have an effect on the choice of an exterior solar shading system. A building on the coast may suffer from strong winds and this may limit the choice of available systems.
- The *height* of the building: very high towers will create wind conditions that make the use of external shading impossible or unpractical. When a building reaches 15 stories or so (there is no absolute figure, it depends on the location and the construction mode), solar shading is mostly limited to interior products – unless the building has a double skin, in which case the ideal integrated position is used.
- The *character* of the building: certain monuments, historic buildings or cultural institutions often demand special considerations that may have an effect on the choice of the system.
- *Regional preferences*: some products prevail in certain countries while in a neighbouring country another product may be more common. Among the external products, Germany and Norway seem to prefer outside Venetian blinds, whereas Denmark, Holland and Belgium show more external vertical roller blinds ('screens'). A development due to the industry's efforts, with an effect on the preferred choice.
- The building's *construction details*: depending on the design, solar shading may or may not have been planned for. If not, the mounting possibilities for external solar shading must be checked before a choice of product is made.
- The *user's expectations and behaviour*: this is a major point of interest. Many buildings are for the rental market where the user is not known at the time of the design and the construction. Buildings that are planned by the owner for his own use will take the expectations into account – in as far as all aspects are thought through early enough. Companies in the knowledge industries (auditors, engineers, lawyers etc.), even if they rent the buildings, often have a strict specification for the buildings they wish to rent. Automation of a solar shading system is needed, but there should be sufficient attention for the user's comfort. More on this in next the chapter on Automation.

In any event, professional advice from the solar shading industry will help select the best product for the application.

7 AUTOMATING AND INTEGRATING SOLAR SHADING

Summary

The benefits of a solar shading system in terms of improved indoor comfort, better visual comfort, energy savings and use of natural daylight can only be harvested if the system is automatically controlled. It will then work properly even when the occupant is absent and it will react to the sun and the wind without requiring any attention, which is important for the energy-saving aspect. In this chapter we will show how this can be done, from simple, stand-alone systems to sophisticated, large-scale bus-systems, fully integrated into advanced building management systems.

7.1 Automation and personal control

A number of things are expected of a newly installed solar shading system: it should provide improved indoor comfort and offer maximized energy savings, but it should also accommodate the personal – very subjective – wishes of the occupants, be they tenants or owners. External shadings should also be secured from damage by strong winds or other extreme weather conditions. If a shading system were to be manually operated, achieving these contradictory conditions would be almost impossible. How to calculate the contribution to energy efficiency of such a system if one cannot – or only partly – model human behaviour? How can you make sure that the system responds to the need for protection against wind and snow, or that it does not stand in the way in case of a fire alarm? That's why ample time and attention should be given to the study and selection of an automatic control system. Motorized blinds, at least if they are exterior, are now almost standard. But the control system for the motors should be carefully studied so that the system gives maximum satisfaction to both occupants and building owners.

If manually controlled systems have severe limitations, as indicated before, should

every system then be fully automated? And if so, what do we do with the strong tendency of the occupants of a building to have their own preferences and a desire to change the settings? In fact, neither a fully automated system, with no facility for personal override, nor a purely manual one is ideal. The best solution is to connect the motorized blinds or shutters to a central control system for optimum energy efficiency, while at the same time allowing people inside the building to interact via local controls during defined hours of the day and within certain limits. Experience has shown that this adds greatly to occupant satisfaction. In case of a rented building this often is of even higher interest to the owner of the building.

7.2 The sensors

What triggers the automatically controlled solar shading system or shutter? If the three major objectives of an automatic control system are to create better comfort conditions inside, to realize energy savings and to secure the system from damage, the system needs sensors that will track the actual climate conditions around the building. Obviously, this is only true for exterior solar shadings, but many of the underlying principles might also be applied to interior blinds. The most frequently used sensors are:

The **sun sensor**: this device – the most important one – reacts on the incident radiation, both direct and diffuse. The level can be measured in W/m^2 or lux. The setting of the sensor – usually 150 to 200 W/m^2 or 15,000 to 20,000 lx – determines the threshold value above which the solar shading system will be called into operation. For optimum performance, each façade may need a separate sensor, sometimes more than one, because vertical irradiance on a particular façade determines the amount of energy that enters the building.

There are also devices that combine several sensor functions, such as incident radiation, wind and rain. The figure at right is an example of such a combined sensor.



Photo: Elsner

Figure 7.1 Sun sensor.

The **wind sensor**, also called anemometer, registers the speed of the wind and translates the values into meters per second. The setting of a threshold value of this sensor determines the maximum wind speed for the solar blind above which the blind will be retracted and protected from damage.



Photo: Somfy

Figure 7.2: Wind sensor.

The **wind direction sensor** monitors the average direction of the wind and is used in combination with the anemometer to give the central control unit information on which façade should possibly be blocked in the 'up' position (shading device retracted) because of too strong wind. In smaller projects normally only wind sensors are used and placed on the different façades. On medium-size or larger projects a combination of the two can be used to manage the whole building from a sensor mast on the roof.

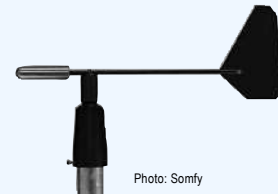


Photo: Somfy

Figure 7.3 Wind direction sensor.

The **outdoor temperature sensor** measures this parameter in case the system is programmed to take this into account. In most cases, it is linked to an inside temperature sensor.



Photo: Somfy

Figure 7.4 Outdoor temperature sensor.

The **rain sensor** tracks precipitation and is only reacting with an 'on' or 'off' signal, for those cases where the system is unsuitable for rain.



Photo: Somfy

Figure 7.5 Rain sensor.

The following sensors are designed to be used inside the building:

The **indoor temperature sensor** is a thermostat measuring the indoor temperature and may be used in combination with the outside temperature sensor to decide how the solar shadings could assist in keeping the building in balance.



Figure 7.6 Indoor temperature sensor.

The **occupancy detector** will monitor presence of human beings and allow the setting of shading devices in an active or energy saving position: 'down' in cooling season with significant solar irradiance, 'up' in heating season with significant solar irradiance.



Figure 7.7 Occupancy sensor

Several of these sensors have not been very common in the recent past as the attention was mainly addressed to the activation of the shadings on the basis of the presence of the sun and their protection from wind damage. But today the story is changing as the industry allows taking into account not only indoor climate but also glare control, energy use and personal settings. The interaction between solar shading, lighting, heating, ventilating and cooling can be obtained with the help of a control system.

7.3 Types of automatic control systems

On the market today, there is a great choice of products and systems to automatically control solar shading systems. Since the focus of all governments is on energy savings in buildings and since the benefits of solar shading in reducing the need for air conditioning have been recognized, the industry has developed a very wide range of control systems. At one end of the range, there is the basic

system that activates the solar shading when the sun is present, protects it from excessive wind and is possibly combined with a simple time function. These are developed for private houses but are frequently used for small commercial installations like on a café or small shop. To reap the full benefits in energy efficiency, a more developed solution is required. This can be done in two ways. Either with a ‘stand alone’ solution developed specifically to manage solar shadings only, or an ‘open’ solution, based on BUS technology like KNX, LON or BACnet and developed to manage several integrated building systems at the same time. Let us take a closer look at each option.

7.3.1 Stand-alone solutions

Not all projects are for large, new buildings and very often it is existing buildings that are retrofitted with solar shading. In most of these situations a stand-alone system is preferable. The solar shading industry today offers a rich selection of these systems, often ‘plug-and-play’, yet functionally mature and with built-in vital and energy-smart functions. The input for those systems is simple and limited: mainly the threshold values for sun, wind and temperature. Often these systems feature smart timers that can be used for blocking the shading systems during weekends, and often there is a connection with a smoke detection or fire alarm system. They are generally easy to understand and to operate, so that they can be

managed by the local operational or maintenance staff. In most cases this is a very cost-efficient solution compared to open BUS solutions. To have a reliable comparison, not only the control equipment should be included, but also the cost of the electrical wiring and installation, of the integration in case of a BUS system, and the commissioning.

The small-size solution can be used in a private house or for a small school, a small office, a day care centre etc. Normally there are 1 to 4 controls groups and the possibility to connect sensors for sun, wind, temperature and possibly rain. A connection to local controls for individual purposes or for subgroups is often also provided. The number of motors controlled does usually not exceed 40.

The medium-size solution offers a lot more features. The number of control groups is increasing to 15 to 20, which allows to cover the need for most office buildings, schools, hospitals or hotels. More sensors can be connected and the level of functionality will be much higher, enabling the user to combine optimized energy savings with local control, reset functions, dry contacts to heating and cooling, etc. There might also be a computer connected logging all events and values, managing the system, enabling remote access for the solar shading installer and offering a connection to a building management system (BMS).

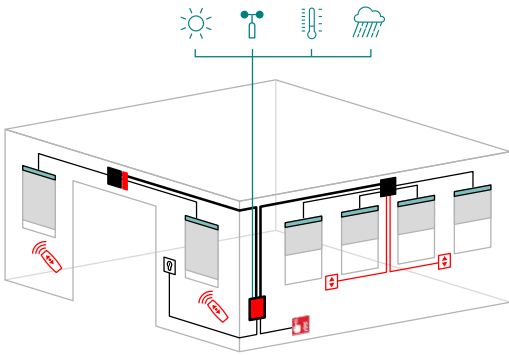




















Figure 7.8 Schematic of a small size control solution.

Table 7.1 Legend to control schematics.

	Motorized blind
	Building controller
	Bus interface
	PC with programming/user interface
	Building management system
	Blind/shading controller
	Wireless control interface
	Central alarm
	Radio receiver
	Connection box
	Key switch contact
	Wired wall switch
	Remote control
	Sun sensor
	Wind sensor
	Temperature sensor
	Rain sensor
	Wind direction sensor

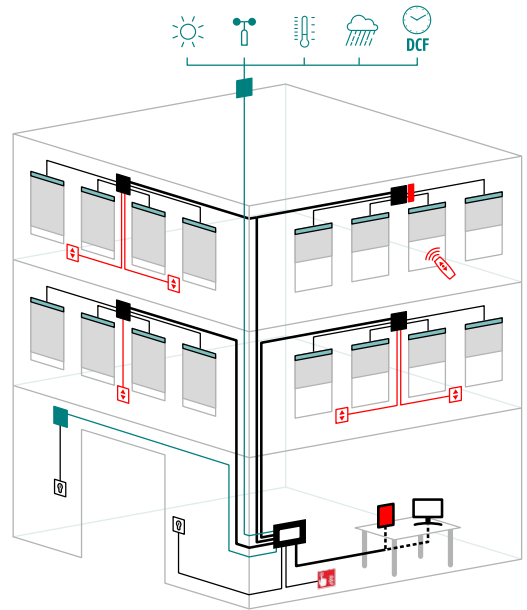


Figure 7.9 Schematic of a medium size control solution (legend see Table 7.1).

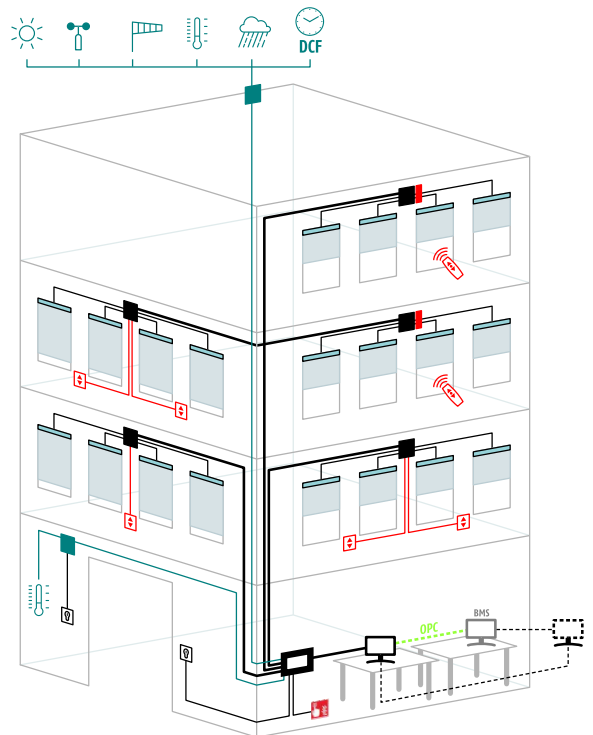


Figure 7.10 Schematic of a large size control solution (legend: see Table 7.1).

7.3.2 Open bus systems

In many buildings installations like heating, lighting, cooling, roller shutters and solar shading were traditionally considered like islands: they were operated separately and did not interact. Any possible influence of one technology on another was basically ignored. In a philosophy of energy efficiency, this is no longer the best solution. The answer is in home automation (sometimes called ‘domotics’) which allows to intelligently connect all the elements of these islands and to take into account the influence of one system on the others. This system is called a ‘bus’. A bus is a network in which all devices are attached directly to a line and all signals pass through each of the devices. Each device has a unique identity and can recognize those signals intended for it. The market already offers a wide range of different solutions, but the most common and well known are KNX (previously called EIB) and LON. Each of these is based on an ‘open’ data transfer language that is non-proprietary and allows different suppliers to connect to the ‘bus’. It allows the user to create a control strategy that is best adapted to the circumstances. Obviously, this ‘tailor made’ work has a cost, as the connections have to be created by a systems integrator, but it offers total flexibility for creating and changing control groups, using and changing various sensors, etc. In case of internal changes or renovation, systems can be reprogrammed when partitionings are moved or rooms are reassigned a new function. All motors, sensors, switches etc. are assigned an individual address as an identification which is used for operating them via the software. That is why it is called an ‘addressable system’. Sensors can be set at different threshold values, depending upon their position and

the use of the rooms. When the partitioning is changed, the control groups can be modified and adapted without any physical change of wiring, just by changing the programming. The solar shading system is connected to the fire alarm system, for example, so that all the blinds at unobstructed windows will go ‘up’ in case of a fire alarm. In similar ways, the system will take into account commands from the heating and cooling system, the lighting system and the access control system, to name but a few. The flexibility is almost limitless, but early contact between the system integrator and the supplier of the shading systems is essential so that the full benefits can be reaped.

7.3.3 Connections to other control systems

Computer technology and advanced software today offer vast possibilities to interconnect systems in a building. But that does not automatically mean that better results in energy efficiency or user satisfaction are obtained. It is easy to overdo things and make the daily use of the systems more complicated than needed. Therefore, it is recommended that a few simple questions are answered before a control system is configured:

- What functions do we really need?
- Why do we need them?
- How would we use them?
- Is there really a significant saving?

These questions are not easy to answer. An building physics engineer or a professional solar shading consultant may be helpful, while a good dose of common sense (Keep It Simple) may be of assistance.

7.3.4 Some other considerations

It may appear as if this chapter presents automatic control as an ideal system. Some customers however report that the practice often shows problems. To avoid this and strive for a perfect operation, the planning and execution of the control system must be done properly. First of all, a detailed specification should be written before the control system is chosen to avoid a poor functionality, the resulting dissatisfaction and higher maintenance costs. A short checklist is helpful and should cover the most important factors in a discussion that should involve both the solar shading installer and the electrical contractor. There is no single recipe for a perfect installation but bearing in mind a few basic considerations may help:

About the sensors.

- Sun sensor: always needed, but where should they be placed? They should provide good data for the controller but must also be accessible for maintenance. Carefully choose the reading angle of the sensor.
- Wind sensor: for outdoor applications only. Take into account the maximum wind load of the shading system. Place them for a relevant reading of the wind and remember that wind behaves strangely in some cases.
- Frost: this is not a separate sensor, but if problems with ice are expected, programming of the combination of rain, frost and time can trigger an ice warning and block the solar shading system to protect it.
- The placement of sensors should always be discussed with the solar shad-

ing installer and be documented on the façade drawings in combination with the definition of the control groups or zones. This will also allow the electrical contractor to plan properly for the wiring through the façade etc.

About the settings.

- One of the most common complaints from end users is that the system will "yoyo" up and down when the weather varies and sun and clouds will alternate. Introducing hysteresis will keep the system in place when the sun suddenly disappears – or reappears – for a short time. What is the ideal delay time to set? Impossible to answer as it relates a lot to human perception and local circumstances. Often values of 8 to 10 minutes or more are used and an evaluation is to follow after a few weeks.

About the commissioning of the system.

- When using stand-alone solutions always make sure that the solar shading installer has an active responsibility in the commissioning, in the follow-up after some time and in training relevant persons on location. This helps secure a long lasting and satisfactory installation.
- When using open systems like LON or KNX it is often a task for the system integrator to create and program all functions. Unfortunately experience shows that their knowledge of solar shadings is very limited, resulting in a simple sun/wind and up/down functionality which might result in loss of energy efficiency and of user comfort. The solar shading installer

should be actively involved in advising the integrator or even take responsibility for part of the actual integration.

- Information to the end users is a vital point that very often is lost in the process. This is important for the user satisfaction and for obtaining the expected energy savings. Make information accessible to all users about the general functions of the automatic system, why the shades might be up on a sunny day – because of wind alarm – or on how to use the local control in their room. This could be

solved via the local intranet, as a pdf file or in a short meeting.

About maintenance.

- Like any other system with moving parts, solar shading installations require a minimum of maintenance. A budget for a yearly check-up should be available which will prevent problems, avoid surprises and secure a long lasting installation. An LCCA (Life Cycle Cost Analysis) is useful. Such an analysis can be downloaded from the ES-SO website, www.es-so.org.

8 EXISTING BUILDINGS

Summary

The existing building stock is much bigger than any total of new constructions at a given time. That is why European initiatives to make buildings more energy-efficient must focus on the existing built environment and its colossal savings potential. Twenty or thirty-year old buildings do not seldom have energy consumptions of 250 kWh/m².a, sometimes much more. The present state-of-the-art is well below 100 kWh/m².a, with countries like France aiming to make it mandatory to have new buildings at maximum 50 kWh/m².a. The number refers to the energy consumption for heating, cooling, lighting, hot water and ventilation, but excludes energy for 'plugged' appliances. Given the total number of existing square meters, this is a gigantic source of possible savings. Windows are part of every refurbishment project and solar shading should be part of every window.

Obviously, measures to reduce energy consumption cannot be limited to new buildings only. The existing building stock makes up for the very large majority of the built environment and new construction represents only 1 to 2% of the total per year. That explains why, understandably, the Recast EPBD of 2009 has considerably strengthened the new rules for renovation by eliminating the 1000 m² threshold for refurbishment. In the original EPBD (2002/91/EC) buildings under that limit undergoing major refurbishment did not need to comply with the objectives of EPBD. That exception has now been removed so that, as soon as the Recast EPBD will be applicable, a very important market for energy saving measures in refurbishment projects will take off. At the same time, the scope of the Eco-Design and the Energy Labelling Directives has been extended from energy-using products to all energy-related products. This means that the European Commission will start studying whether implementing measures covering windows would make sense in order to fix minimum performance requirements and/or label these products similarly to what is being done for household appliances with the A to G rating.

There are plenty of well-publicized, successful refurbishment projects in which massive energy savings have been realized. One of these, located in Frankfurt, is often mentioned by experts from the International Energy Agency (IEA). Using passive house technology, measured energy consumption was reduced by an impressive 87%.

8.1 The window replacement market

EuroWindow, the European umbrella organization of the window and door industry, estimates that approximately 1000 million square meters of window surface need to be replaced in the EU. That was the number still in place in 2009 with single-glazing and first-generation double glazing. Between 100,000 and 200,000 GWh/a could be saved in this renovation market, if new, energy-efficient windows were installed. "Energy-efficient windows include low-e glass, solar control glass, thermally improved profiles and spacers as well as blinds and shutters and improved air tightness", says EuroWindow's position paper of January 2009⁵, suggesting

⁵ "The European house needs better windows", EuroWindow, Brussels, January 2009 (www.faecf.org)

that blinds and shutters are part and parcel of modern windows. Almost simultaneously, in its “Proposal for Energy Rating System of Windows in EU”, the Danish Technical University⁶ concludes that “as the solar gain becomes high in the summer period, it is necessary to include summer conditions for windows in a labelling scheme where dynamic solutions for summer comfort could be used also”. ‘Dynamic solutions for summer comfort’ is another word for operable solar shading.

The refurbishment market holds great potential for both the solar shading industry and the HVAC business, as energy-efficient installations obviously are part of the solution for energy-efficient buildings. Installing solar shading or shutters on existing buildings at the time of the replacement of windows has been good practice since many years. Given the synergies between glass and solar shading and the great need to realize energy savings, it is necessary to look closely at every renovation job and choose the best combination of glass and solar shading, for maximum energy efficiency and comfort. Building physics simulation programs can give a fair indication of the effect of a given combination of glass and solar shading (external or internal) on the indoor temperature and on the energy needs for heating and cooling. We all now have increased expectations for our comfort level and the availability of relatively cheap, portable air conditioners is a great danger for more energy waste and for huge demands on the peak load of our electricity grids. Shading, mainly external solar shading,

can help reduce the peak load and avoid the investment in additional power plants or specific peak load plants.

8.2 Retrofitting solar shading

All too often, property developers put buildings on the market without proper solar shading solutions. In office buildings in particular, tenants frequently move into spacious, brand-new premises and find almost immediately that the light conditions are unsatisfactory, that too much sunlight is coming into the building and there is no provision for controlling the light levels and avoiding glare. The first thing tenants then have to do is get some sort of solar shading to reduce the contrast levels. Moreover, very often in buildings without air conditioning overheating will occur in summer times and working conditions will deteriorate. Therefore, the solar shading market is often a market for retrofitting existing buildings where solar shading has been neglected in the design stage.

For internal solar shading, this is normally not a big problem. But for external systems, it can be more difficult to fit shading neatly to a building that has not taken it into account on the drawing board. Professional advice is needed to achieve both a good functional performance of the system and ‘good looks’. The industry has the solution.

The pictures on next page show what can be done – or how desperate the needs are when nothing has been done in the original design. Figure 8.1 on the left shows a school class in a building where no provision had been made for good visual comfort. The improvised solution by the stu-

⁶ Jesper Kragh, Jacob Lauststen, Sven Svendsen, “Proposal for Energy Rating System of Windows in EU”, DTU Civil Engineering, Lyngby, Denmark, December 2008 (<http://www.byg.dtu.dk/www.byg.dtu.dk>)

dents and their teachers may appear farcical, but it shows how strong the need is. Later on, a professional solution was chosen, shown on the right. Figure 8.2 is of another dimension. A big Belgian bank moved into a spectacular new head office with several large glass atriums. As the bank's staff numbers grew, the luxury of

abundant natural daylight quickly collided with the discomfort from glare caused by the glass roofs. Huge internal roller blinds, up to 15 meter long and 2.5 m wide with special fibreglass fabrics were installed to improve visual comfort. The blinds are controlled by the position of the sun and are remotely monitored by the manufacturer.



Figure 8.1 A British school class, before and after.
[Photo: De Leeuw Ltd]



Figure 8.2 A bank building in Belgium, after the installation of blinds to cut the glare.
[Photo: Hunter Douglas, Helioscreen]

9 DOUBLE-SKIN FAÇADES

Summary

Currently transparent building envelopes represent an important architectural trend in commercial buildings. The skyline of most major cities nowadays is characterised by tall, fully glazed office buildings that often become an attractive landmark. The Post Tower of Murphy/Jahn Architects Inc. in Bonn (Germany) is one of these landmark buildings that have a very distinct personality. Very often, these iconic buildings are double-skinned. How does that affect the solar shading technology?



Figure 9.1 Post Tower in Bonn, by Murphy/Jahn, Inc. Architects. [Photo: Scheldebouw-Permasteelisa]

9.1 The rationale for double skin façades

Architects love to design highly glazed office buildings, offering both more natural daylight and better contact with the outside world while expressing a corporation's philosophy of transparency. Whereas conventional buildings may have 35 or 40% window surface in the exterior wall, highly glazed buildings are almost all-glass and although they

present many challenges, certainly from an energy and comfort point of view, they have become very popular and most high-rise buildings look that way nowadays. But can these buildings respond dynamically to quickly varying outdoor weather conditions and to changing occupants' needs? Solar shading is part of the solution to that problem.

The current architectural trend toward fully transparent façades with clear glass over the full height of the façade can create several difficulties:

- excessive heating demand during the winter;
- overheating of the building and/or high cooling requirements during the summer;
- a difference in surface temperature of external and internal walls resulting in discomfort for the occupant placed near the façade, e.g. draughts and asymmetric radiation;
- difficulties in demonstrating compliance with ever more stringent energy regulations and comfort requirements.

Double skin façade (DSF) technology has been developed to take care of these problems and to increase the building's energy performance and indoor comfort.



Figure 9.2 Solar shading blinds in the cavity of a double skin façade of The Helicon in London (Arch. Sheppard Robson). [Photo: Scheldebouw-Permasteelisa]

A double skin system consists of an external glazing, a ventilated cavity and an internal glazing. There are two types:

- *Naturally ventilated façades*, also called *interactive façades*, composed of an external single layer of glass and an internal double glazing unit. The cavity between the two skins is naturally ventilated with outdoor air, which comes up through the base of the glazing and returns to the outside at the top.
- *Mechanically ventilated* or *active façades* are composed of an external insulating glazing unit and an internal single layer of glass. The cavity bet-

ween the two skins is ventilated with return room air, which is extracted from the room at the base of the glazing and returned to the air-handling unit at the top.

Solar shading is placed in the cavity where the ventilation (either natural, buoyancy driven or forced, mechanically driven, or mixed) creates an airflow, upwards or downwards, which depends on the type of ventilation and the general system design. The internal glass skin can be operable for cleaning and maintenance purposes, which may allow for natural ventilation of the indoor environment.

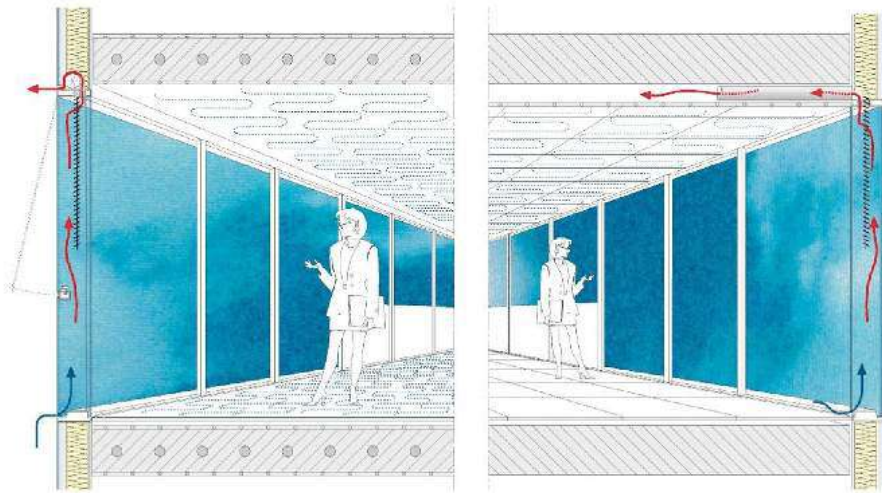


Figure 9.3 Schematic: Interactive façade (left) and Active façade (right).
[Photo: Scheldebouw-Permasteelisa]

9.2 Function of the solar shading system in the double skin façade

Shading systems can be placed between the two skins and thereby combine the benefits of both external and internal solar control. In this way the shading system can be used all year long and will not be influenced by wind or other outdoor conditions. The combination of intermediately placed solar shading and ventilation of the cavity is the major advantage of double skin façades. The solar shading system will absorb the short wave radiation that enters the cavity of the double skin façade and part of this absorbed energy will be evacuated via the ventilation (natural or mechanical) in the cavity. This will result in a lower g-value of the façade, and a better indoor climate.

In the following pictures the thermal simulation is shown of a conventional single skin façade with an internal shading system compared to a double skin façade with a blind system in the mechanically ventilated system.

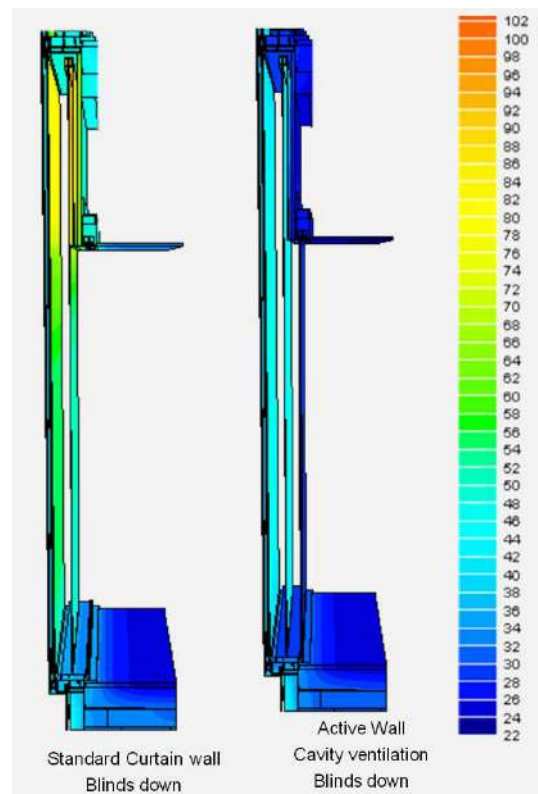


Figure 9.4 Thermal simulation of a conventional single skin façade with an internal shading system (left) compared to a double skin façade with a blind system in the mechanically ventilated cavity. [Photo: Scheldebouw-Permasteelisa]

The strength of most double skin façade systems is that the façade can be designed to have variable properties so that both solar gain and heat loss through the façade can be optimised by the use of a building management system (BMS). The system performance depends on numerous design parameters (glass type, blind type, blind setting, airflow rates and panel geometry), nevertheless, in order to allow a rough comparison, a set of indicative performance parameters is given in Table 9.1.

Given the all-glass structure of the façade, selection and installation of solar shading systems deserve special consideration and great care. The type of glazing and the nature of the ventilation of the cavity will have a considerable influence on the performance of the shading system. Professional advice is required. As an example, the colour of the shading device will be important. Dark colours will absorb more heat while lighter colours will reflect more of the solar energy. This will influence the temperature of the shading device and its temperature build-up inside the cavity.

Choosing for innovative façades and environmentally sound systems does not necessarily represent an additional cost if

the design of the building is considered in a holistic approach. The synergies between the façade and the environmental system will result in a better visual, thermal and acoustic performance, improved occupant comfort, hence increased productivity, and also energy savings and reduced HVAC system cost.

9.3 Energy fluxes in a double-skin façade

Figure 9.5 illustrates the energy fluxes in a double-skin façade. The influence of the sun consists of the direct q_t and indirect solar gains q_i , consisting of a convective (q_{ci}) and radiative (q_{ri}) component (see section 4.2). The product of the transmission coefficients of the different layers can be used as a first estimate for the direct gains, while the heating of the cavity, which can be considerable, determines the indirect gains. However, the air flowing through the cavity also has an influence on the energy performance of the building and should be taken into account (q_v). Both in winter and summer the air heats up. In winter this contributes to a reduction of the heating demand, while in summer the additional gains should be removed to prevent an increase of the cooling demand.

Table 9.1 Indicative performance parameters (whole façade).

Façade type	Light transmittance	g-value	U-value	Acoustic insulation
	τ_v [-]	g [-]	W/m ² K	[dB(A)]
Conventional fully glazed	0.5 – 0.6	0.30 – 0.40	2.0	32 - 34
Naturally ventilated	0.6 – 0.7	0.10 – 0.20	1.4	32 - 34
Active wall	0.6 – 0.7	0.15 – 0.25	1.0	36 - 40
Interactive wall	0.6 – 0.7	0.10 – 0.20	1.2	36 - 40

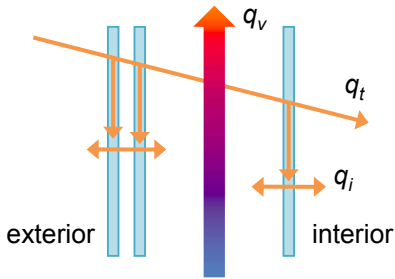


Figure 9.5 Energy fluxes in a double-skin façade due to solar radiation.

When integrating shading devices in double-skin façades it is important to realise that the cavity may become very hot, increasing the indirect solar gains. In order to realise the best shading for the building it is imperative to reduce the build-up of the heat in the cavity and to prevent this heat from entering the building. To reduce heat build-up, the cavity can be ventilated so that the excessive absorbed solar radiation is transported away. Care should be taken that this removed heat is not transferred to the building through unexpected ways, such as un-insulated exhaust ducts returning from an airflow window. Preventing heat from entering the building can be realized by well insulating the cavity from the building.

Figure 9.6 illustrates the influence of the position of the shading device on the cooling demand of an office building. Two double-skin façades and two traditional cladding systems with exterior (IGUe) and interior (IGUi) shading device are analysed. The first double-skin façade is a mechanically ventilated airflow window (AFW) with insulated glazing at the outer part of the cavity and the inner glass (a normal clear float glass) at the inside. The second double-skin façade is a naturally ventilated façade (DSF) in which the insulated double glazing unit is positioned at

the inside of the building. The cooling demand strongly depends on the indirect solar gains. Despite the higher direct solar gains, the IGU with exterior shading device (IGUe) has the lowest cooling demand. It shows that the best option to reduce to indirect gains is to prevent the solar radiation from entering the building. The IGU with interior shading device (IGUi) not only has a high direct solar gain but also suffers from high indirect solar gains. As a result it requires 55 % more cooling energy than the IGUe. The AFW does not perform much better. Although it has lower direct solar gains compared to the IGUs it has high indirect gains because the single glass at the inside does not insulate the cavity well from the building. The DSF is able to approach the performance of the IGUe as it has an inner pane with high thermal resistance.

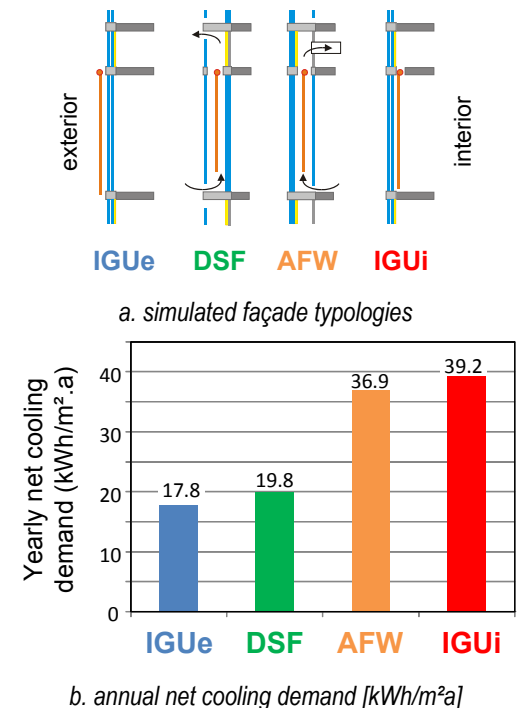


Figure 9.6 Simulated annual cooling demand for a typical office building.

10 MAINTENANCE OF SOLAR SHADING SYSTEMS

Summary

The intensity of the sun's radiation, both in terms of light and heat, varies enormously over time, and may change tenfold time and again in the course of one day. Mobile solar shading, certainly when automated, helps control the entry of both light and energy from the sun. But 'mobile' means that the system may be operated several, often many, times a day. Systems with moving parts need maintenance. As we can see in the cityscape, external solar shading systems are often left without any serious maintenance for years. That creates problems: they become dirty and may not function properly. We offer a few ideas to promote the practice of regular maintenance and to avoid unpleasant experiences and unwelcome repairs. Because properly maintained and automated solar shading systems will greatly improve indoor comfort conditions and occupant satisfaction.

In the text of the EPBD recast 2008/0223 (COD), as agreed by the Commission, the European Parliament and the Council in November 2009, recital 20 states: *Regular maintenance and inspection of heating and air conditioning systems by qualified personnel contributes to maintaining their correct adjustment in accordance with the product specification and in that way ensures optimal performance from an environmental, safety and energy point of view.* This is a very important subject indeed and it applies equally well to solar shading systems. Especially the mobile and automated systems with many moving parts, must be installed correctly, adjusted properly and have a minimum of regular maintenance. Enjoying the comfort and energy-saving benefits of solar shading systems requires that the right decisions are taken in the various steps of a construction project. A few suggestions, some of which may be a reminder of what was said in earlier chapters.

- Integrate the solar shading system *in the initial design*. Very often, solar shading is 'forgotten' in the design stage while later on the owner or the occupant feels the need for it and then has to install systems for which no

provisions have been made. Solar shading will be a very attractive addition to the building, if the systems are planned early enough.

- Think *practical* and aim for efficiency. Frequently, architects will be driven primarily by aesthetic considerations and will make a choice that is pretty -- but not necessarily best-in-class. Solar shading systems can be both attractive and efficient. A professional advice from a qualified vendor, critically examined, will lead to the best choice, satisfying both the architect's wishes and the end-users' expectations.
- Make sure the operating conditions are *within the technical limits* of the selected solar shading system. This would seem to be an obvious requirement, but leads often to discussions and disputes. Maximum sizes of systems should be respected, as is the case for the distance between an external shading system and the window, or the maximum wind resistance. The industry offers a great choice for virtually any application, but certain limitations of physical nature or of technical feasibility must be taken into account.

- Take great care to have the systems *properly installed*. This is crucial: flawed installation work can ruin the effect of a well-chosen, early-designed system and bring about conflicts about responsibilities. Proper installation according to the manufacturer's instructions will also ensure that all safety measures have been respected and the system is in conformity with safety-in-use regulations.
 - Make sure the *control settings* are right: as has been explained in Chapter 7, the automatic control system responds to certain parameter settings: the light level at which the system kicks in (representing the amount of impinging solar energy), the wind speed at which it will be retracted, the temperature below which it will not come down and more, depending on the degree of sophistication. It does happen that the optimum settings for energy efficiency collide with the user's preference. Make sure this is discussed so that the occupant is happy with the performance of the system.
 - Place the sensors in an *accessible* way: make sure they can be reached for adjustment and maintenance without avoidable cost for sky lifts or other special equipment.
 - Make sure there is an *annual check-up* of the system by a qualified solar shading professional. The function of the solar shading system must be verified regularly, but at least once a year. Maintenance and cleaning instructions should be provided by the manufacturer and must be followed.
- The use of original spare parts is important.
- Essentially for external *textile* solar shading systems: when choosing the solar shading material, consider the quality in terms of easy cleaning properties, physical strength and constancy (durability) of colour and construction. Also: provide for the replacement of the textile cover after 5 to 10 years, depending upon location.
 - Wherever possible make an LCCA (*Life Cycle Cost Analysis*): maintenance and cleaning cost should be part of such an exercise. Regular preventive maintenance has a cost but ensures continued reliable performance of the system and is to the benefit of an optimum life cycle cost.
 - Seek an *extended warranty* on your shading system: suppliers should be requested to extend the warranty on the systems in exchange for a maintenance contract. This is an excellent way to keep the systems in perfect condition with a predictable maintenance cost.
 - Make use of state-of-the-art *control systems*: if properly automated, solar shading systems will result in improved indoor conditions and savings on the cooling load and the heating energy needs. The industry today offers flexible control systems that can be easily adapted to changing occupants' needs, by adapting the system's algorithms when required. In some cases, remote monitoring of the solar shading systems allows for easy troubleshooting and early detection of problems.

Summary

How does it look? What is the benefit? These questions often come up in discussions about the many possible solutions of solar shading. In this chapter we will show a few selected cases from around Europe and we will try to explain what special effects of the solar shading were expected. These cases are just a few among many, many others and are mainly shown to visualize what solar shading could look like.

■ *Trafalgar House, an office building in Croydon, UK*

When ING REAL ESTATE in 2007 developed an office building for the Land Registry in Croydon, a major commercial center in south London, one of the requirements for PRC Architects was that the building should qualify for a BREEAM Excellent rating, the maximum under this assessment method. Called Trafalgar House, the building did obtain the expected rating and the £10M striking nine-storey development has become a UK benchmark in sustainable building design.

Government buildings should be exemplary when it comes to energy efficiency and environmental qualities. That is why the Land Registry – a government department responsible for keeping records on registered land in England and Wales – had this ambition. On the south and west façades, 400 mm structural solar shading (moving aerofoils) were installed. The lower part of the window is left uncovered to allow visual contact with the outdoors. The east façade was shaded by the adjoining building and the main access core. The top floor remained uncovered, providing an uninterrupted view across London. This top floor is protected from the sun by horizontal sun louvers which project 1400 mm outwards from the top of the building.



[Photos: Hunter Douglas]

The design challenge really began when focus was laid on limiting CO₂ emissions during the exploitation phase of the building. One of the key elements proposed to achieve this was that the building was to have no mechanical cooling and be naturally ventilated. Figure 11.1 shows the venting and shading concept.

Fresh air is drawn into the raised floor through automatic opening vents in the perimeter wall. If the external temperature drops, fresh air can be drawn in, partly or fully, from mechanically supplied ducts shown at the right of Figure 11.1. This air is then fed into the building through swirls set in the raised floor panels. Hot air rises and transfers heat to the concrete slab above. When the internal temperature level rises above a set level, the high level

windows will open automatically to let the air out. Alternatively, as the temperature balance changes, air can be extracted mechanically through the extract duct. To reduce solar heat gain, fixed external sun louvers are employed. At each level all the windows can be individually opened, so occupants can open or close windows to suit their needs locally. Internally, Venetian blinds are provided to give individual users the ability to control solar glare, whilst allowing a certain amount of heat gain in the winter. Radiators around the perimeter of the building will supply the remaining heat as required in winter. The complex combination of high and low level vent openings and air being compensated from the mechanical plant is controlled by a Building Management System (BMS).

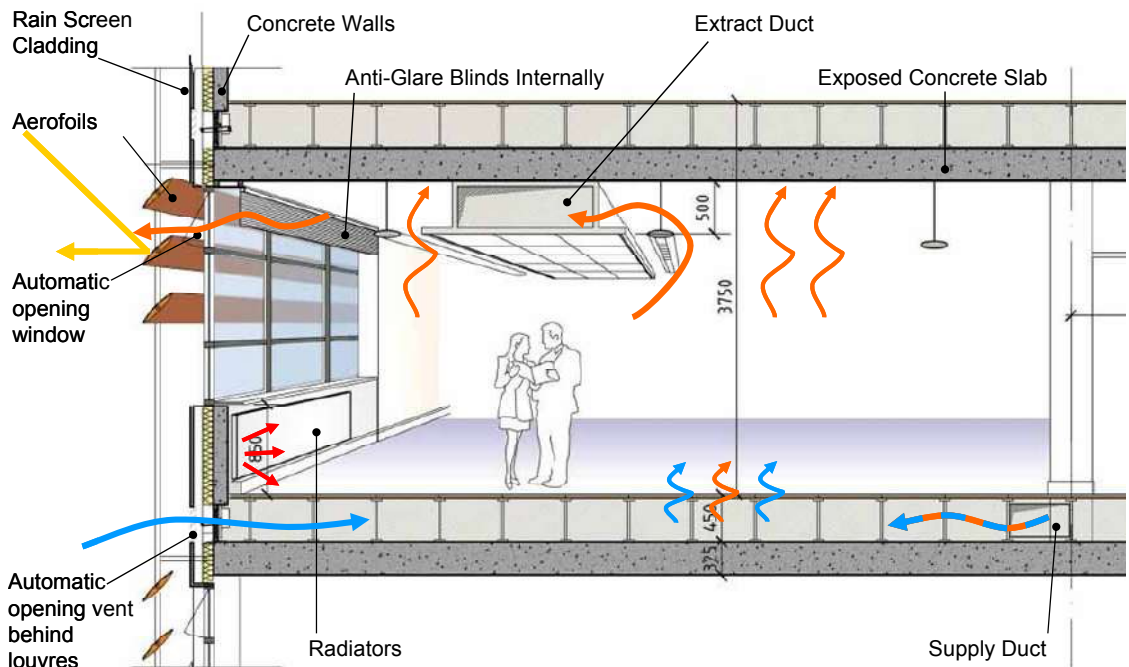
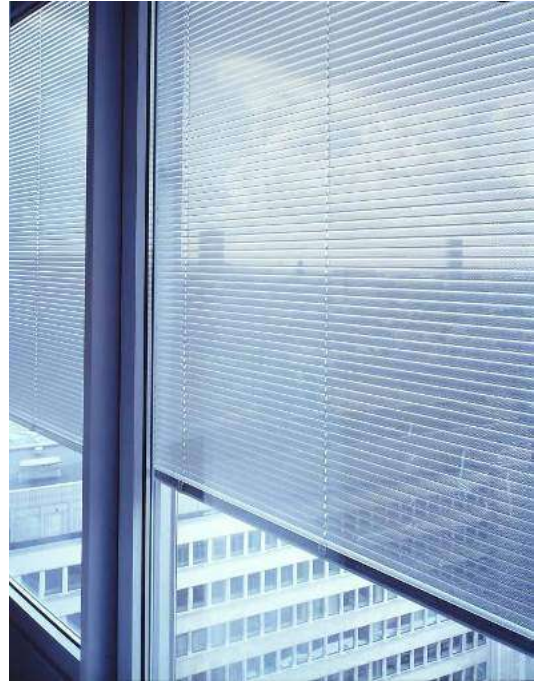


Figure 11.1 Detail section of a typical floor, demonstrating the venting and shading concept (Trafalgar House, an office building in Croydon, UK). [Figure: Hunter Douglas]

■ *Central Plaza, an office building in Brussels, Belgium*



[Photos: Hunter Douglas, Helioscreen]

CENTRAL PLAZA is the name of a recently completed 23.000 m² office building of 15 floors in the centre of Brussels. It was built on the site of the former headquarters of the Belgian National Lottery, next to Brussels Central Station. In a joint venture between MONTOIS PARTNERS and ART AND BUILD, the architects succeeded in delivering a state-of-the-art, comfortable facility that is appreciated by the occupants for its pleasant working environment. Owner FORTIS REAL ESTATE has located several of its services in the building which is also home to a large international law firm.

Controlled by a central façade management system, 1033 motorized perforated Venetian blinds take care of the visual comfort of the office space. The blinds are integrated into the building’s double-skin façade. In a press release, the tenant – a well-known international law firm – boasts the merits of the building’s “high level of comfort, abundant natural daylight and flexibility”, as well as “the low energy and operational costs thanks to the use of modern technology”. Chilled ceilings take care of the cooling needs.

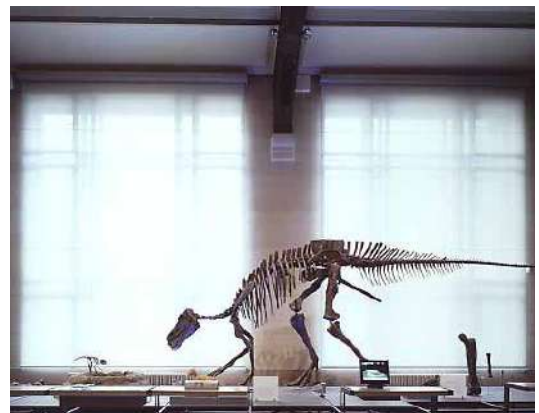
■ *Royal Belgian Institute of Natural Sciences, Brussels, Belgium*

Climate monitoring, nature conservancy, zoological and geological research are only a few of the activities of the Royal Belgian Institute of Natural Sciences (RBINS) in Brussels. It is also a museum with a leading position in the fields of anthropology and prehistory. Founded as early as 1846, it has been located since 1891 in one of Brussels' monumental buildings, which was part of King Leopold II's grand Belgian construction schemes.



Recently, a major part of the Institute has been renovated. As part of this renovation program, a completely new dinosaur hall, the largest in the world, was inaugurated. SUM, a Brussels-based architectural practice, took special interest in the light distribution inside the museum. Large-size internal roller blinds have been chosen to gently filter the daylight and protect the exhibits from harsh, intense sunlight.

The RBINS is not the only cultural institution taking particular care to protect its valuables from solar heat and light. The Brussels Museum of Musical Instruments also chose a specific solar shading solution to reduce the luminance levels on its rare antique treasures.



[Photos: Hunter Douglas, Helioscreen]

■ **Allianz Kai, a life insurance company's head office, Frankfurt am Main, Germany**



[Photo: Warema]

This recent 23000 m² office building was designed by HPP Architects to consolidate nine insurance companies of the Allianz Group and provide superlative working conditions to its 2500 employees. Windows can be opened manually and provide natural ventilation. Instead of open-plan offices, user-oriented offices for two, four or six people are provided, as well as five-meter deep individual offices. Spacious green courtyards and expanses of glazing create a high degree of transparency both towards the inside and the outside.

Particular care was taken for sun and glare protection and for optimum natural light in the offices, right into the depth of the work space. External Venetian blinds with a special perforation were designed to ensure that visual contact with the outside world is maintained and that natural daylight can enter the building. This reduces the need for artificial lighting, which saves energy. The blinds are placed externally, further reducing the energy cost as cooling requirements are lower. Optimizing the use of natural daylight is obtained by the two separate sections in each Venetian blind that can be tilted individually, so that more light can enter the building at the top of the windows. The building also has a number of roller blinds with a special transparent fabric.

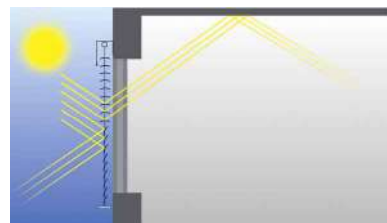


Figure 11.2 *Optimizing the use of natural daylight by two separate sections in each Venetian blind.*
[Photos: Warema]

■ *Headquarters for Saegeling Medicine Technologies, Heidenau, Germany*



[Photos: Warema]

The German Sustainable Building Council (DGNB for Deutsche Gesellschaft für Nachhaltiges Bauen e.V.) helps identify and advance solutions for sustainable building, from the planning stage through the construction, up to and including the operation. The organization intends to spread the knowledge about, and raise the awareness for, future-oriented building. “Sustainable building”, says the website, “means to build intelligently: the focus is on a comprehensive quality concept that serves the building and real estate sectors, as well as society in general. Sustainable properties are beneficial to the environment, conserve resources, comfortable and healthy for their users, and fit optimally into their socio-cultural surroundings. In the same way, they stand for economic efficiency and long-term value-retention. Sustainable properties are cost effective due to their lower operation and maintenance costs. The manageable additional planning and construction costs will usually amortize in a few years”.



[Photo: Warema]



[Photos: Warema]

One of the first DGNB-certified buildings in Germany is the Saegeling Medizintechnik Headquarters in Heidenau, Germany. Conceived by Gert Priebe Architects & Consultants, it is an intriguing construction as the pictures will show. The solar shading manufacturer states in one of its brochures: “A harmonious and rhythmic building has materialised from the successful interplay of the curved glazed façade, white plastered surfaces, floor slabs visible to the outside and external sun shading systems. The building's unique style and form creates a high degree of brand recognition impressively reinforcing the company's presence in Heidenau.”

However, the generously glazed external façades do not only provide a stunning view, they also result in more solar radiation entering the building, which requires

effective solar shading and glare control measures. The extremely curved sections of the façade could not be equipped with standard products. With the help of a laser process, special, flat, dimensionally-stable outside Venetians were designed with 80 mm wide slats of 1 mm thickness. On the straight sections of the façade, the same slats were used to obtain a uniform appearance. The angle of the straight slats can be adjusted to reflect more natural daylight into the building. The system is completely automated and reacts to limit values such as brightness, wind speed and wind direction, outdoor temperature and precipitation. The slats are adjusted according to the position of the sun, providing ideal protection from overheating and glare while offering excellent contact to the outside.

■ *Marguerite Yourcenar Media Library, Paris, France*

Inaugurated early 2008, the Parisian Media Library named after France's famous writer Marguerite Yourcenar, boasts an innovative steel and concrete web-like structure with large span beams, freeing up vast, completely de-compartmentalized spaces. There is a comfortable reading area, an exhibition space, a youth-oriented multimedia section and a large selection of prime reference materials, with over a hundred consultation posts, as well as a conference room on the garden level. And what makes it particularly unique: an extensive collection of reference materials specialised in environmental responsibility and sustainable development.

The architects Seban, Mauplot and Douillet of the BABEL firm made a bold choice by installing roller blinds in a wide range of different colours, making the solar shading a conspicuous element of the architecture. The double-skin façade offered the possibility to lodge the solar shading blinds in between the two glazed walls and the mosaic of colours makes it a unique, easy-to-maintain and environmentally friendly solution.



[Photo: Dickson Constant]



[Photo: Dickson Constant]

The specific effects sought by the designers were solar and thermal protection, visual comfort, transparency and durability. The blinds offer a high-tech response to France's most recent and stringent legislation on the thermal behaviour of buildings.

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APPENDIX 1:

EN STANDARDS CONCERNING SHUTTERS AND BLINDS

This appendix lists the main standards used in solar shading performance evaluation.

Note that some of these standards may currently be subject to a revision process. These standards apply to all types of blinds, awnings and shutters, regardless of their purpose, design and the component materials, as they are normally used and applied in buildings. They apply to products installed inside or outside, designed to shut or to protect an opening.

Terminology

- **EN 12216** – *Shutters, external blinds, internal blinds – Terminology, glossary and definitions.*

Products

- **EN 13120** – *Internal blinds – Performance requirements including safety.* Applies to internal products such as roller blinds, Venetian blinds, vertical blinds, pleated blinds etc.
- **EN 13561** – *External blinds – Performance requirements including safety.* Applies to all external blinds and similar products, regardless of their design and component materials: awnings, slide arms awnings, conservatory awnings, roof light awnings, solar screens etc.
- **EN 13659** – *Shutters – Performance requirements including safety.* Applies to all shutters and similar products, regardless of their design and

component materials: roller shutter, wing shutter, sliding panel shutter, Venetian shutter, concertina shutter, external Venetian blind etc.

Test methods for thermal and visual performance

- **EN 410** – *Glass in building – Determination of luminous and solar characteristics of glazing.* Defines transmittance, reflectance and absorptance values for glazing. These values are essential to calculate the g value and other characteristics of a complete assembly of “glazing + blind”
- **EN 14500** – *Blinds and shutters – Thermal and visual comfort – Test and calculation methods.* Defines the measurement procedures for the transmittance, reflectance and absorptance coefficients and describes the instruments used to make these measurements. Results depend on colour of component material, rate of holes, and, in some cases, on tilt of slats. These are, with the Openness Factor (OF), the values needed for calculation related to the thermal and visual performance of products.
- **EN 14501** – *Blinds and shutters – Thermal and visual comfort – Performance characteristics and classification.* Defines criteria for visual comfort, opacity control, glare control, night privacy, visual contact with the outdoors, daylight utilisation and the rendering of colours. These parameters are classified in 5 classes from 0 (less

efficient) to 4 (more efficient). EN 14501 also gives a normative reference for glazing types A through D that are often used in calculations to compare the performance of products.

- **EN 13363-1** – *Solar protection devices combined with glazing – Calculation of solar and light transmittance – Part 1: Simplified method.* Calculation is available for blind parallel to the glazing, or at an angle of less than 30° with the glazing; for other cases, the detailed calculation method is needed.
- **EN 13363-2** – *Solar protection devices combined with glazing – Calculation of solar and light transmittance – Part 2: Detailed calculation method.*
- **EN 15251:2007** – *Environmental input parameters for design and as-*

essment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

- **EN 15232:2007** – *Energy performance of buildings – Impact of Building Automation, Controls and Building Management.* This European Standard specifies:
 - a structured list of control, building automation and technical building management functions which have an impact on the energy performance of buildings;
 - a method to define minimum requirements regarding the control, building automation and technical building management functions to be implemented in buildings of different complexities.

APPENDIX 2: SPECIFICATION EXAMPLE

Specifying in an early stage is an important aspect of the right choice of a shading system. This is just an example of what a complete specification could look like.

Subject	Description or Requirement
Background	The project concerns Sunlight Ltd., 52 Energy St., Brighton. The property already has window awnings in place, but additional shadings are needed.
Introduction	The property is located in the town centre next to a park to the west. The surrounding buildings are the same height and there are trees in the park which partly shade the façade to the west during periods of the year.
Scope	The project concerns the installation of window awnings on the west façade as indicated on drawing X.
Documents / descriptions	Exhibits AZ, BZ
Tender and Execution	The quotation period will end at 12.00 on <i>Friday .. June</i> . Quotations submitted after this deadline will not be considered. The decision as to which contractor is selected will be communicated in writing by <i>Thursday .. June</i> at the latest. The contract can start immediately afterwards, and the work must be completed by <i>.. August</i> .
Façade	The façade is made of bricks and allows the installation of window awnings with associated arms. The solar shading must be motorised and be connected to an automated control system.
Solar shading	The window awnings are described in detail in appendix AA:1 from XYZ Architects. Before production all measures must be checked on site by the SSC.
Type of solar shading	Window awning of type <i>SunShade</i> in cassette without front cover. All profiles in RAL colour ABCD. Awning fabric of type <i>SunBlock</i> , colour 123. Each window has its own awning. All awnings must be motorised but may be linked with a shaft if the distance between outside frames is less than 50 cm and if the windows are for the same room. The awning arms must be made of at least XY mm profiles and the built-in springs must have a documented adjusted strength consistent with the size of the awning.
Automation	The motorised awnings must be connected to a central automation system of type <i>SunSmart</i> and must have integrated sensors allowing adjustments to be made for the following functions: <ul style="list-style-type: none"> ▫ Sun, wind, rain, fire alarm and 24-hour clock for locking in the up position on Level 1 to prevent damage outside office hours. ▫ Location of sensors on the roof or façades will be advised by the SSC (solar shading contractor) to the EC (electrical contractor) to secure optimised functionality of the system. ▫ The façade shall be divided into five groups or zones. It must be possible to operate each group from the automation system. Each room must be equipped with a local control switch for all awnings in that room. ▫ The system shall be fitted with the number of relays necessary in order to connect the motors to the automation system correctly. ▫ Necessary information must be given to the electrical contractor or installer to enable a proper installation of all cables according to requirements.
Installation of components in the control system	The automation system must be installed in an equipment cabinet in the equipment room on Level 1.
Motors	The motors must be silent motors of type <i>SunMove</i> 230V AC and must have documented torque in combination with the specified awning to ensure the lifespan of the installation.
Matrix of Responsibilities, see appendix	This matrix shall be adjusted according to this specific project in co-operation between Project Manager and representatives from solar shadings, electrical installation and electrical consultant.
Other	The client will erect scaffolding for use during the period of the contract. The scaffolding will be erected away from the façade or in a position that allows testing of the solar protection during installation.
Inspection and quality	At the kick-off meeting, the contractors submitting a quotation must be able to provide a quality plan for their company and a proposal for self-inspection for approval by the client's representative.
Documentation	Complete documentation on the solar shading must be submitted to the client's representative in the form of a technical declaration of the products, their place of origin/manufacture, manuals and CE documents for future traceability.
Rules governing the contract	Solar shading contractors are governed by xxxxxx
List of documents	Drawings X and Y
Appendix:	List of responsibilities

APPENDIX 3: MATRIX OF RESPONSIBILITIES

This matrix of responsibilities serves as an example and may need to be adapted depending on which contractors are involved. CL = client, TE = tenant, BC = building contractor, EC = electrical contractor, SSC = solar shading contractor, CM = control and monitoring contractor.

Item	Delivery	Installation	Connection	Operation	Comments
Control boxes	SSC or EC	EC	EC	SSC	
Power supply to control boxes	EC	EC	EC	EC	
Outdoor sensors	SSC or EC	EC	EC	SSC	SSC should advise on locations for sensors.
Holes through external walls	EC	EC	EC	EC	
Relay boxes for solar protection	SSC or EC	EC	EC	SSC	SSC should advise on grouping
Power supply to relay boxes	EC	EC	EC	EC	
Ducting	EC	EC	EC	EC	
Indoor control units for solar protection	SSC or EC	EC	EC	SSC	SSC should advise on grouping
Solar protection system	SSC	SSC	EC	SSC	Boundary between SSC or EC in the relevant half of the contact.
Motors for solar protection	SSC	SSC	EC	SSC	Sufficient motor type to be documented.
Central equipment, software	SSC or EC	SSC or EC	SSC or EC	SSC or EC	
Isolating switches next to solar protection outside	SSC	EC	EC	EC	
Control lines	EC	EC	EC	EC	
Error signal, sum alarm	CM	CM	EC	SSC	
Connection of GSM modem	SSC or EC	EC	EC	SSC	Applies for remote access.
Connection to phone network	EC	EC	EC	EC	Applies for remote access.
Connection to fire alarm	CM	CM	CM	CM	
Information to TE	SSC	-	-	SSC	IMPORTANT
Information to CL	SSC	-	-	SSC	Operating personnel

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