SOLAR SHADING FOR **LOW ENERGY AND HEALTHY BUILDINGS**

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Edition 2

How blinds and shutters reduce the energy needs of buildings and improve the thermal and visual comfort of users.

EUROPEAN SOLAR-SHADING ORGANIZATION
Energy Savings & Comfort

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ES-SO is indebted to its member associations and their company members for providing images for use in the ES-SO Manual “Solar shading for low energy buildings ”.

FOREWORD

This book is about solar shading (including shutters), its influence on the energy balance and natural comfort of a building.

Buildings are the biggest energy consumers in Europe, absorbing 40% of all energy. About 75% of the building stock is energy-inefficient and, depending on the member state, only 0.4 to 1.2% of them are renovated each year. This explains why Europe is targeting on improving their efficiency by continuous legal frameworks (energy related directives) stimulating member states to adapt their national legislation and drastically change the building methods.

The EPBD (Energy Performance Buildings Directive) released since 2002, strengthened in 2010, has affected building construction significantly towards new energy efficient buildings (NZEB) focusing on preventing heat losses through higher insulation and airtight sealing of the building envelope. Since the first edition of the ES-SO Technical Guidebook more and more countries in Europe report an increased overheating risk in buildings directly related to the changing building practice. That's why solar shading becomes increasingly essential in the design of low energy buildings. Depending on the outcome of the upcoming EPBD review, solar shading will become formally recognized as a technical building system and integrated in the dynamic building envelope of the so called "smartness indicator", a tool supporting consumers in monitoring the energy consumption of their dwellings and buildings. With the renewed EPBD the overall building stock needs also to become NZEB. Solar shading will grow exponentially as it will become a necessity.

Solar shading is a generic term used to cover all the passive measures limiting the entry of excessive solar energy, ranging from shade trees, fixed awnings to fully automated blinds and shutters. EPBD has stimulated solar shading and shutter manufacturers to innovate in fabrics and materials with improved values on thermal comfort properties for heat rejection and/or heat retention including a great range of visual comfort properties. Managing daylight entrance throughout the day to optimize glare control is equally important. In order to cover the needs of large glazed areas also on high-rise buildings, manufacturers are able to make solar shading systems very resistant to wind loads. Installation of shading and shutters can now also be integrated in highly insulated buildings.

It is also clear that solar shading in connection with night cooling is the most effective way to reduce or even avoid active cooling. This is exactly the purpose of the energy efficiency first principle of the EU as this is the cheapest road to low energy use in buildings. Solar shading and shutter technology are incorporated in CEN/ISO Standards created by our industry and they form the technical backbone of good craftsmanship. This second edition stresses the importance of smart solar shading being part of the dynamic building envelope in smart buildings.

The entire chain from manufacture to installation should be based on professionals understanding the performance properties of what shading can do in order to create thermal and visual comfort in buildings. The essence of solar shading is contributing to natural comfort and wellbeing for the occupants while improving the energy efficiency thus lowering their energy bills. New chapters are added e.g. on the importance of daylight and Standards developments have also been included.

The sun is the biggest source of energy in our universe. And solar shading is able to manage the power of the sun in the most optimal way in our living areas. Smart solar shading is the innovation as we are able to offer real solutions lifting up our technology to the next level.

We wish you an interesting reading and strongly encourage you to use the gained knowledge into your daily practice.

Peter Winters, President ES-SO,
the European Solar-Shading Organization
www.es-so.com

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VI. QUALITY OF DAYLIGHT

#1

INTRODUCTION

I. INTRODUCTION

Solar shading is a key element for improving the energy efficiency and daylight management of existing buildings and optimising the low-energy designs of new buildings. This technology is still under-utilised despite the fact it provides a major impact on the reduction of energy consumption of the built environment whilst improving the thermal and visual comfort of the occupants.

Indeed, solar protection devices enable adjustment of the properties of windows and façades to the weather conditions and the needs of the occupants. A proper management of these systems can then maximise the solar heat gains in winter – hence reducing the heating loads – and minimise these heat gains in summer – hence reducing the cooling loads, while at the same time providing good visual comfort to the occupants.

In order to make the right choice in term of products and façade management when designing a new building or preparing works to an existing one, it is necessary to take into consideration the characteristics of solar protection devices. Indeed, these products impact the insulation level of the façade, its solar transmittance and its visual transmittance. As a consequence, it is necessary to find the best balance between all these characteristics depending on the building properties, its location and orientation.

This technical guidebook is intended to give the basic knowledge to understand how solar shading characteristics are evaluated and what the physical properties involved in the transmission of the solar radiation are. It is mainly based on calculation methods provided by European and International standards.

Examples of simulations carried out in Europe showing the impact of solar shading on the energy loads of buildings are also presented.

Although it is mainly intended to be used by solar shading manufacturers and installers, this guidebook will also be useful to building designers, energy engineers and sustainability consultants.

#2

BASIC **PRINCIPLES**

II. BASIC PRINCIPLES

This chapter shows some basic elements of the different types of radiation that have to be considered in the performance of solar protection devices with regards to the position of the sun. It also shows how a material behaves when it is affected by such radiation.

II.1. Different types of radiation

People are exposed to a large variety of radiation that could be natural or artificial. Radiation has differing wavelengths (see Figure 1).

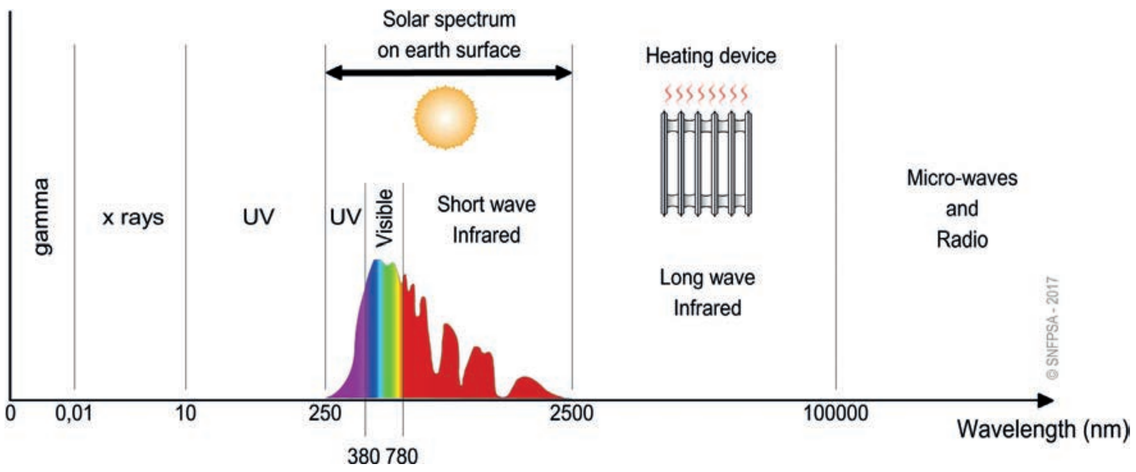


FIGURE 1 – Classification of various electromagnetic radiation depending of their wavelength

A solar protection device is concerned with these two types of radiation:

- The solar radiation with wavelength between 250 nm to 2500 nm that is subdivided into three parts: UV, visible and short wave infrared. This radiation is emitted by the sun (see II.2).
- The long wave infrared with wavelength between 2500 nm to 100000 nm that is due to the temperature level of a material (e.g. a heater or any warm surface). This radiation is in the infrared which is in the invisible range (see II.4).

II.2. Solar radiation

The sun produces an enormous amount of energy (66 million W/m²) that is transmitted to the Earth through radiation. Only a fraction of this energy reaches the atmosphere (around 1300 W/m²). Around 15% of this radiation is then absorbed by the atmosphere and emitted in all directions in the form of diffuse radiation. Around 6% is reflected back into space and about 79% is directly transmitted to the ground through the atmosphere.

As a consequence, the energy of solar radiation hitting the ground is much lower than that reaching the atmosphere. It is generally considered that the energy reaching the ground when there is a clear blue sky is **around 1000 W/m²**.

Hence, when considering a solar protection device, it is necessary to divide the total solar incident radiation into three parts (see Figure 2).

- **Direct radiation,** which is the solar radiation neither absorbed nor reflected by the atmosphere (around 85%),
- **Diffuse radiation,** which is the part of the solar radiation absorbed by the atmosphere and emitted in all directions (around 15%),
- **Reflected radiation** which corresponds to the combined reflection of the direct and diffuse radiation from the ground.

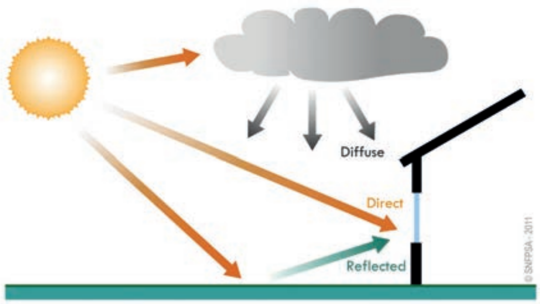


FIGURE 2 – Incident parts of the solar radiation

The solar radiation is grouped into three main sections which form the Solar Spectrum:

- **Ultraviolet (UV):** from 250 nm to 380 nm, these rays are invisible to the human eye and may be dangerous in case of overexposure. They age materials and damage surfaces and colours.
- **Visible:** from 380 nm (violet) to 780 nm (red), these rays are detected by the human retina and enable the sight of shapes, relief and colours.
- **Short wave Infrared (IR):** from 780 nm to 2500 nm, these rays are invisible but are felt as heat.

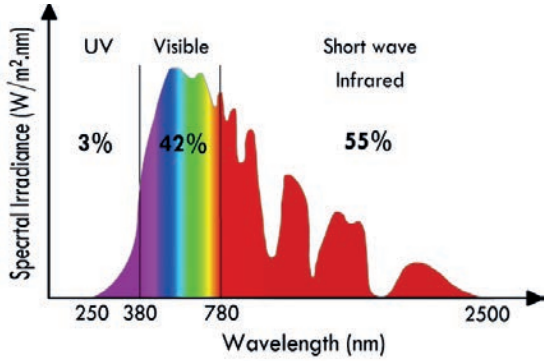


FIGURE 3 – Spectral irradiance at sea level for the solar spectrum

The "power" of radiation is represented by its irradiance (in W/m²). For a given wavelength, it is called spectral irradiance (in W/m².nm). Figure 3 gives the distribution of the spectral irradiance of the solar spectrum at sea level.

II.3. Influence of the position of the sun

In addition, the solar irradiance depends on the position of the sun in the sky (altitude and azimuth). This position varies throughout the year and during the day (see Figure 4). It also depends on the latitude.

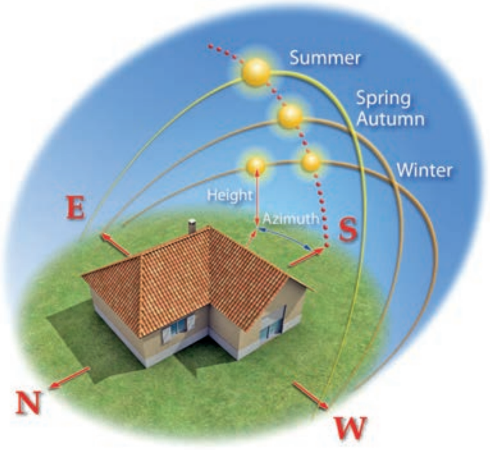


FIGURE 4 – Position of the sun in the sky

Figure 5 shows the solar irradiance on vertical surfaces, such as building façades, in summer (21 June) and in winter (21 December). As these graphs have been calculated based on a cloudless sky and no surrounding buildings, the level indicated can be considered the maximum solar irradiance a vertical surface can receive.

These figures are for a latitude of 50° N. At other latitudes, these figures will be different. Overall, in Europe, the general pattern is very similar.

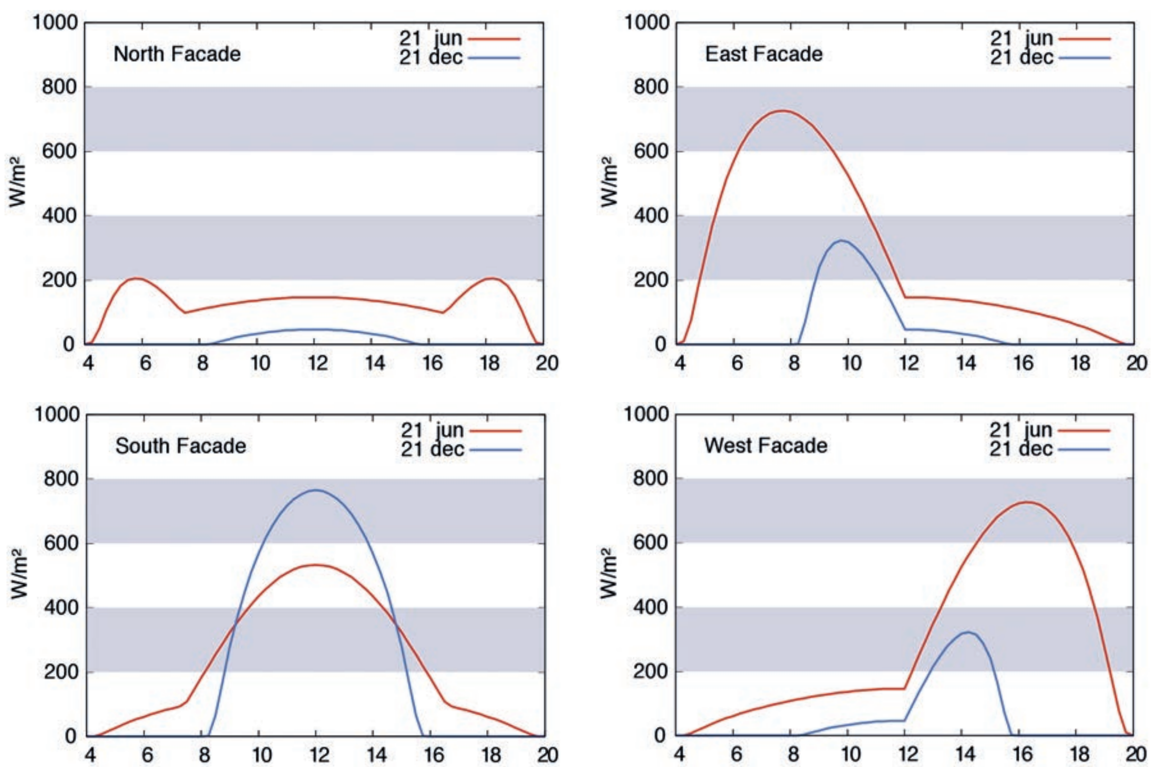


FIGURE 5 – Irradiance for north, east, west and south vertical facade at 50° N of latitude (source ES-SO & REHVA guidebook)

It can be seen that:

- North exposed façades, receive the lowest level of solar irradiance due to their position. Only a small amount of solar radiation hits the vertical surface at the beginning of the morning and late in the evening in summer.
- East and west orientated façades show an opposite pattern: the east surface will receive the largest part of the radiation before noon, whereas the west surface receives its in the afternoon. It can be seen that the irradiance is at a maximum when it is composed of the direct radiation. After noon for the east façade and before noon for the west façade, the radiation is mainly composed of the diffuse radiation coming from the sky. That is the reason why it is lower.
- South exposed façades receive solar radiation almost throughout the most of the day. In order to maximise the solar gain for the winter time benefit, it is necessary to maximize the glazed surfaces on this orientation. However, it is essential to protect the façades in summer with shading devices to avoid overheating. Because of the low altitude of the sun, it can be seen that the irradiance is higher in winter than in summer.

II.4. The long wave infrared

All materials continuously emit radiation in all directions in the form of energy. While the solar spectrum comprises short wavelength radiation emitted at various temperatures, the thermal radiation is mainly composed of long wavelength infrared radiation emitted at low temperature.

In practice, this means that a material which is irradiated by solar radiation will warm up and emit long wavelength radiation to the surrounding area. This radiation will then warm up the materials in the proximity which will once again re-emit radiation, and so on.

A heater is a perfect example of an object/material which emits long wave infrared radiation. **Any material warmed up by solar radiation becomes a kind of a heater.**

The ability of a material to emit this type of radiation is given by its emissivity (see II.5). As long as a material has no holes, it is opaque to the long wave infrared. Therefore walls and glazing do not allow transmission of this type of radiation. Therefore, heat is kept in the room. This is known as the “greenhouse effect” which is beneficial in winter as it generates free heating and becomes critical in summer as it generates overheating.

II.5. How a material is affected by radiation

When a surface (glazing, fabric or slat for example) is irradiated, incident radiation E splits into three parts (see Figure 6):

- A part which is transmitted through the material. It is characterised by the transmittance τ, the ratio of the transmitted flux to the incident flux;
- A part which is reflected by the material. It is characterised by the reflectance ρ, the ratio of the reflected flux to the incident flux;
- A part which is absorbed by the material which is characterised by the absorptance α.

so that $\boldsymbol{\tau + \rho + \alpha = 100\%}$

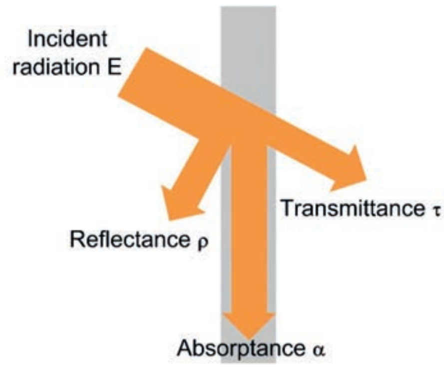


FIGURE 6 – Behaviour of a radiation in contact with a material

For a given incident radiation E, the transmitted radiation is equal to τ x E, the absorbed radiation to α x E and the reflected radiation to ρ x E.

Transmittance, reflectance and absorptance are characteristics specific to the material. With a fabric for example, these values will mainly depend on the type of material, on the openness of the fabric and the colour. It also depends on the wavelength of the solar radiation. It is possible to measure these properties for specific wavelength (for example for 250, 260, 270 nm, etc.). These values are called **"spectral data"**.

However, they are often defined for:

- The complete solar spectrum, i.e. from 250 nm to 2500 nm (see Figure 3). These properties are identified by the subscript "e" (for "energetic" or "solar") : τ_e, ρ_e and α_e,
- The visible part of the spectrum, i.e. from 380 nm to 780 nm. In this case these characteristics are used to calculate the visual properties of the product (mainly the light transmittance) and they are identified by the subscript "v" (for "visible") : τ_v, ρ_v and α_v,
- The long wave infrared radiation, i.e. from 2500 nm to 100000 nm. These values are necessary for the detailed calculation of some of the thermal characteristics of the products. They are identified by the subscript "IR": τ_{IR}, ρ_{IR} and the emissivity ε (in this case the emissivity is equal to α_{IR}).

In this case, they are called **"integrated data"**.

More details on spectral and integrated data are available at the ES-SDA website.

NOTE

In all cases, the relationship between transmittance, absorptance and reflectance is governed by the following generic formula:

- $1 = \tau_e + \rho_e + \alpha_e$ for the complete solar spectrum
- $1 = \tau_v + \rho_v + \alpha_v$ for the visible part of the solar spectrum
- $1 = \tau_{IR} + \rho_{IR} + \varepsilon$ for the long wavelength infrared radiation

Therefore, in practice, only two values are needed to characterise a material (e.g. τ_e and ρ_e or τ_{IR} and ε).

In addition, it should be noted that a radiation is transmitted in two ways. The transmittance τ comprises:

- **Direct transmittance,** stated as τ_{n-n}, for which the radiation is not affected by the material, and
- **Diffuse transmittance,** noted τ_{n-dif}, which corresponds to the diffusion in all directions of the radiation by the material (see Figure 7).

The sum of the direct and diffuse transmitted part is equal to the total value: e.g. $\tau_{v,n-n} + \tau_{v,n-dif} = \tau_v$

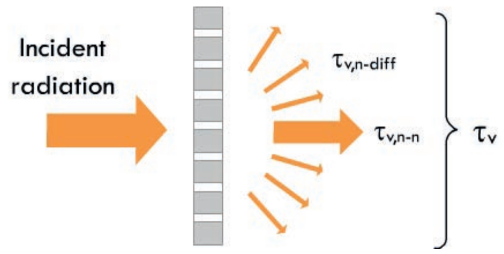


FIGURE 7 – Direct and diffuse visual transmittance

The visual direct transmittance $\tau_{v,n-n}$ is mainly linked to the openness factor and the visual diffuse transmittance $\tau_{v,n-dif}$ is affected by the colour, the thickness, the construction of the curtain material (e.g. fabric, laths, slats).

Finally, reflectance and absorptance may also depend on the faces of the product, for example in case of coating or colour difference. Two values may then be necessary: ρ and ρ' that correspond with the two faces of a fabric.

Figure 8 illustrates the characteristics of the shutter or blind material (fabric, slat or lath) required for a detailed calculation of the thermal and visual properties of the product. This figure does not consider the characteristics of the glazing which are also needed. This part is detailed in I.1 and V.

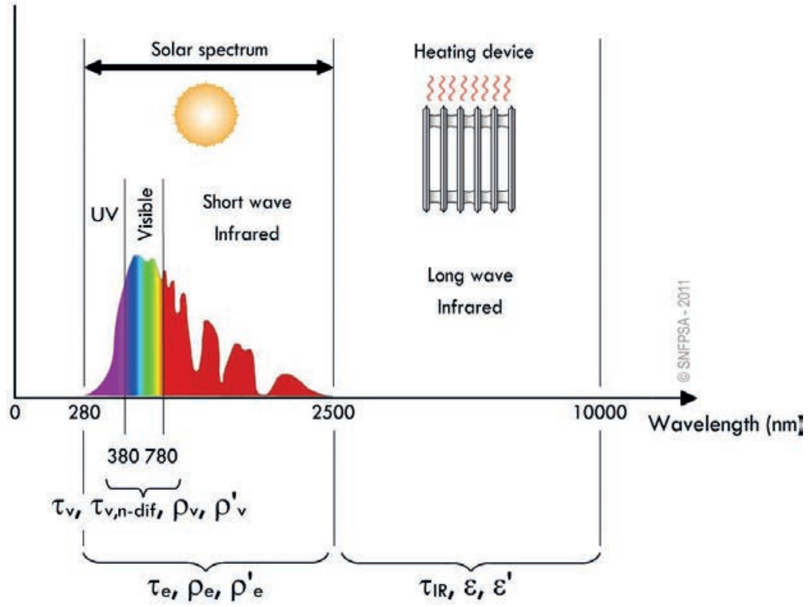


FIGURE 8 – Illustration of the material characteristics

These characteristics are measured in accordance with the European Standard **EN 14500 "Blinds and shutters - Thermal and visual comfort - Test and calculation methods".**

#3

THE THERMAL CHARACTERISTICS: **THE U AND ΔR VALUES**

III. THE THERMAL CHARACTERISTICS: THE U AND ΔR VALUES

The U value (designated by U_w) represents the thermal losses going through a window. For a single window (with a blind or a shutter in the retracted position), this coefficient depends on the U value of the glazing (U_g) and the frame (U_f) and the link between the glazing and the frame (ψ_g), the area of the glazing and frame (A_g and A_f) and the perimeter of the glazing (l_g).

It is calculated according to the European Standard EN ISO 10077-1 with the following formula:

$$Uw = \frac{A_g U_g + A_f U_f + I_g \psi_g}{A_g + A_f}$$

The lower the U_w value the better the insulation of the window. A U value is given in W/m².K.

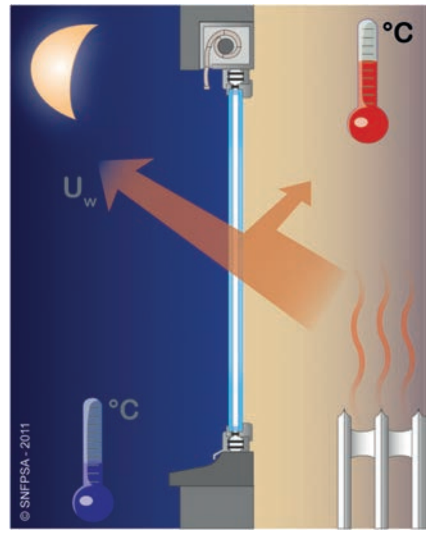


FIGURE 9 – Illustration of the U_w value

A solar protection device extended in front of a window introduces an additional air space characterised by **an additional thermal resistance designated by ΔR (in m².K/W)**. The ΔR value is calculated according to the European Standard EN 13125 and depends mainly on the air permeability of the device and the thermal resistance of the curtain (designated by R_{sh}).

According to EN 13125, the air permeability of a shutter or a blind is calculated by considering the peripheral gaps of the curtain (see Figure 10).

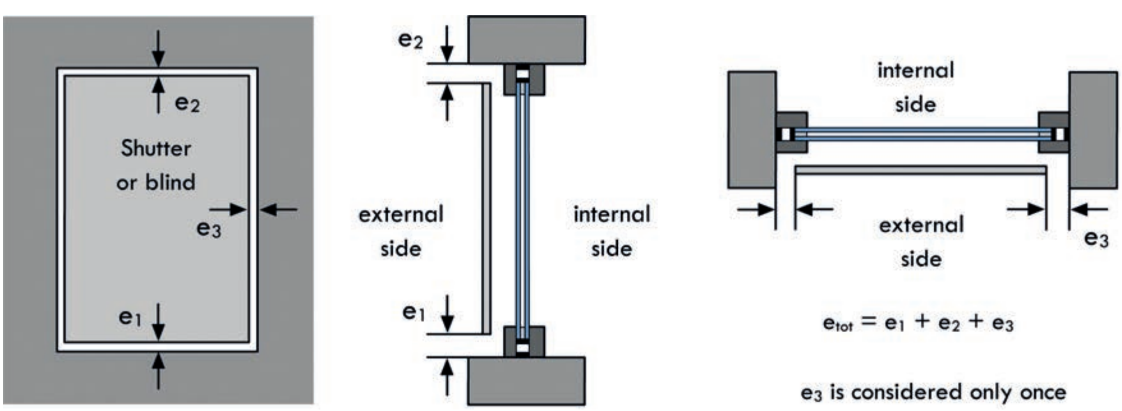


FIGURE 10 – Calculation of e_{tot} according to en 13125

For external and internal blinds, EN 13125 also considers openings that may be present in the curtain (the openness factor of a fabric for example). The air permeability criteria is then expressed by the following formula:

$$P_e = e_{tot} + 10p$$

where e_{tot} is calculated according to Figure 10 and p is the ratio between the total opening area and the total area of the curtain.

The following Tables give the different formulae determined in EN 13125 for the calculation of the ΔR value for shutters, external blinds and internal and mid-pane blinds.

TABLE 1 – Calculation of ΔR of shutters

Very high air permeability (e_{tot} > 35 mm)	ΔR = 0,08 m^2.K/W
High air permeability (15 mm < e_{tot} ≤ 35 mm)	ΔR = 0,25.Rsh + 0,09
Average air permeability (8 mm < e_{tot} ≤ 15 mm)	ΔR = 0,55.Rsh + 0,11
Low air permeability (e_{tot} ≤ 8 mm)	ΔR = 0,8.Rsh + 0,14
Very low air permeability (e_{tot} ≤ 3 mm and $e_1 + e_3$=0 or $e_2 + e_3$=0)	ΔR = 0,95.Rsh + 0,17

TABLE 2 – Calculation of ΔR of external blinds

High and very high air permeability (P_e ≥ 35 mm)	ΔR = 0,08 m^2.K/W
Average air permeability (8 mm ≤ P_e < 35 mm)	ΔR = 0,11 m^2.K/W
Low air permeability (P_e < 8 mm)	ΔR = 0,14 m^2.K/W

TABLE 3 – Calculation of ΔR of internal and mid-pane blinds

High and very high air permeability (P_e ≥ 80 mm)	ΔR = 0,08 m^2.K/W
Average air permeability (20 mm ≤ P_e < 80 mm)	ΔR = 0,11 m^2.K/W
Low air permeability (P_e < 20 mm)	ΔR = 0,14 m^2.K/W

The effect of the additional thermal resistance of a shutter or a blind on the window is given by the following formula:

$$U_{ws} = \frac{1}{\frac{1}{U_w} + \Delta R}$$

This formula is defined in the standard EN ISO 10077-1. For a given window, it can be used to evaluate the improvement of the U value of a window provided by a blind or the shutter in the extended position. Table 4 gives examples of calculations for three different ΔR values and three different types of windows. The ΔR values considered are:

- 0,08 m^2.K/W, for example a very permeable external blind,
- 0,15 m^2.K/W, for example a standard roller shutter in aluminum,
- 0,25 m^2.K/W, for example a air tight roller shutter.

TABLE 4 – Example of U_{ws} calculation

	Window with single glazing $U_w = 4,90$ ΔR (m^2.K/W)			Window with double glazing $U_w = 1,8$ ΔR (m^2.K/W)			Window with double glazing $U_w = 1,2$ ΔR (m^2.K/W)		
	0,08	0,15	0,25	0,08	0,15	0,25	0,08	0,15	0,25
U_{ws} (W/m^2.K)	3,52	2,82	2,20	1,57	1,42	1,24	1,09	1,02	0,92
Improvement factor	28,2%	42,4%	55,1%	12,6%	21,3%	31,0%	8,8%	15,2%	23,0%

It can be seen from these examples that in all cases, the shutter or the blind decreases the U value of the window ($U_{ws} < U_w$) and therefore reduces the heat losses when the outdoor temperature is cold.

Of course the effect of the shutter or blind is higher when the window has a low performance: it halves the U value in case of a single glazing. It still has a good effect for a high performance window: an airtight shutter will still reduce the U value of a double glazing window with a U_w value of 1,2 W/m^2.K (which means a window using a glazing with a U_g = 1,0 W/m^2.K) by 23%.

#4

THE SOLAR CHARACTERISTIC: **THE SOLAR FACTOR**

IV. THE SOLAR CHARACTERISTIC: THE SOLAR FACTOR

IV.1. General

The total solar energy transmittance, also called solar factor, represents **the part of the incident flux which is transmitted into a room.**

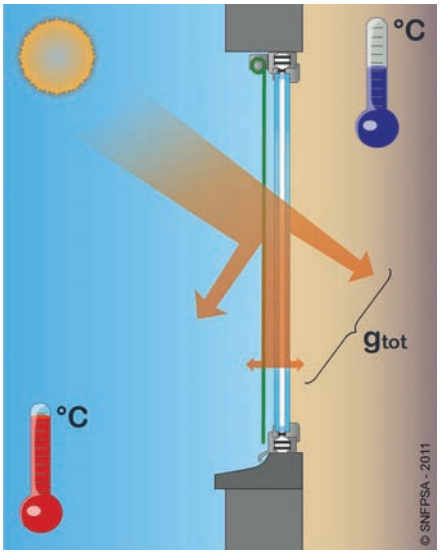
g is the solar factor of the glazing alone. g_{tot} is the solar factor of the combination of a glazing and a solar protection device.

The value of g or g_{tot} is between 0 and 1: 0 means no radiation is transmitted into the room and 1 means all radiation is transmitted.

The g value of a glazing alone is determined by the calculation method given in the EN 410.

There are two methods for the calculation of the g_{tot} of a solar protection device associated to a glazing:

- Either a simplified method given by EN ISO 52022-1,
- Or a detailed method given in EN ISO 52022-3.



Both methods use the properties of the glazing and of the material constituting the solar protection device – fabric, laths or slats – as shown in II.5.

IV.2. Simplified calculation method: EN ISO 52022-1 (replacing EN 13363-1)

The standard EN ISO 52022-1 gives a simplified method to evaluate the g_{tot} value. This calculation takes into consideration the U value and the g value of the glazing and the energetic transmittance and reflectance of the solar protection device.

The standard specifies that the deviation of the simplified calculation compared to the exact values lie within the range between +0,10 and -0,02. It is therefore strongly recommended that the detailed calculation method (see IV.3) is used to determine the benefits of solar gain and thermal comfort.

The advantage of this standard is that calculations can be made easily without a help of a calculation tool.

Indeed the formulae to be used are the following:

- For an external blind or shutter:

$$g_{tot} = \tau_e g + \alpha_e \frac{G}{G_2} + \tau_e (1-g) \frac{G}{G_1}$$

With G_1 = 5 W/m².K ; G_2 = 10 W/m².K and $G = \left(\frac{1}{U_g} + \frac{1}{G_1} + \frac{1}{G_2} \right)^{-1}$

- For an internal blind:

$$g_{tot} = g(1 - g\rho_e - \alpha_e \frac{G}{G_2})$$

With G_2 = 30 W/m².K and $G = \left(\frac{1}{U_g} + \frac{1}{G_2}\right)^{-1}$

- For a mid-pane blind:

$$g_{tot} = \tau_e g + g(\alpha_e + (1-g)\rho_e)\frac{G}{G_3}$$

With G_3 = 3 W/m².K and $G = \left(\frac{1}{U_g} + \frac{1}{G_3}\right)^{-1}$

In all these equations:

- τ_e is the solar transmittance of the blind or shutter
- ρ_e is the solar reflectance of the blind or shutter
- α_e is the solar absorptance of the blind or shutter

} with $1 = \tau_e + \rho_e + \alpha_e$ (see II.5)

- g is the solar factor of the glazing
- U_g is the thermal transmittance of the glazing
- G_1, G_2 and G_3 are fixed values defined by the standard

It should be noted that these formulae can be applied only if the solar transmittance and reflectance of the solar protection devices are within the following ranges:

$$0 \leq \tau_e \leq 0{,}5 \text{ and } 0{,}1 \leq \rho_e \leq 0{,}8$$

and with the additional requirement that the solar factor g of the glazing is between 0,15 and 0,85.
In all other cases, calculation according to EN ISO 52022-3 should be carried out.

Example of calculation for an external blind (grey colour)

Properties of the blind:

- Direct solar transmittance τ_e: 0,05
- Solar reflectance ρ_e: 0,21
- Solar absorptance $\alpha_e = 1 - \tau_e - \rho_e$ = 0,74

Properties of the glazing:

- Thermal transmittance U_g: 1,2 W/m².K
- Solar factor g: 0,59

According to EN ISO 52022-1, the g_{tot} value is given by the following formula:

$$g_{tot} = \tau_e g + \alpha_e \frac{G}{G_2} + \tau_e(1-g)\frac{G}{G_1}$$

With G_1 = 5 W/m².K ; G_2 = 10 W/m².K and $G = \left(\frac{1}{U_g} + \frac{1}{G_1} + \frac{1}{G_2}\right)^{-1}$

Therefore G= 0,885 m².K/W

Then, g_{tot} = 0,05 x 0,59 + 0,74 x 0,0885 + 0,05 x (1-0,59) x 0,177
g_{tot} = 0,029 + 0,0655 + 0,0036
g_{tot} = 0,10

IV.3. Detailed calculation method: EN ISO 52022-3 (replacing EN 13363-2)

As it tries to represent the real physical behaviour of the combination of a blind and a glazing when it is struck by a radiation, this method of calculation is far more complex than the formulae given by EN ISO 52022-1. **It requires the use of a specific calculation tool.**

The principle of the calculation is to consider the blind, the glazing and the gas space as separate layers in defined positions (see Figure 11), each layer having its own properties (transmittance, reflectance, emissivity, etc.). The external conditions (temperature, solar irradiance, ventilation...) are also considered. The goal of the calculation is to evaluate the interaction of each layer with these conditions.

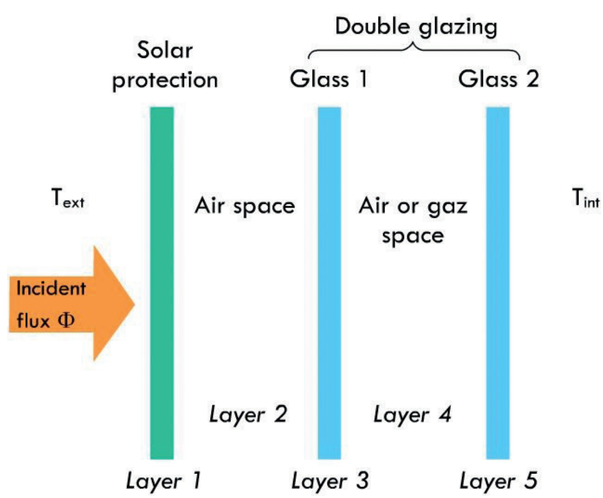


FIGURE 11 – Example of layers in case of an external blind associated to a double glazing

Therefore, this calculation consists of three parts:

• **The solar radiation transfer**

This part of the g_{tot} **is quantifying the part of the incident solar radiation which is transmitted into the room through multiple transmission and reflection of both faces for each layer of the system.** The temperature of the system has no impact in this calculation.

Figure 12 gives an example of the calculation that has to be done for a system made of an external blind and a double glazing. In this example, the calculation leads to solve the following matrix of flux:

$$E_1 = \Phi$$
$$E_2 = \rho_1 E_3 + \tau'_1 E_4$$
$$E_3 = \rho'_e E_2 + \tau_e E_1$$
$$E_4 = \rho_2 E_5 + \tau'_2 E_6$$
$$E_5 = \rho'_1 E_4 + \tau_1 E_3$$
$$E_6 = 0$$

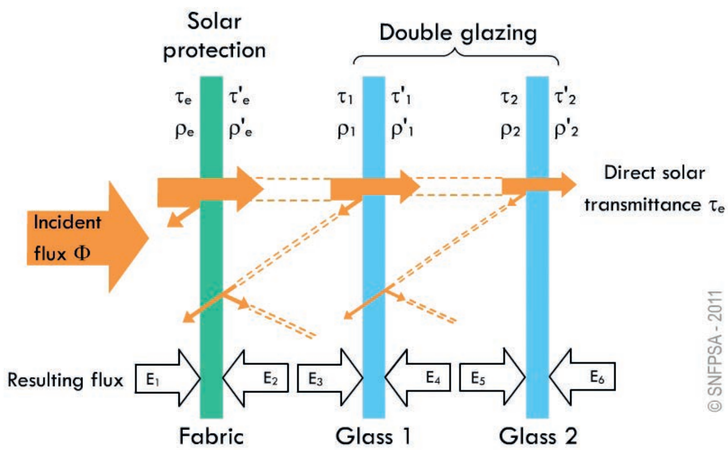


FIGURE 12 – Illustration of the solar direct transmittance for an external blind and a double glazing

This transfer is characterised by the direct solar transmittance τ_e of the system "blind and glazing". It relates to the complete solar spectrum.

• **The heat transfer**
This type of transfer considers the impact of the external and internal temperature in conjunction with the effect of the solar irradiance (that will increase the temperature of each material by absorption).

This transfer is subdivided into two parts (see Figure 13):

- *Transfer by thermal radiation*
This transfer is due to the emission of long wave infrared radiation (see II.4) by each layer being warmed up by the external temperature and the solar radiation. The heat is transmitted from one layer to the next one through this radiation.
This transfer is characterised by the **thermal radiation factor g_{th}**.

- *Conductive and convective heat transfer*
The conductive heat transfer is due to direct heat circulation within the material of the layer and the gas space in-between by a direct molecular interaction. The convective heat transfer is due to heat displacement from the material of the layer to the gas space (e.g. the air space of a double glazing).
This transfer is characterised by the **convection factor g_c**.

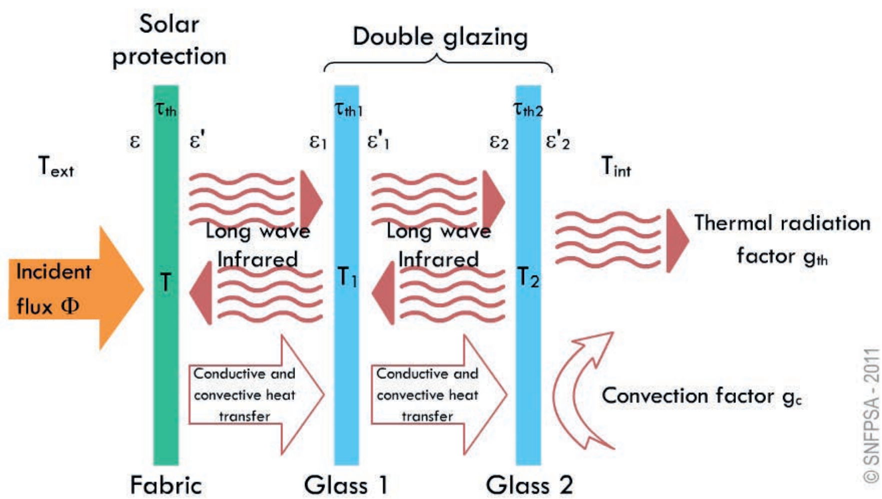


FIGURE 13 – Illustration of the heat transfer for an external blind and a double glazing

- **The presence of a stack effect in case of an internal blind**

This effect is due to the air displacement inside the air space created between the glazing and the internal blind. It is due to the heating of the airspace by the glazing which generates an upward heat flow between the glazing and the blind (see Figure 14).

This effect is characterised by the **ventilation factor g_v**.

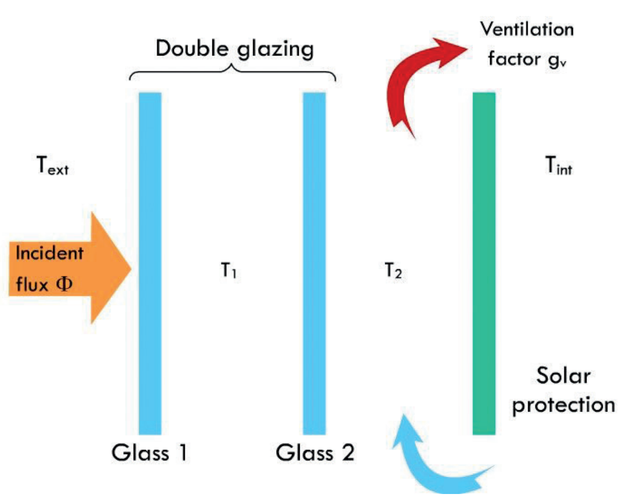


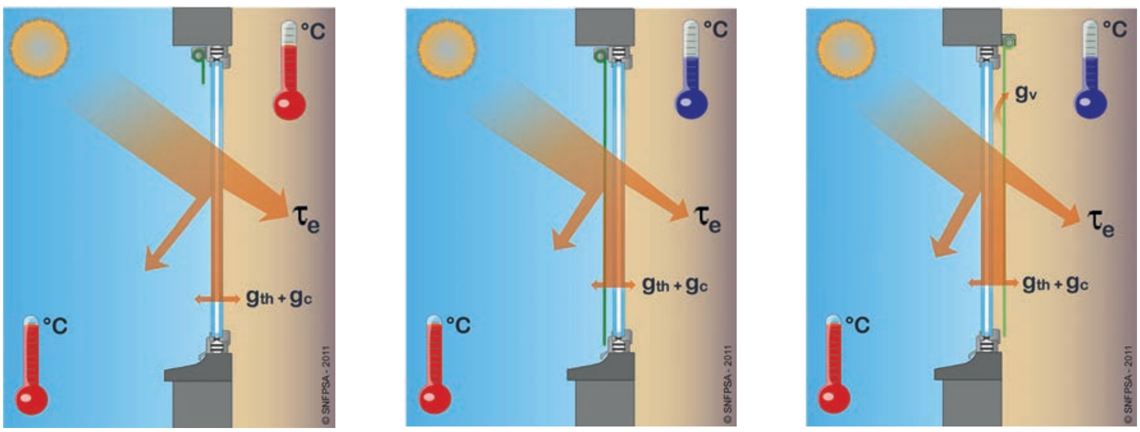
FIGURE 14 – Illustration of the stack effect in case of an internal blind

The g_{tot} value is then given by the addition of the solar direct transmittance τ_e, the thermal radiation factor g_{th}, convection factor gc and the ventilation factor g_v:

$$g_{tot} = \tau_e + g_{th} + g_c + g_v{}^{(1)}$$

(1) $g_v = 0$ in the case of an external blind

Therefore EN ISO 52022-3 gives a good description of the solar factor. However it requires the consideration of different physical phenomena that have to be considered simultaneously. The use of a specific calculation tool is therefore necessary. Examples of calculation in accordance with EN ISO 52022-3 are given in IV.4.



In this case the protection device is retracted

In this case the external protection device is extended

In this case the internal protection device is extended

FIGURE 15 – Illustration of g_{tot}

IV.4. Comparison of the simplified and detailed calculations

The simplified and detailed calculation methods can both be used to calculate the solar factor g_{tot} and the visual transmittance $\tau_{v,tot}$ (see V).

For the same combination of glazing and blind, a comparison can be made of the different colours of the same fabric. Three configurations of colourways are shown in Table 5.

TABLE 5 – Properties of the fabric

	Colour of the fabric		
	White pearl	White grey	Grey
Solar transmittance τ_e	0,13	0,09	0,05
Solar reflectance ρ_e [(1)]	0,53	0,44	0,21
Visual transmittance τ_v	0,11	0,07	0,03
Diffuse visual transmittance $\tau_{v,n\text{-}dif}$	0,08	0,04	0,01
Visual reflectance ρ_v [(1)]	0,58	0,47	0,18
Long wave IR transmittance τ_{IR} [(2)]	0,03	0,03	0,03
Emissivity ε [(1)]	0,89	0,89	0,89

[(1)] *The properties of both sides of the blind are identical. Therefore :* $\rho_e = \rho'_e; \rho_v = \rho'_v$ *and* $\varepsilon = \varepsilon'$

[(2)] *Equal to the openness coefficient of the fabric*

In EN 14501, typical glazing that are used as benchmarks have been defined to enable comparisons to be made. The standard glazing C according to the standard (double glazing 4-16-4, with low emissivity coating in position 3 (outer surface of the inner pane), space filled with argon) is considered below (see Table 6).

It should be noted that EN 14501 and EN ISO 52022-1 specify different reference glazing. Considering product standards EN 13659 and EN 13561 make reference to EN 14501, glazing specified in this standard should prevail. The ES-SO convention is that manufacturers should specify standard glazing C from EN 14501 for comparison purposes.

TABLE 6 – Properties of the glazing

	External pane	Internal pane
Solar transmittance τ_e	0,85	0,58
Solar reflectance on the side of the incident radiation ρ_e	0,08	0,30
Solar reflectance on the side opposite to the incident radiation ρ'_e	0,08	0,24
Visual transmittance τ_v	0,90	0,82
Visual reflectance on the side of the incident radiation ρ_v	0,08	0,08
Visual reflectance on the side opposite to the incident radiation ρ'_v	0,08	0,04
Long wave IR transmittance τ_{IR}	0,00	0,00
Emissivity on the side of the incident radiation ε	0,89	0,04
Emissivity on the side opposite to the incident radiation ε'	0,89	0,89

The results for an external blind are shown in Table 7.

TABLE 7 – Calculation of g_{tot} and $\tau_{v,tot}$ for an external blind

	Method of calculation						
	Simplified		Detailed [1]				
	g_{tot}	$\tau_{v,tot}$	g_{tot}	τ_e	$g_{th} + g_c$	$\tau_{v,tot}$	$\tau_{v,n\text{-}diff}$
White Pearl	0,12	0,09	0,11	0,08	0,03	0,09	0,06
White grey	0,10	0,06	0,09	0,05	0,04	0,06	0,03
Grey	0,10	0,02	0,08	0,03	0,05	0,02	0,01

[1] *calculations carried out with the software "Win-Shelter" developed by the Italian National agency for new technologies, Energy and sustainable economic development and available at the following address : www.pit.enea.it*

The results for an internal blind are shown in Table 8.

TABLE 8 – Calculation of g_{tot} and $\tau_{v,tot}$ for an internal blind

	Method of calculation							
	Simplified		Detailed [2]					
	g_{tot}	$\tau_{v,tot}$	g_{tot}	τ_e	$g_{th} + g_c$	g_v	$\tau_{v,tot}$	$\tau_{v,n\text{-}diff}$
White Pearl	0,40	0,09	0,38	0,06	0,13	0,19	0,09	0,06
White grey	0,43	0,06	0,41	0,04	0,16	0,21	0,06	0,03
Grey	0,50	0,02	0,49	0,015	0,225	0,25	0,02	0,01

[2] *calculations carried out with the software "Physalis" developed by BBS Slama (12, rue Colbert BP 382 63010 Clermont-Ferrand Cedex 1France ; +33 (0)4 73 34 96 60 ; contact@bbs-slama.com)*

In all cases, for the g_{tot} figure, the **detailed calculation method gives more accurate results than the simplified one which overestimates the solar transmittance.** It should be noticed on these examples that the difference in the results obtained is higher for dark fabrics when the blind is external and for light coloured fabrics when the blind is internal.

The greatest benefit of the detailed calculation method is to differentiate the part of the flux which is transmitted as radiation or as heat.

However, these examples show that the simplified method gives the same results for visual transmittance. This could allow easy and accurate calculation using this method. Even if the results are not shown in these tables (as not considered in the standard EN ISO 52022-1), it can be seen that a calculation of the diffuse visual transmittance is also possible with the simplified calculation method.

IV.5. Reference glazing

The previous chapter shows that the performance of a solar shading is appreciated together with the glazing to which it is combined.

In order to compare solar shading on the same basis, EN 14501 defines **5 reference glazing** that shading manufacturers shall use to declare the performance of their products when the glazing to which it will be fitted is unknown.

TABLE 9 – Reference glazing according to prEN 14501

Glazing A : Clear single glazing (4mm float)							
U W/(m² K)	g	τ_e	ρ_e	ρ'_e	τ_v	ρ_v	ρ'_v
5,8	0,85	0,83	0,08	0,08	0,90	0,08	0,08
Glazing B : Clear double glazing (4 mm Float + 12 mm space + 4 mm Float), space filled with air							
U W/(m² K)	g	τ_e	ρ_e	ρ'_e	τ_v	ρ_v	ρ'_v
2,9	0,76	0,69	0,14	0,14	0,82	0,15	0,15
Glazing C : Double glazing (4 mm Float + 16 mm space + 4 mm Float), with low emissivity coating in position 3 (outer surface of the inner pane), space filled with argon							
U W/(m² K)	g	τ_e	ρ_e	ρ'_e	τ_v	ρ_v	ρ'_v
1,2	0,59	0,49	0,29	0,27	0,80	0,15	0,10
Glazing D : Solar control double glazing 4 + 16 + 4 with a low emissivity soft coating in position 2, (inner surface of the outer pane), space filled with Argon							
U W/(m² K)	g	τ_e	ρ_e	ρ'_e	τ_v	ρ_v	ρ'_v
1,1	0,32	0,27	0,29	0,38	0,44	0,43	0,38
Glazing E : Triple glazing 4 + 14 + 4 + 14 + 4 with a low emissivity soft coating in position 2 and 5, (inner surface of the outer pane and external surface of the inner pane), space filled with Argon							
U W/(m² K)	g	τ_e	ρ_e	ρ'_e	τ_v	ρ_v	ρ'_v
0,80	0,55	0,50	0,22	0,23	0,73	0,16	0,16

The characteristics of the glazing are presented in Table 9. The glazing C shall be used as a default glazing. **THE EUROPEAN SOLAR SHADING DATABASE (ES-SDA)**

ES-SO has created a product database that calculates energy performance figures for solar shading products in combination with glazing often called complex glazing systems.

There is an increasing demand for accurate product information in building design. An authoritative reference point for the accuracy of data for products used in the construction of buildings is an objective of the EU Qualicheck initiative.

The ES-SDA database has been developed to meet the objectives of Qualicheck by providing validated data for solar shading materials.

DATA INTEGRITY

The performance data is derived from an approved laboratory testing wavelength intervals of 5 nm, using a spectrophotometer, in accordance with the requirements of the European Standards EN 14500 and EN 410.

Before being included the data is checked and scrutinised by a Peer Review Committee to validate the data and testing process. This is an identical process to that used by the glazing industry and is a robust and effective way of ensuring the integrity of the database.

ENTRY ON TO THE DATABASE

When that data is approved and entered on the ES-SDA database, calculations of the energy performance of blind and shading products when used in combination with reference glazing defined in EN 14501 are possible.

The ES-SDA product database allows users to search for manufacturer's products and export the product and energy performance data. The data is available either as complete product information or in a format for specific national building codes, modelling data inputs and energy performance indicators.

#5

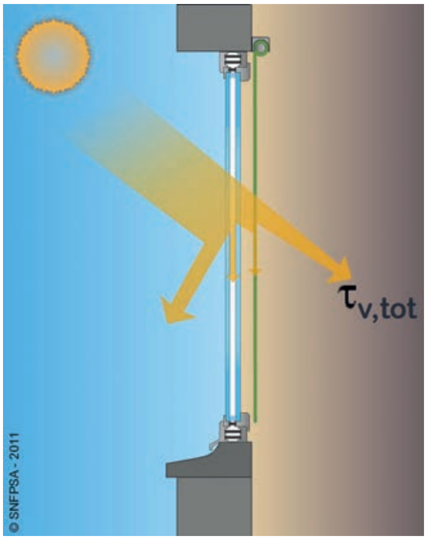
THE VISUAL CHARACTERISTICS: **THE LIGHT TRANSMITTANCE, GLARE CONTROL, DARKENING PROPERTIES, THE VIEW TO THE OUTSIDE**

V. THE VISUAL CHARACTERISTICS: THE LIGHT TRANSMITTANCE, GLARE CONTROL, DARKENING PROPERTIES, THE VIEW TO THE OUTSIDE

V.1. General

Light transmittance τ_v represents **the part of daylight which is transmitted into a room.**

Like the solar factor, it is necessary to distinguish the visual transmittance of a glazing alone and of a glazing used with a solar protection device. Unfortunately, according to the European standards, the symbol used is the same (τ_v in both cases). For clarification, the symbol $\tau_{v,tot}$ is used in this guidebook to identify the case of a solar protection device used with a glazing.



The value of τ_v is between 0 and 1: 0 means no light is transmitted into the room and 1 means all visible radiation is transmitted.

The reference τ_v calculation standards are the same as for the solar factor: EN 410 for a glazing alone and two options for a solar protection device associated with a glazing:

- Either a simplified method given by EN ISO 52022-1,
- Or a detailed method given in EN ISO 52022-3.

V.2. Simplified calculation method: EN ISO 52022-1 (replacing EN 13363-1)

The conditions of use of this standard are the same as for the calculation of the solar factor (see IV.2).

According to EN ISO 52022-1, the formulae to be used for the calculation of $\tau_{v,tot}$ are:

- For an external blind or shutter:

$$\tau_{v,tot} = \frac{\tau_v \tau_{v,blind}}{1 - \rho_v \rho'_{v,blind}}$$

- For an internal blind or shutter:

$$\tau_{v,tot} = \frac{\tau_v \tau_{v,blind}}{1 - \rho'_v \rho_{v,blind}}$$

Where:
- τ_v is the visual transmittance of the glazing
- $\tau_{v,blind}$ is the visual transmittance of the blind or shutter
- ρ_v is the visual reflectance of the side of the glazing facing the incident radiation
- ρ'_v is the visual reflectance of the side of the glazing opposite to the incident radiation
- $\rho_{v,blind}$ is the visual reflectance of the side of the blind or shutter facing the incident radiation
- $\rho'_{v,blind}$ is the visual reflectance of the side of the blind or shutter opposite to the incident radiation

V.3. Detailed calculation method: EN ISO 52022-3 (replacing EN 13363-2)

In the visual part of the spectrum, no heat transfer or ventilation factor has to be considered. Therefore the calculation principle of the solar radiation transfer (see IV.3) applies for radiation between 380 nm and 780 nm instead of the complete solar spectrum.

This calculation method considers the part of the radiation which is transmitted without any deviation from the blind or the shutter, i.e. the direct visual transmittance $\tau_{v,n-n}$, and the part of the radiation which is diffused in all directions after reflection by the blind or shutter, i.e. the diffuse visual transmittance $\tau_{v,n-dif}$ (see Figure 16).

The al visual transmittance is then made of the two parts combined:

$$\tau_{v,tot} = \tau_{v,n-n} + \tau_{v,n-dif}$$

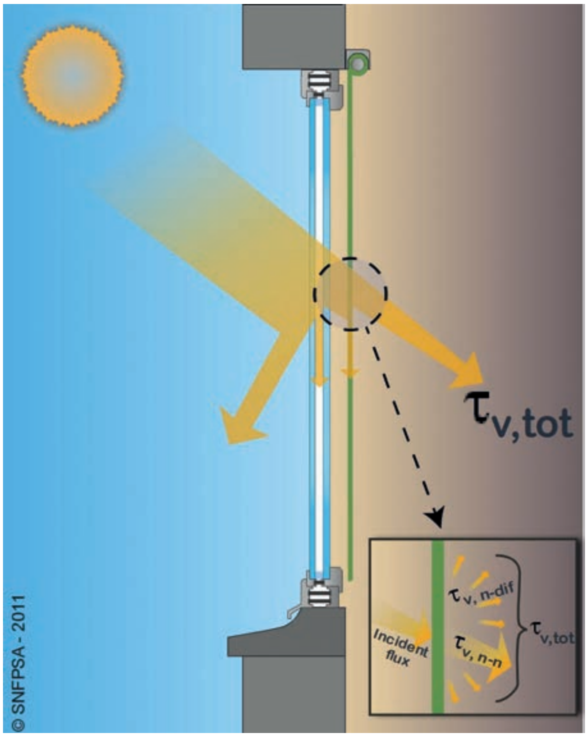


FIGURE 16 – Illustration of the visual transmittance of an internal blind

V.4. Other visual characteristics

V.4.1. General

To choose the right shading device for a building implies to consider a variety of criteria. The previous chapters were dedicated to the main characteristics for a product selection: the solar factor g_{tot}, the light transmittance τ_v and the additional thermal resistance ΔR.

Some additional visual characteristics should be also considered depending on the type of building where shading devices will be installed (offices, hotels, residential premises, etc.), the main purposes (solar control only, visual control only, both); etc.

These principle characteristics are:
- **Quality of daylight,**
- **Control of glare,**
- **Darkening properties,**
- **View to the outside.**

Depending on the configuration and the needs, a compromise should be found between these characteristics to select the most suitable product: for example, an opaque blind will be the ideal product for glare control but it will not allow any view to outside.

The following chapters present projects of classification that are intended to be integrated into the proposed standard prEN 14501. This standard is now under revision[1]. Classifications should therefore be considered with care as they may be modified before final publication of EN 14501.

The performance classes presented in the following chapters are quoted in Table 10.

TABLE 10 – Definition of classes

Class	Influence on visual comfort				
	0	1	2	3	4
	very little effect	little effect	moderate effect	good effect	very good effect

[1] CEN Enquiry is planned to be launched in 2018.

V.4.2. Control of glare

People suffer from glare either when an area in the field of view is too bright, or when the contrast between an area and its surrounding is too high.

Glare may be caused also by a disturbing reflection on a PC screen due to the luminance of the window and the surrounding areas.

FIGURE 17 – Example of glare caused by a high luminance level of the window

Therefore, the shading device must be specified in order to reduce:
• the solar rays on the work surface and its immediate surrounding;
• the direct vision of the solar disk;
• the brightness of the window and the contrast with its surroundings.

In order to cover the two first aspects, a special attention should be given to the normal visual transmittance $\tau_{v,\,n\text{-}n}$ of the curtain material (e.g. fabric, laths, slats), and to address the third criteria, a special attention should be given to the diffuse visual transmittance $\tau_{v,\,n\text{-}dif}$.

The perception of glare depends on many criteria such as:
• Person (age, visual acuity ...),
• Building (location, surroundings ...),
• Façade (orientation, glazing transmittance, percentage of glazing ...),
• Room (area, position and number of windows, reflectance of walls and furniture...),
• Activities in the room (office, computer screens, private use ...),
• Position of the person within the room (distance from the façade, viewing direction ...).

Therefore, it is not possible to define the performance level for shading devices that will be suitable for every configuration. When glare is considered a key criteria to select a product, a reference may be made to the detailed approach (see EN 17037 “Daylight of Buildings”).

However, prEN 14501 provides a generic classification which is intended to evaluate the capacity of shading devices to control glare. It has been established considering fixed assumptions on the location and orientation of the building, the room size, the glazing properties and sizes, the distance of the observer from the façade, etc.

This classification is based on the following visual transmittance factors $\tau_{v,\ n\text{-}dif}$ and $\tau_{v,\ n\text{-}n}$ (see II.5).

The classification is reproduced below:

TABLE 11 – Glare classification according to prEN 14501

$\tau_{v,\ n\text{-}dif}$	$\tau_{v,\ n\text{-}n}$					
	$\tau_{v,\ n\text{-}n} = 0,00$	$0,00 < \tau_{v,\ n\text{-}n} \leq 0,01$	$0,01 < \tau_{v,\ n\text{-}n} \leq 0,02$	$0,02 < \tau_{v,\ n\text{-}n} \leq 0,03$	$0,03 < \tau_{v,\ n\text{-}n} \leq 0,05$	$\tau_{v,\ n\text{-}n} > 0,05$
$\tau_{v,\ n\text{-}dif} \leq 0,03$	4	4	3	3	1	0
$0,03 < \tau_{v,\ n\text{-}dif} \leq 0,06$	4	3	2	2	1	0
$0,06 < \tau_{v,\ n\text{-}dif} \leq 0,10$	4	3	2	1	0	0
$0,10 < \tau_{v,\ n\text{-}dif} \leq 0,15$	3	2	1	1	0	0
$0,15 < \tau_{v,\ n\text{-}dif} \leq 0,20$	2	2	1	1	0	0
$0,20 < \tau_{v,\ n\text{-}dif} \leq 0,25$	1	1	0	0	0	0
$0,25 < \tau_{v,\ n\text{-}dif}$	0	0	0	0	0	0

V.4.3. Darkening properties

Darkening performance represents the capacity of a **shading device in the fully extended and closed position to prevent light penetration.** The performance is expressed by the level of illuminance under which no light is perceivable behind the shading device.

The principle of the test is the following: surrounded by a light tight environment, an observer shall detect if light is perceptible through a shading device when the product is illuminated on the outer surface at different levels of illuminance (see Figure 18).

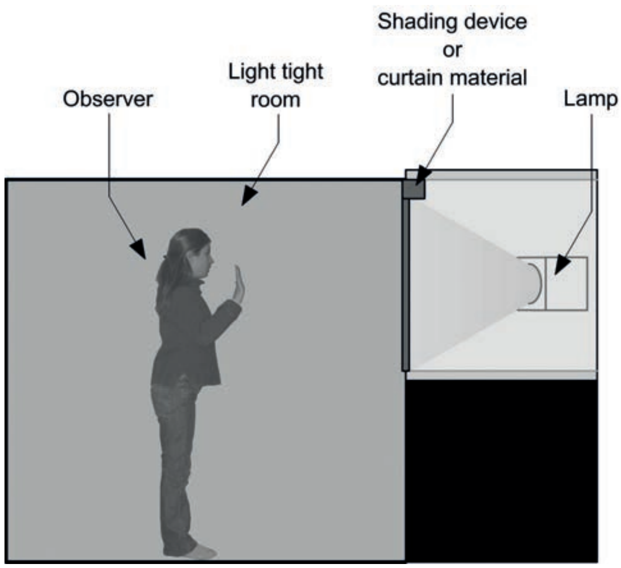


FIGURE 18 – Principle of the evaluation of darkening properties

For some classes, an additional light source is placed in the observer room in order to reproduce a minimal internal light condition, e.g. light produced by clock face, light passing under the door.

The human eye is extremely sensitive in the dark adapted condition (scotopic vision). Therefore the standard considers that the use of a human being is for now the best way to evaluate the products for the determination of darkening and opacity performances.

At the present time no electronic device other than a photon counter is sensitive enough to replicate the human eye. Since this system is very complex and expensive to use, the standard considers that the human eye is the most relevant present solution. The standard includes a procedure to evaluate the ability of the observer to carry out the test.

The classification for the darkening performance defined by prEN 14501 is based on three elements:
- The opacity performance of the curtain material (e.g. fabric, laths, slats), according to Table 13.
- The choice of the frame (whether with or without light exclusion system),
- The result of the test carried out on the complete solar protection device according to Table 12.

The classification defined by prEN 14501 is the following:

TABLE 12 – Darkening performance classification for complete shading devices, according to prEN 14501

			Internal incident light	No light perceived at the following external incident light level (L)	Curtain material classification (see Table 13)				
					0	1	2	3	4
France	A	With light exclusion system	No	75 000 lux					A.4
	B	With light exclusion system	0,002 lux	30 000 lux				B.3	B.4
	C	With light exclusion system	0,002 lux	1 000 lux			C.2	C.3	C.4
	D	With light exclusion system		No test	D.0	D.1	D.2	D.3	D.4
	E	Without light exclusion system		No test	E.0	E.1	E.2	E.3	E.4

For example, when a shading device is classified C.3:
- C means that the frame design includes a light exclusion system and that the complete product has passed the test with an external incident light of 1 000 lux and an internal light of 0,002 lux.
- 3 is the class of the curtain material (no light perceived at 30 000 lux).

Class A.4 is a technical class intended to cover specific applications such as high grade laboratory work, advanced optics, photochemical, handling highly light sensitive material.

A light exclusion system is defined by the standard as a “solution intended to reduce peripheral light penetration”. A guiding system may fit the purpose of a light exclusion system. However, when the curtain does not enter the guiding system (e.g. cable guiding), it is not qualified as a light exclusion system.

The curtain material classification to which the product classification is referring to is the following:

TABLE 13 – Opacity performance classification for curtain material, according to prEN 14501

	No light perceived at the following incident light level (L)	Class
With internal incident light (2 mlx)	L < 200 lux or not tested	0
	200 lux ≤ L < 1 000 lux	1
	1 000 lux ≤ L < 30 000 lux	2
	L ≥ 30 000 lux	3
Without internal incident light	L ≥ 100 000 lux	4

V.4.4. View to the outside

This is the ability of a shading device to allow a view to the outside when it is fully extended. The performance of shading devices will vary depending on the internal and external light conditions. Therefore, the classification of products should be considered as a mean of comparison between products. The classification of products is given by the properties of the curtain material. Therefore tilting products, such as venetian and vertical blinds, should be considered in the closed position.

The classification is characterised by two parameters:
- the normal visual transmittance $\tau_{v,n-n}$;
- the diffuse visual transmittance $\tau_{v,n-dif}$.

High values of $\tau_{v,n-n}$ are favourable because they allow shape recognition. Conversely, a high value of $\tau_{v,n-dif}$, such as a light colour, is unfavourable because it distorts the direct vision and generates a parasitic luminance on the curtain when illuminated by the sun.

The classification of products defined in prEN 14501 is the following:

TABLE 14 – Classification for the visual contact with the outside, according to prEN 14501

$\tau_{v,n-n}$	$\tau_{v,n-dif}$		
	$0 < \tau_{v,n-dif} \leq 0{,}04$	$0{,}04 < \tau_{v,n-dif} \leq 0{,}15$	$\tau_{v,n-dif} > 0{,}15$
$\tau_{v,n-n} > 0{,}10$	4	3	2
$0{,}05 < \tau_{v,n-n} \leq 0{,}10$	3	2	1
$\tau_{v,n-n} \leq 0{,}05$	2	1	0
$\tau_{v,n-n} = 0{,}00$	0	0	0

#6

QUALITY **OF DAYLIGHT**

VI. QUALITY OF DAYLIGHT

VI.1. General

Architectural design of office environments, houses and other dwellings **should place more emphasis on providing sufficient exposure to daylight for people in order to promote health and well-being.** Therefore, daylight calculation should become standard in the early planning stage so planners, investors and owners get an indication of the impact of different building concepts.

Fixed shading (overhangs, PV-panels, louvers, grids and other building elements like solar glass) might reduce the amount of solar heat but they will also increase the need of artificial light throughout over the year and will reduce solar gains in the heating season (see Figure 19).

This is not a criticism of PV and other technologies which help us to change to renewable energy but it suggests that building design must be seen holistically and that natural daylight cannot and should not simply be replaced by the light of LEDs during daytime.

Daylight is essential for life (mankind, animals and plants).

Solar control glass | Vertical louvres | PV panel | Overhang

FIGURE 19 – Examples of fixed shading devices reducing daylight in buildings[2]

An unpleasant workplace due to inadequate consideration of the need for daylight

A pleasant workplace with dynamic blinds which redirect daylight to the ceiling which lights the whole room

FIGURE 20 – Examples of good and bad consideration of daylight in office premises[2]

[2] Source of all pictures : Hannes Gerstmann, Geniolux

VI.2. Daylight is more than light

The daylight we see might not be the daylight our bodies need. When considering daylight three areas must be discussed:

- Our **sense of vision** which we need for visual information and which also gives us orientation. Our visual sense is very flexible; we can see and even read by the light of a full moon on a clear night as well as on sunny days, the illumination level ranges from 0;25 to 120 000 lux. And our visual perception will correct defects in colour rendering that can occur for instance when using artificial light.

- The **colour temperature,** which is measured in Kelvin [K] can range from 1800 K (warm light such as at sunrise and sunset or the flame of a candle) up to over 15 000 K (cold light such as the sky at the earth's poles). During daytime, the colour temperature ranges mostly between 5500 to 6500 K. **The colour temperature influences our psyche;** warm light is relaxing while cold light induces activity. Light and shade create the ambiance of our rooms and contribute to how we respond to a space - this affects efficiency.

Temperature	Source
1700 K	Match flame, low pressure sodium lamps (LPS/SOX)
1850 K	Candle flame, sunset/sunrise
2400 K	Standard incandescent lamps
2550 K	Soft white incandescent lamps
2700 K	"Soft white" compact fluorescent and LED lamps
3000 K	Warm white compact fluorescent and LED lamps
3200 K	Studio lamps, photofloods, etc.
3350 K	Studio "CP" light
4100 – 4150 K	Moonlight[2]
5000 K	Horizon daylight
5000 K	Tubular fluorescent lamps or cool white/daylight compact fluorescent lamps (CFL)
5500 – 6000 K	Vertical daylight, electronic flash
6200 K	Xenon short-arc lamp[3]
6500 K	Daylight, overcast
6500 – 9500 K	LCD or CRT screen
15,000 – 27,000 K	Clear blue poleward sky

FIGURE 21 – Temperature of light sources[3]

[3] Source: https://en.wikipedia.org/wiki/Color_temperature

- The full spectrum of the daylight (from ultra violet to near infrared) and its dynamism (density of light and light colour) affects **human biological senses.** It synchronises our body clock (circadian rhythm) and affects the quality of sleep as well as the production of vitamins and hormones (vitamin D3, Melatonin, Serotonin, Cortisol etc.). It also strengthens the immune system. It's also known, that lack of daylight contributes to illnesses as for example rickets, osteoporosis, Psoriasis, muscle suffering, etc. Some cancer types are suspected to be connected to light or irradiation defect phenomena.

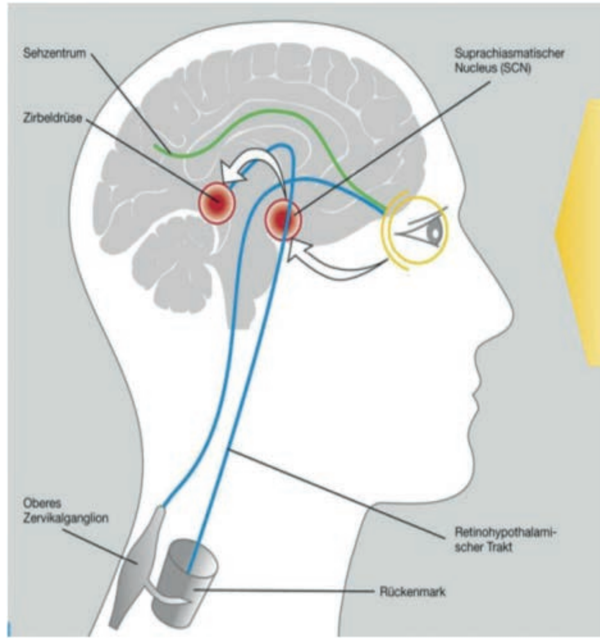


FIGURE 22 – How light tiggers the inner clock[3]

Visual information goes to the visual centre of the brain (green line) while other daylight criteria affects SCN (suprachiasmatic nucleus), pineal gland and other parts of vegetative system (blue lines)

The range of biologically effective spectrum (human centric lighting) is much wider than the visual spectrum (see Figure 23).

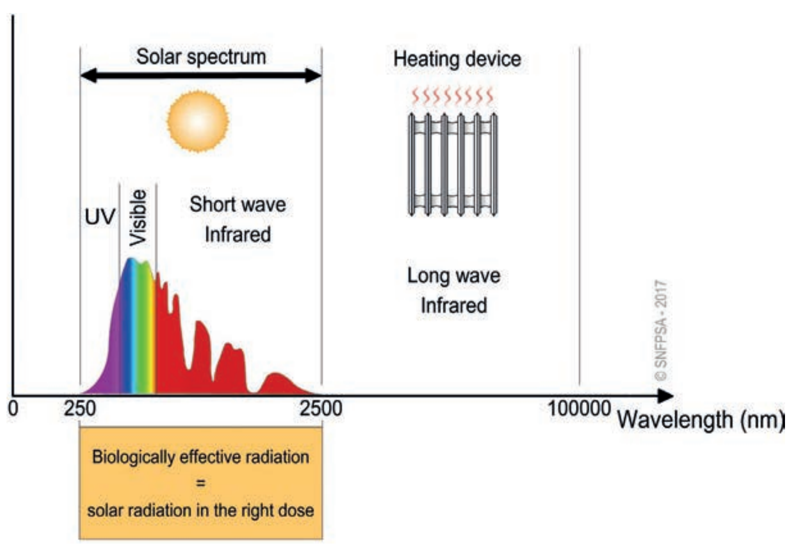


FIGURE 23 – Part of the spectrum impacting human biological behaviour

[4] Source: Licht.de "Licht triggers the inner clock"

The visible spectrum also changes during the day (see Figure 24). These variations also impact all living species on earth, including human beings.

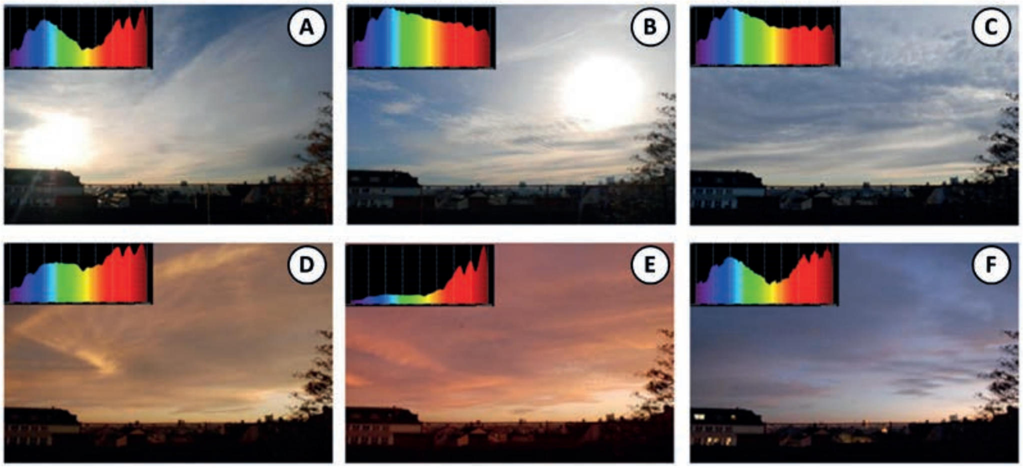


FIGURE 24 – Visible spectrum at various time in the day[5]

Dynamic sky with visual spectra starting at sunrise with warm colour (temperature about 2000 – 3500 K) due to a red peak (Figure 24 A). During daytime, the spectrum of sky remains the same depending if there is direct sun or overcast sky (Figure 24 B and C). The colour temperature of 5500 to 6500 K prevails during daytime. At sunset, all parts of the spectrum, except red, are decreasing (Figure 24 D and E). The colour temperature decreases to app. 2500 K. Before the sky gets dark there is a short period of time called "the blue hour" when the blue part of the spectrum is increasing (Figure 24 F).

These spectra show the nature of daylight at different times in the day but are not reflecting the quantity of light. This evolutionary cycle impacts the circadian rhythm (biological clock, hormones, etc.) on all life on earth.

VI.3. Natural daylight, filtered daylight and artificial light

When considering the lighting of rooms, the biological factor must always be considered as well. There is only one kind of air humans can breathe, but there are two ways a space can be supplied with light, that is either, during day time, with daylight through transparent components in the building envelope or with artificial lighting.

Any reduction of the light or solar transmittance may have an impact on the light spectrum. Glazing (such as solar control glazing, glass with solar-films or electrochromic glazing) changes the spectral composition of the natural daylight whereas solar shading systems can control the quantity of daylight entering a room without changing its nature. This is due to the fact that shading reduces the energy transmittance whilst keeping a part of direct light transmittance (through holes or slats for example).

VI.3.1. Visual spectra of different daylight sources

The following pictures show different daylight spectra (visible part only) as perceived by a human eye for various configurations (with or without glazing or shading). To present the impact of glazing and shading, only the shapes of the diagrams are significant, the amount of light is different (depending on the light transmittance).

[5] Source: Gregor Radinger, Danube University Krems & Hannes Gerstmann, Geniolux

From these spectra in the visible range only, one can extrapolate the variations in the UV range (left part, below 360 nm) and in the near infrared range (right part, above 760 nm) which influence the biological senses. The white dotted line in Figure 26 to Figure 30 represents the shape of Figure 25 (natural daylight without glazing and/or shading) at the time that spectra have been measured.

The eye is only sensitive to three colours while the human body is sensitive to the complete spectrum.

The Colour Rendering Index CRI (or Ra) characterises the quality of the visual daylight perceived by humans at a cloudy sky (CRI 100).

When the light passes through a transparent element, CRI can be changed depending on the material and/or layers such as coatings, colours, etc.

If the CRI drops below 95, the visual perception behind a glazing can be altered.

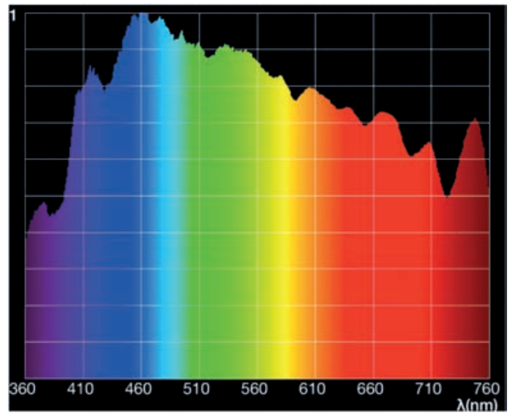


FIGURE 25 – Visual spectrum outside (in front of glazing), cri 100[6]

A part of the blue and red light is reduced (blue because of the panes themselves and red because of the coating).

Although it is not shown on the diagram, the non-visible part of the spectrum will be affected in the same way, that is reduction of the UV and infrared parts.

The CRI is above 95 which is considered a very good visual performance.

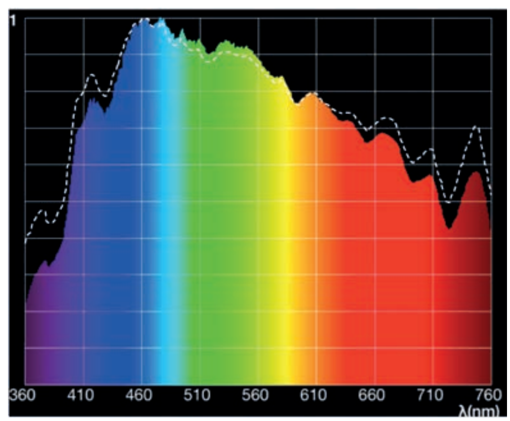


FIGURE 26 – Visual spectrum behind typical 2-pane low-e glass (g = 0, 65 / cri 98)

The spectrum is almost the same as the one without shading thanks to the transmitted light which is not filtered (direct transmittance through holes).

Only a part of the violet section is reduced because of the colour of the fabric (grey with an aluminium coating on the external face).

The CRI is above 95 which is considered a very good performance.

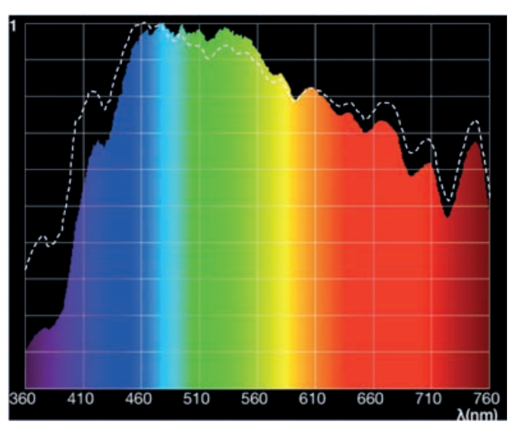


FIGURE 27 – Visual spectrum behind a typical 2-pane low-e glass with external grey screen fabric (g_{tot} = 0, 07 / cri 96)

[6] All pictures, source: Hannes Gerstmann, Geniolux

The spectrum is the same as the one without shading thanks to the transmitted light which is not filtered (direct transmittance through holes).

Here also, only a part of the violet section is reduced because of the colour of the fabric (grey with an aluminium coating on the external face).

The CRI is above 95 which is considered a very good performance.

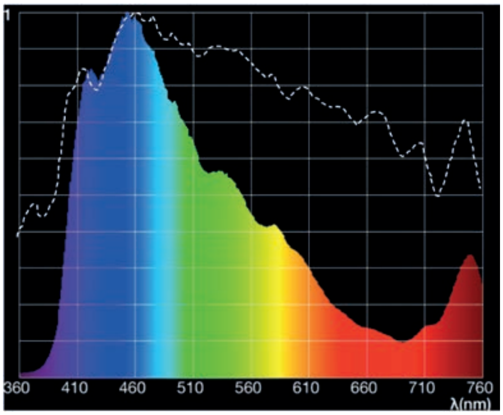


FIGURE 28 – Visual spectrum behind a typical 2-pane low-e glass with internal grey screen fabric (g_{tot} = 0, 43 / cri 97)

As the reduction of the solar factor (energy transmittance) is obtained by filtering the light, the visible red and the near infrared parts of the spectrum are reduced.

For g values > 0,45, almost all of the near infrared section is blocked.

For g values < 0,45, also the visible section from red to green is reduced.

This impacts the biological effectiveness of light as it is no longer natural daylight.

The CRI is reduced far below 95: the appearance of the outside and the visual information become unnatural.

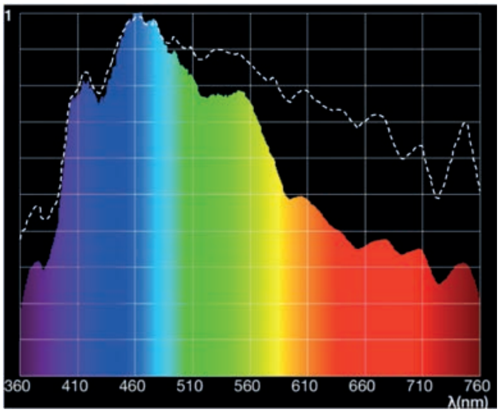


FIGURE 29 – Visual spectrum of a solar control glass (g = 0, 35 / cri 89, tinted blue)

As it is the same filtering principle which is applied, this technology has the same effect as the solar control glass: the complete spectrum is modified.

The CRI is reduced far below 95: the appearance of the outside and the visual information become unnatural.

The solar and daylight transmittances are reduced permanently which reduces the free solar gains during the heating period and increases the artificial lighting costs.

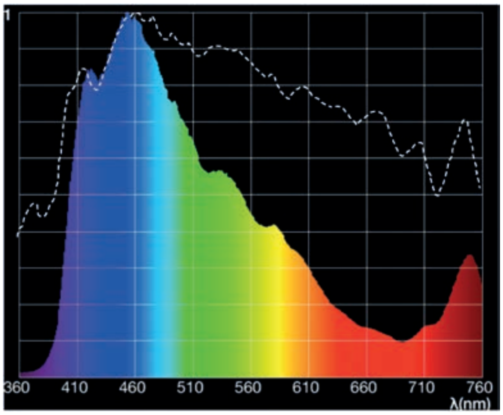


FIGURE 30 – Visual spectrum of a 2-pane low-e glass with external “solar film” (g = 0,22 / cri 87, tinted blue)

VI.3.2. Visual Spectra of different artificial light sources

Artificial lighting cannot be a substitute to natural daylight, neither in the spectral composition nor in the variation during the day (intensity and direction). This must be correctly taken into consideration by designers in order to maximise daylight distribution in the rooms.

Artificial light should always be only a supplement to daylight: energy-demand for lighting during daytime can be optimised by an effective daylighting concept.

This spectrum is the same as the spectrum of sunset, fire or candlelight (see Figure 24 E). It extends also to the near infrared!

Advantages:
It has a full spectrum without gaps (important for biological effectiveness). Because of the low level of blue light, it triggers the production of the “sleeping” hormone, Melatonin. It’s the only artificial light which generates NIR, which is important for relaxing and for the immune system. Colour Rendering Index is 100%.

Disadvantage:
Effectiveness: only 5% of the energy-output is light, 95% is heat.

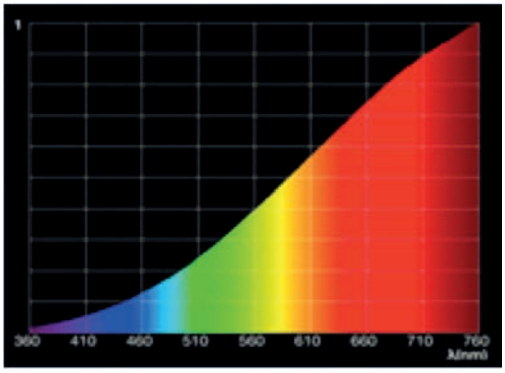


FIGURE 31 – Spectrum of halogen spot (exceeding to nir) [7]

This spectrum is totally different from that ingrained in mankind by evolution. As it is produced by photon emission (instead of by incandescence), it is characterised only by two peaks. Even if the colour of such lamps can be selected (from cold to warm), the spectrum will remain with a blue peak.

Advantages:
Energy efficient, long lasting, many new opportunities for integration in furniture and accessories

Disadvantages:
Designed to fulfil visual needs; for biological need, a full spectrum with red and NIR is missing. The blue peak triggers the “stress” hormone, Cortisol which can cause insomnia and it can affect medical problems for the eye[8]. LED-light can flicker, that can also lead to medical problems.
Colour Rendering Index typically about 81 - 83%.

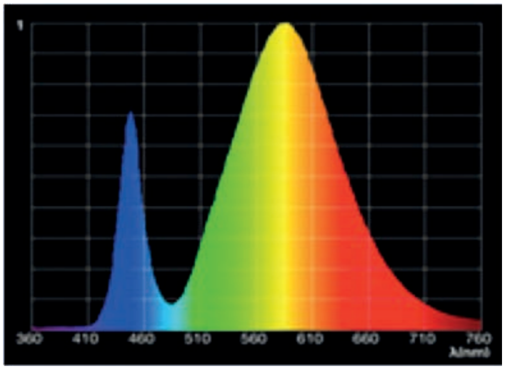


FIGURE 32 – Spectrum of led (only visual, no nir)

[7] All pictures, source: Hannes Gerstmann, Geniolux

[8] Read more about blue light hazard. https://en.wikipedia.org/wiki/High-energy_visible_light).

The spectrum is totally different from the natural daylight spectrum. Fluorescent tubes work like an ink jet printer (activating blue, green and red rods of the retina). This may satisfy the visual needs but does not reproduce the biological effect of natural daylight.

Advantages:
Energy efficient, long lasting, inexpensive

Disadvantages:
No biological benefits due to many gaps in the spectrum.
Colour Rendering Index typically about 77 - 82%.

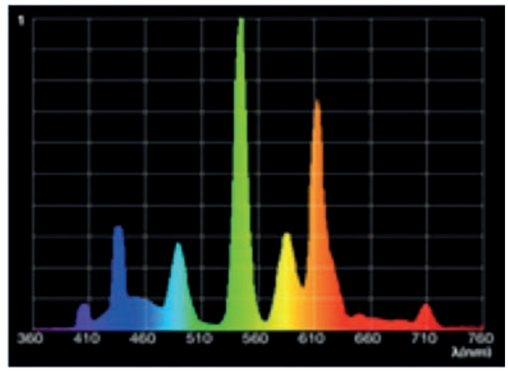


FIGURE 33 – Spectrum of fluorescent tube or energy saving lamps (only visual, no nir)

Building designers should therefore consider high transmittance glazing combined with dynamic solar shading in order to:

- **Maximise the daylight transmittance of the glazing, ensuring that the full daylight spectrum is not filtered**
- **Optimise the daylight level so that occupants will have enough daylight without suffering glare and overheating.**

Fulfilling these principles will lead at the same time to the best possible energy balance, allowing free solar gains in the cold period and preventing overheating or air cooling consumption out of the heating season.

VI.4. Impact of daylight on human well-being and performance[9]

Many studies have explored the relationship between daylighting, psychological well-being, and workers' productivity or school children's performance. The impact of daylight in the workplace, on sleep, quality of life, and overall health also depends on the quality of daylight.

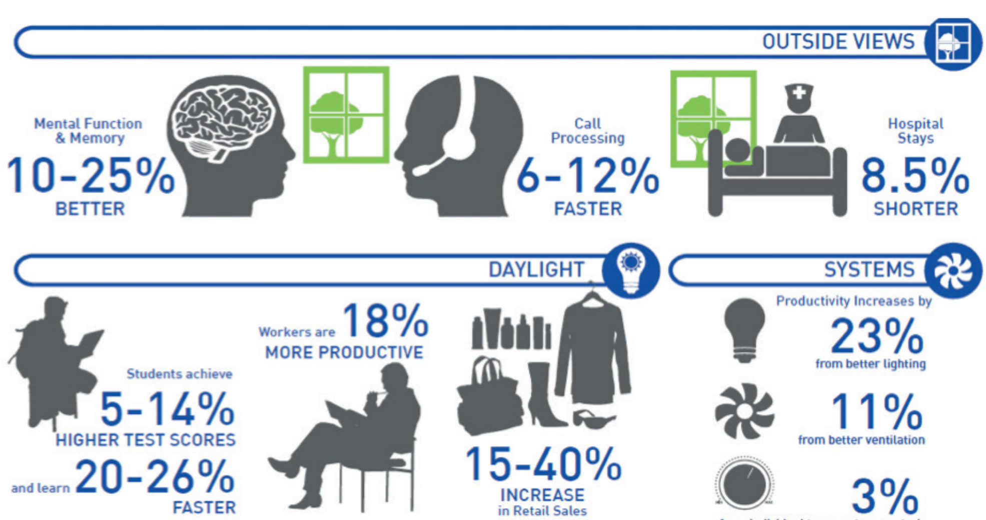


FIGURE 34 – Impact of daylight on human well-being and performances[10]

[9] Source : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4031400/ adapted by Hannes Gerstmann

[10] Source : World Green Building Council, 2013 "The Business Case For Green Building"

The sequences of day and night are one of the main environmental factors for circadian rhythms that influence the biological, mental, and behavioural patterns such as sleep and activity. The variation of the light exposure during the day has a large impact on these rhythms. Given that office hours occur during biologically natural daylight hours, light exposure in the office environment will have effects on sleep, and sleep and other influences will also have effects on physical and mental health.

Since the sick building syndrome of the 1970s and the World Health Organization's Declaration on Occupational Health for All in 1994 occupational health has become a relevant issue among health professionals and architects alike. With the increased interest today in green architecture, daylighting is becoming an important design consideration. Typically, daylighting recommendations are made in the form of daylight factor (DF), with levels ranging between 1% to 6% depending on building types and activities. This is not really a challenge and most of buildings achieve a DF < 2%. Since scientists now have a better understanding of the influence of daylight on humans, building standards are being amended to achieve a higher daylight factors such as the upcoming prEN 17037:2016 “Daylight of buildings”.

The daylight factor (DF) is the percentage of indoor illuminance compared to the outdoor illuminance on a horizontal surface. The daylight factor principle is only valid for consistent overcast sky conditions (approx. 10.000 lux). Light-intensity of the sun is 7 to 10 times higher compared to overcast sky, so light transmittance can be dimmed by shading devices without making rooms darker.

There is much evidence that links insufficient sleep and/or reduced sleep quality to a range of significant short-term impairments such as memory loss, slower psychomotor reflexes, and diminished attention. If environments without windows, or those that lack daylight, affect workers and pupils' sleep quality, there will be subsequent effects not only to individuals but also on a societal level, leading to more accidents, workplace errors, and decreased productivity. Sleep quality is also an important health indicator that may have effects on, and interactions with mood, cognitive performance, and health outcomes such as diabetes and other illnesses. Therefore, it is crucial to investigate the effects of daylight as it may provide a profound way to improve workers' productivity and health as well as the safety of the community they work and live in. Deprivation to light damages monoamine neurons and produces a depressive behavioural phenotype in rats. In humans, a direct correlation between the severity level of Seasonal Affective Disorder and exposure to natural daylight is well documented. Results of several studies suggest that both natural and artificial bright light (much higher than minimum requirement for lighting of 300 or 500 lux), particularly in the morning, can significantly improve health outcomes such as depression, agitation, sleep, circadian rest-activity, and Seasonal Affective Disorder.

These effects of light exposure, or the lack of it, illustrate the importance of proper light exposure for physical well-being and mental health. In our modern society, many responsibilities in the workplace and at home dictate self-imposed alterations and/or loss of daylight in our daily lives. Researchers suggest that the light exposure determined by our daily schedules will have subsequent consequences on our mood, cognitive performance, and overall well-being.

VI.5. Conclusion

"Good light" in the sense of biological activating dynamic light combined with glare free natural lighting is essential for health, general wellbeing, better performance at work or at school, better relaxation, and last but not least, a better mood.

A high rate of daylight autonomy minimises the need for artificial light during daytime; and therefore reduces the energy consumption of artificial lighting, cooling and heating plus reduces costs for maintenance due to extended time interval for service.

Dynamic solar shading combined with clear glass or insolating glass ensures the best quality of daylight by reducing its intensity without changing its spectrum. It is key, that shading can be retracted because sun shines only for a few hours per day on each specific façade. Depending on climate and region, solar protection is needed between 10 and 20% of the 4500 hours of daylight.

If solar protection is static (overhangs, grids, louvers, PV-shields, solar glass, solar films, etc.) the energy demand for lighting increases and can be higher than energy demand for cooling and even that for heating. Daylight is not a renewable energy but it must be understood as a worthy resource that can increase the energy efficiency of buildings and help to prevent the national economies from increasing health care costs. It makes the interiors more vibrant and creates the atmosphere of comfort and well-being for the occupiers. Life was created by light, therefore animated beings depend on natural daylight. Today many people spend 90% or more of their time indoors[11]. That's a new phenomenon in evolution. Building designers and occupiers should be aware of this.

It is important to avoid designing buildings with glazing that eliminate natural daylight to achieve cooling savings[12]. In order to promote healthy living, shading controls both heat and daylight for a comfortable environment with a reduced energy cost. Shading is the solution for all windows and glazed façades.

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[12] E.g. Solar control glazing, electrochromic glazing

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EN 14500 “Blinds and shutters - Thermal and visual comfort - Test and calculation methods”

EN 13125 “Shutters and blinds - Additional thermal resistance - Allocation of a class of air permeability to a product”

EN ISO 52022-1[13] “Energy performance of buildings — Thermal, solar and daylight properties of building components and elements — Part 1: Simplified calculation method of the solar and daylight characteristics for solar protection devices combined with glazing”

EN ISO 52022-3[14] “Energy performance of buildings - Thermal, solar and daylight properties of building components and elements - Part 3: Detailed calculation method of the solar and daylight characteristics for solar protection devices combined with glazing”

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(4) Informative links

ES-SO web site: www.es-so.com

Textinergie tool: www.textinergie.org

Win-Shelter software : www.pit.enea.it

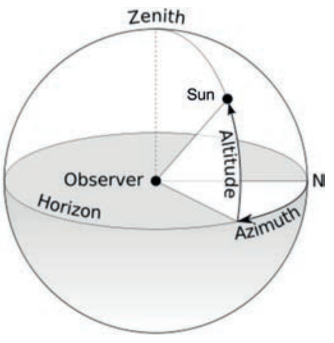
GLOSSARY

radiation
Transport of energy in the form of waves or particles from a source (heat, light…)

wavelength
Wavelength is the distance between two identical adjacent points in a wave.

W/m²
Watt per square meter

solar irradiance
power per unit area received from the Sun in the form of electromagnetic radiation. Measured in W/m².



altitude
angle between the sun and an observer's local horizon

azimuth
angle of the sun around the horizon, usually measured from the north increasing towards the east

latitude
angular distance north or south from the equator of a point on the earth's surface, measured on the meridian of the point.

emissivity
measure of the ability of a surface to radiate energy; ratio of the radiant flux emitted per unit area to that emitted by a black body at the same temperature

transmittance
ratio of the transmitted flux to the incident flux

reflectance
ratio of the reflected flux to the incident flux

curtain
part of the product which is set in motion by the operating system and fulfils the purpose of the blind, awning or shutter

openness coefficient
ratio between the area of the openings and the total area of a fabric

Design graphic: Planète Graphique Studio, 95 boulevard, Berthier, 75017 Paris

EUROPEAN SOLAR-SHADING ORGANIZATION

Energy Savings & Comfort

Within the building envelope, the glazed part plays a key role as it allows light and heat to enter into the building. However, light and heat levels vary throughout the year. They need to be controlled firstly to reach the goal of 'nearly zero-energy' and, secondly, to ensure the comfort of the building's occupants. Solar shading – which covers a huge variety of products and controls – is designed to answer these needs as it adapts the glazed envelope properties to the weather conditions and the human needs.

That is why solar shading cannot be considered as a secondary equipment of the glazed envelope but should be integrated in the building design at the very first stage of the project's development. In this way, the performance impact of the building development can be assessed and the heating and cooling equipment specified accordingly. The visual and thermal comfort of the occupants can also be determined well in advance avoiding possible modifications of the building façade or the internal environment after commissioning.

This guidebook is the second edition of the ES-SO technical document published in 2012. It is intended to give the technical information needed to evaluate the performance of solar shading. It contains the basic principles required to understand the physical properties involved in the radiation transmission. It highlights the standardised calculation methods that are used to evaluate the thermal, solar and visual characteristics of blinds and shutters.

Compared to the first edition, the section related to visual aspects has been developed: a new chapter on quality of daylight has been integrated and the provisions on shading systems for visual comfort (glare control, darkening properties, the view to outside) are now presented.

Although it is intended to be used by solar shading manufacturers and installers, this guidebook will be of interest to building designers and energy engineers.

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