EUROPEAN SOLAR-SHADING ORGANIZATION

Energy Savings & Comfort

Solar shading for low energy buildings






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

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ABOUT ES-SO

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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 although 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 need 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 are the physical properties involved in the transmission of the solar radiation. It is mainly based on calculation methods provided by European 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 and energy engineers.

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 and 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).

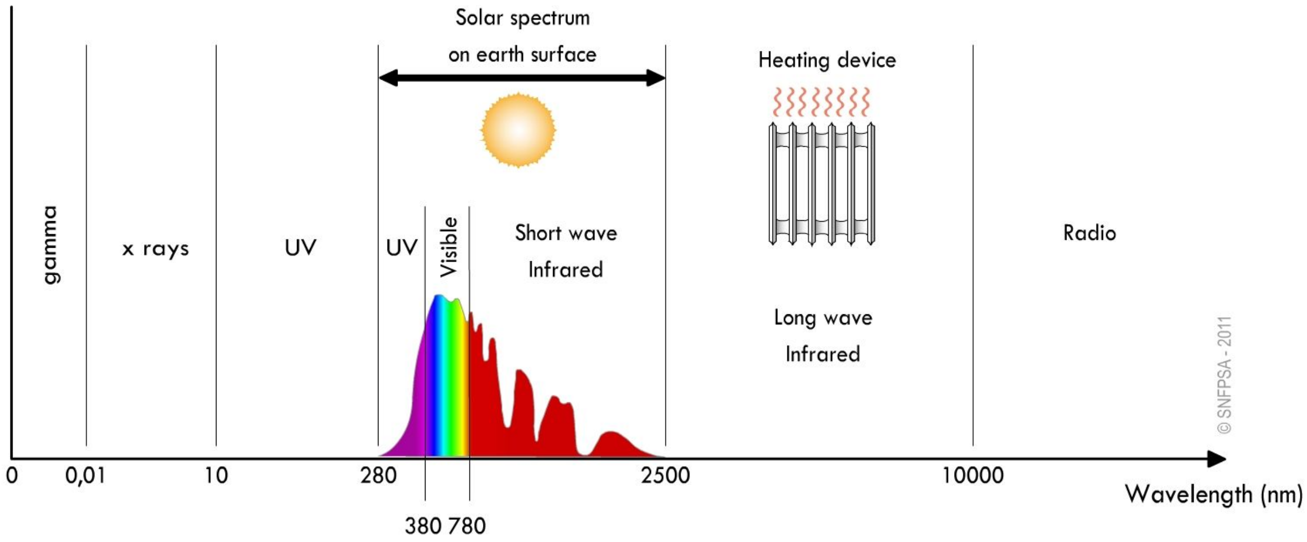


FIGURE 1 – CLASSIFICATION OF VARIOUS ELECTROMAGNETIC RADIATION DEPENDING OF THEIR WAVELENGTH

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

- The solar radiation with wavelength between 280 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 10000 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).

NOTE The values defining the limits of each type of radiation are not standardised. It may vary from one document to another.

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 the space. The remaining part (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 at the limit of 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 global incident radiation into three parts (see Figure 2).

- Direct radiation, which is the solar radiation neither absorbed nor reflected by the atmosphere,
- Diffuse radiation, which is the part of the solar radiation absorbed by the atmosphere and emitted in all directions,
- Reflected radiation which corresponds to the reflection of the direct and diffuse radiation on the ground.

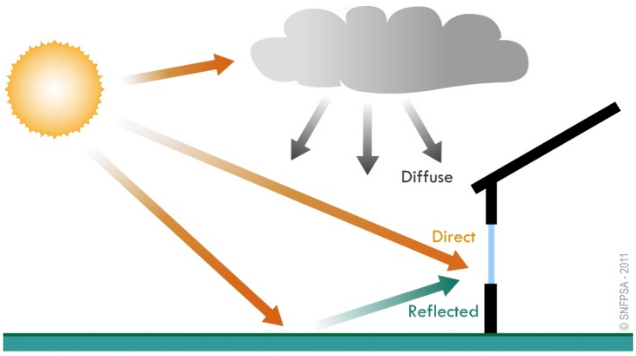


FIGURE 2 – INCIDENT PARTS OF THE SOLAR RADIATION

This 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.

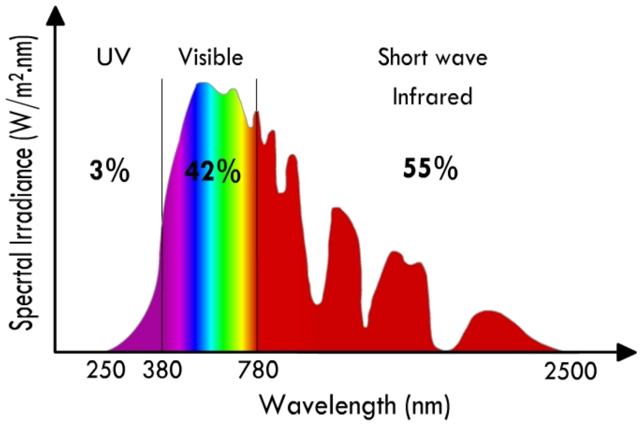


FIGURE 3 – SPECTRAL IRRADIANCE AT THE SEA LEVEL FOR THE SOLAR SPECTRUM

The "power" of a 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 the 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.

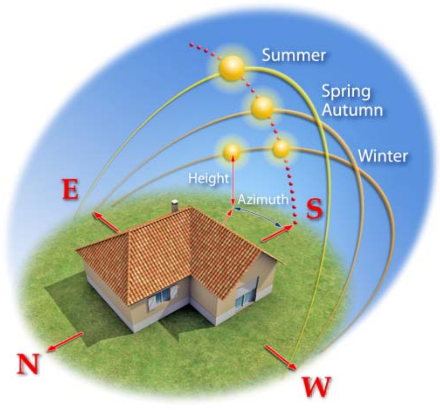


FIGURE 4 – POSITION OF THE SUN IN THE SKY

Figure 5 shows the solar irradiance on vertical surfaces in summer (21 June) and in winter (21December). As these graphs have been calculated with a cloudless sky and without consideration of the 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. However, in Europe, the general pattern is the same.

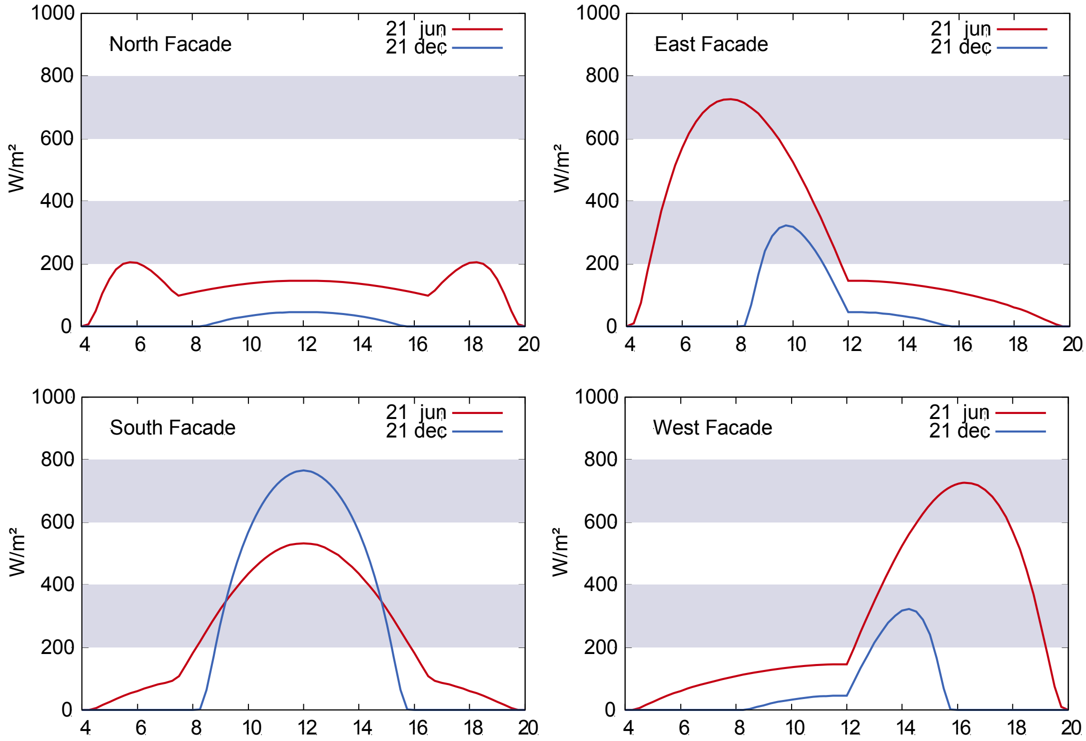


FIGURE 5 – IRRADIANCE FOR NORTH, EAST, WEST AND SOUTH VERTICAL SURFACE AT 50° N OF LATITUDE (SOURCE ES-SO & REHVA GUIDEBOOK)

It can be seen that:

- North exposed façades, receive the lowest level of solar irradiance. 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 a symmetric pattern: the east surface will receive the largest part of the radiation before noon, whereas the west surface receives it in the afternoon. It can be seen that the irradiance is at a maximum when it is composed of the direct part of the radiation. After noon for the east façade and before noon for the west façade, the radiation is mainly composed of the diffuse part coming from the sky. That is the reason why it is lower.
- South exposed façades receive solar radiation almost throughout the day. That is why it is essential to maximize the glazed surfaces on this orientation

to optimize the solar gain that could enter the building in winter and to protect the façades in summer 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. It is here also important to ensure glare protection of the building users.

II.4. The long wave infrared

All materials continuously emit radiation in the form of energy in all directions. 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.

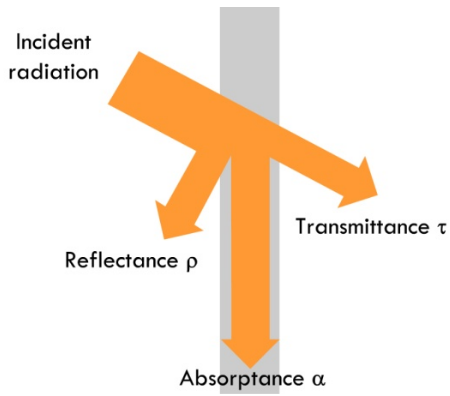
In practice, this means that a material which is irradiated by solar radiation will warm up and emit long wavelength radiation to the surrounding area. This radiation will then warm up the materials in the vicinity which will once again emit radiation, and so on.

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

The capacity of a material to emit this type of radiation is given by its emissivity (see II.5). As long as a material has no openings, it is opaque to the long wave infrared. Therefore walls and glazing do not allow the transmission of this type of radiation. Therefore, heat is kept in the room. This is known as the "greenhouse effect".

II.5. How a material is affected by radiation

When it irradiates a surface (glazing, fabric or slat for example), incident radiation 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

FIGURE 6 – BEHAVIOUR OF A RADIATION IN CONTACT WITH A MATERIAL

- A part which is absorbed by the material which is characterised by the absorptance α

so that $\tau + \rho + \alpha = 100\%$

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, 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 10000 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".

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

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.

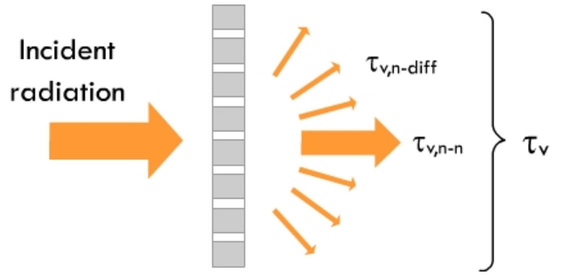


FIGURE 7 – DIRECT AND DIFFUSE VISUAL TRANSMITTANCE

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

Finally, reflectance and absorptance may also depend on the product sides, for example in case of coating or colour difference. Two values may then be necessary: ρ and ρ' for example corresponding to 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 III.2 and III.3.

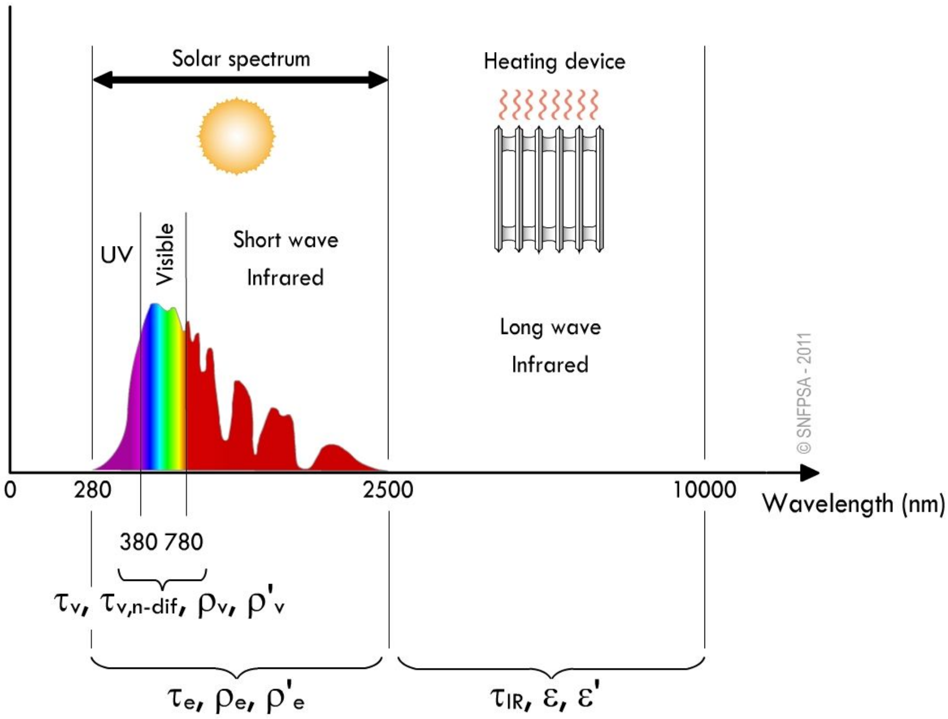


FIGURE 8 – ILLUSTRATION OF THE MATERIAL CHARACTERISTICS

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

III. THE THERMAL AND VISUAL CHARACTERISTICS OF BLINDS AND SHUTTERS

The previous chapter presented the properties of the solar radiation and the way this radiation is modified by the material of the shutter or blind. This chapter will identify how the visual and thermal characteristics of solar shading products are determined.

III.1.Thermal transmittance (U value)

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).

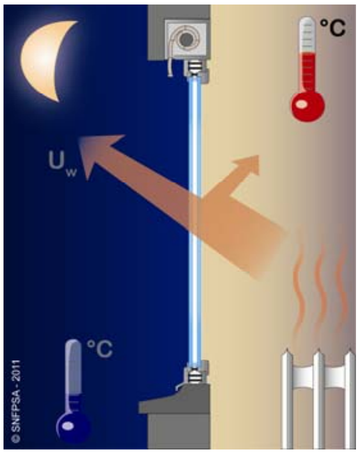


FIGURE 9 – ILLUSTRATION OF THE U_w VALUE

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

$$U_w = \frac{A_g U_g + A_f U_f + l_g \psi_g}{A_g + A_f}$$

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

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 considering the peripheral gaps of the curtain (see Figure 10).

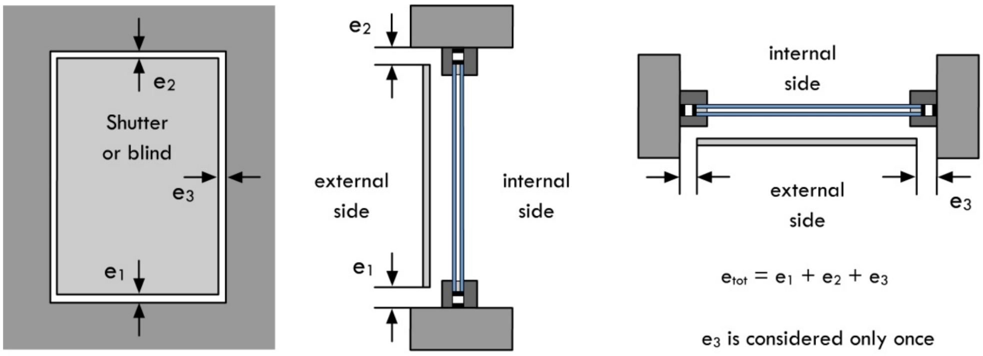


FIGURE 10 – CALCULATION OF E_{TOT} ACCORDING TO EN 13125

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 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 m².K/W
High air permeability (15 mm $< e_{tot} \leq$ 35 mm)	ΔR = 0,25.Rsh + 0,09
Average air permeability (8 mm $< e_{tot} \leq$ 15 mm)	ΔR = 0,55.Rsh + 0,11
Low air permeability ($e_{tot} \leq$ 8 mm)	ΔR = 0,8.Rsh + 0,14
Very low air permeability ($e_{tot} \leq$ 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 ($P_e \geq$ 35 mm)	ΔR = 0,08 m².K/W
Average air permeability (8 mm $\leq P_e <$ 35 mm)	ΔR = 0,11 m².K/W

Low air permeability (P_e < 8 mm)	ΔR = 0,14 m².K/W

TABLE 3 – CALCULATION OF ΔR OF INTERNAL AND MID-PANE BLINDS

High and very high air permeability ($P_e \geq 80$ mm)	ΔR = 0,08 m².K/W
Average air permeability (20 mm $\leq P_e <$ 80 mm)	ΔR = 0,11 m².K/W
Low air permeability (P_e < 20 mm)	ΔR = 0,14 m².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 ISO EN 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 m².K/W, for example a very permeable external blind,
- 0,15 m².K/W, for example a standard roller shutter in aluminum,
- 0,25 m².K/W, for example a air tight roller shutter.

TABLE 4 - EXAMPLE OF U_{WS} CALCULATION

Window with single glazing U_w = 4,90	Window with double glazing U_w = 1,8	Window with double glazing U_w = 1,2
ΔR (m².K/W)	ΔR (m².K/W)	ΔR (m².K/W)

	0,08	0,15	0,25	0,08	0,15	0,25	0,08	0,15	0,25
U_{ws} (W/m².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 %

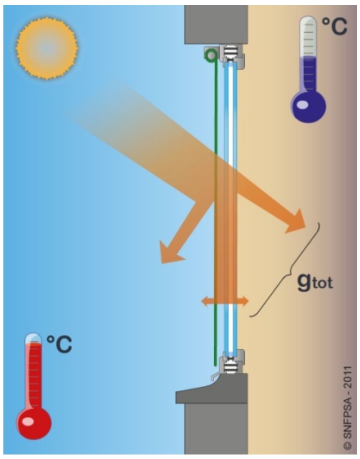
It can be seen from these examples that in all cases, the shutter or the blind decreases the U value of the window ($U_{ws} < U_w$) and therefore reduces the heat losses when the outdoor temperature is cold.

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. However, 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/m².K by 23% (which means a window using a glazing with a U_g = 1,0 W/m².K).

III.2. Total solar energy transmittance g_{tot} (solar factor)

III.2.1. 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. τ_v

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:

- Either a simplified method given by EN 13363-1,
- Or a detailed method given in EN 13363-2.

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.

III.2.2. Simplified calculation method: EN 13363-1

The standard EN 13363-1 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. Therefore the results are not intended to be used for calculating beneficial solar gains or thermal comfort criteria.

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:

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

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:

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

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 (see II.5)
- α_e is the solar absorptance of the blind or shutter
- 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

with $1 = \tau_e + \rho_e + \alpha_e$

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 13363-2 should be carried out.

III.2.3. Detailed calculation method: EN 13363-2

As this method 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 13363-1. 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.

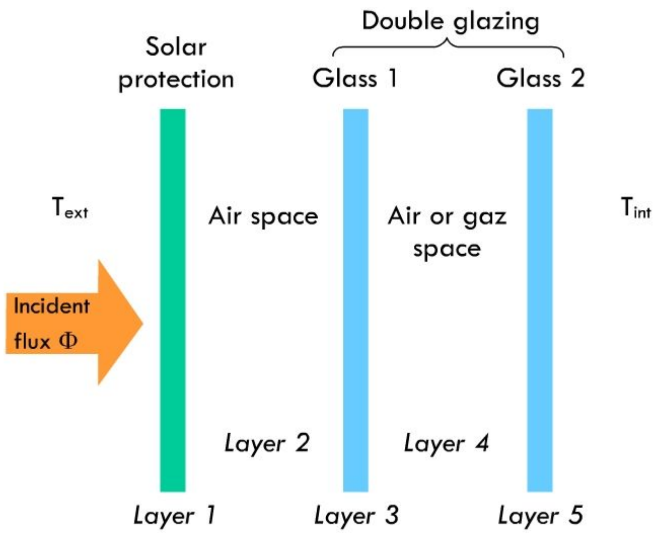


FIGURE 11 – EXAMPLE OF LAYERS IN CASE OF AN EXTERNAL BLIND ASSOCIATED TO A DOUBLE GLAZING

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 of 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 carried for a system made of an external blind and double glazing. In this example, the calculation leads to solve the following matrix of flux:

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

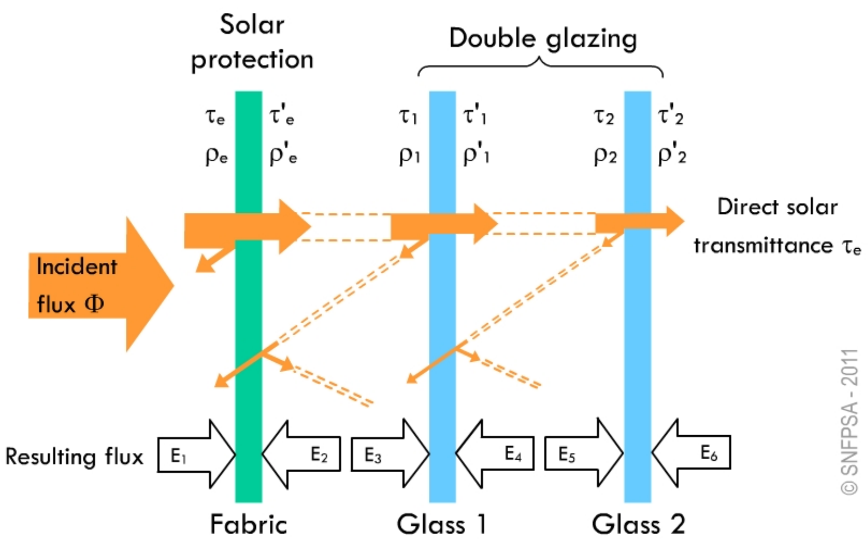


FIGURE 12 - ILLUSTRATION OF THE SOLAR DIRECT TRANSMITTANCE FOR AN EXTERNAL BLIND AND A DOUBLE GLAZING

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 is considering the effect of the external and internal temperature together with the effect of the solar irradiance (that will increase the temperature of each material by absorption).

  This transfer is subdivided into two parts:

  - 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.

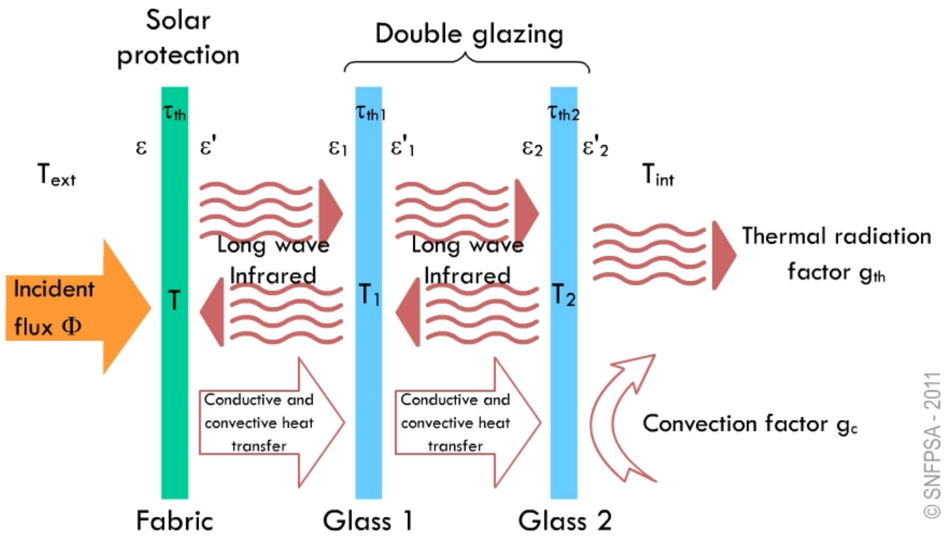


FIGURE 13 – ILLUSTRATION OF THE HEAT TRANSFER FOR AN EXTERNAL BLIND AND A DOUBLE GLAZING

- 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.

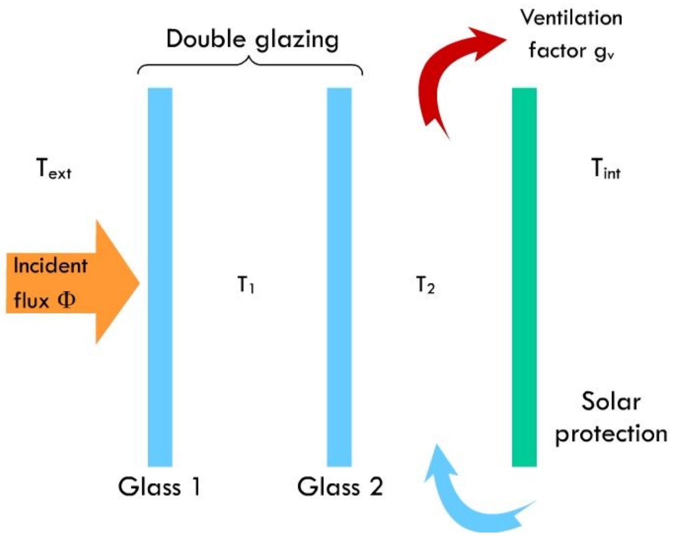


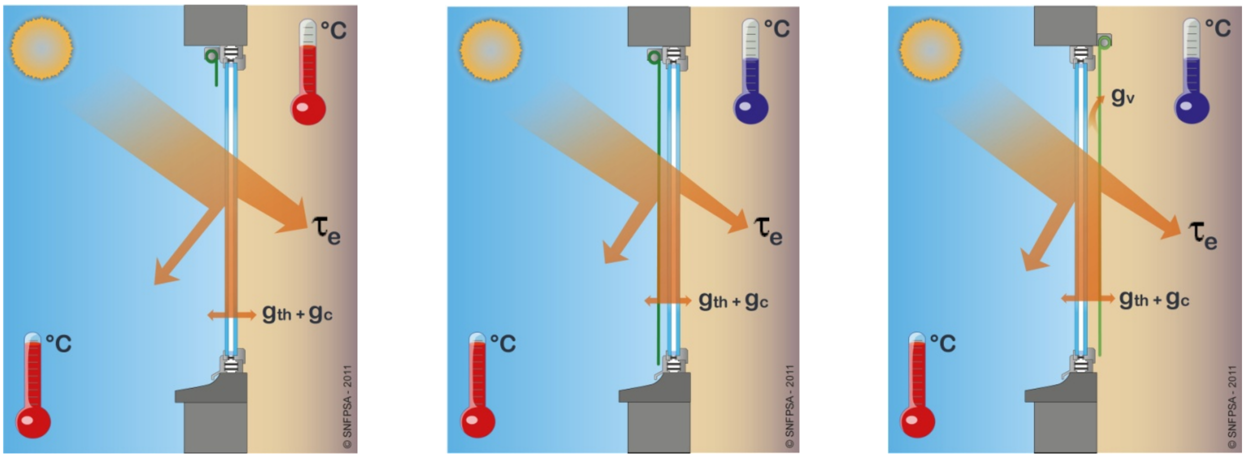
FIGURE 14 – ILLUSTRATION OF THE STACK EFFECT IN CASE OF AN INTERNAL BLIND

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 g_c 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 13363-2 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.



In this case the protection device is retracted

In this case the external protection device is extended

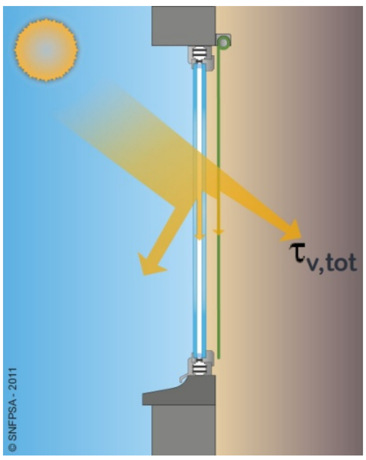
In this case the internal protection device is extended

FIGURE 15 – ILLUSTRATION OF G_{TOT}

III.3. Light transmittance τ_v

III.3.1. 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 notation used is the same (τ_v in both cases). For clarification, the notation $\tau_{v,tot}$ 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 for the solar factor: EN 410 for a glazing alone and two possibilities for a solar protection device associated to a glazing:

- Either a simplified method given by EN 13363-1,
- Or a detailed method given in EN 13363-2.

III.3.2. Simplified calculation method: EN 13363-1

The conditions of use of this standard are the same than for the calculation of the solar factor (see III.2.2).

According to EN 13363-1, 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

III.3.3. Detailed calculation method: 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 III.2.3) 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 total visual transmittance is then made of the two parts:

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

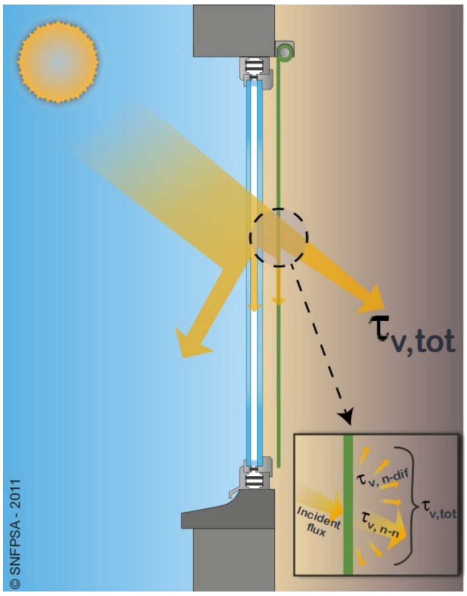


FIGURE 16 – ILLUSTRATION OF THE VISUAL TRANSMITTANCE OF AN INTERNAL BLIND

III.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 $\tau_{v,tot}$.

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).

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	$g_{th} + g_c$	$\tau_{v,tot}$	$\tau_{v,n-diff}$
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_v	$\tau_{v,tot}$	$\tau_{v,n-diff}$

			g_c					
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} determination, the detailed calculation method gives better results than the simplified one. 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 13363-1), it can be seen that a calculation of the diffuse visual transmittance is also possible with the simplified calculation method.

Shade Specifier Database

The British Blind & Shutter Association (BBSA), in conjunction with partners in the European Solar Shading Organisation (ES-SO), have developed a database of solar shading materials. This database includes independently validated energy performance data of blind and shutter fabrics and materials to European standards. The database calculates the energy performance of blind and shutter products when used in combination with reference glazing defined in the European Standards EN 13363-1 and EN 14501. All calculations are performed in accordance with the relevant European standards and procedures that have been covered in Chapter III.

The benefits of solar shading have been known for centuries. However, comparison of specific and independently proven performance characteristics of solar shading materials has not been possible, until now. Shade Specifier allows the specifier and building owner to make an informed choice.

This process used by the Shade Specifier database is identical to that used by the glazing industry and is a robust and effective way of ensuring the integrity of the database.

Outputs include:

- Total solar energy transmittance, g_{tot}
- Visible transmittance, Tvis
- Thermal transmittance, U-value

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IV. HOW BLINDS AND SHUTTERS REDUCE THE ENERGY NEEDS OF A BUILDING

Previous chapters show the characteristics of products and what could be the impact of the solar shading when used in conjunction with a window or glazing system. This chapter presents the impact of solar shading on the energy demand of a building. It refers to existing tools or studies.

IV.1. "Textinergie®" tool

IV.1.1. What is Textinergie®?

Textinergie® is a simple tool which quantifies potential energy savings in office buildings by using fabric solar protection devices. It has been developed by the French association of blinds and shutters manufacturers and installers (SNFPSA). It is accessible at the following address: www.textinergie.org.

Textinergie® compares the energy needs within a room before and after being fitted with solar protection devices.

The user selects:

- The climatic zone,
- The facade orientation,
- The glazed surface of the room,
- The type of double glazing (B, C or D as defined in EN 14501),
- The position of the blind (internal or external),
- The type of fabric,
- The fabric colour.

Once the configuration has been defined, Textinergie® gives two different levels of results:

- Simplified results: percentage of energy saving associated with air-conditioning and other installations (air-conditioning + heating + artificial lighting),

- Detailed results: calculated temperature (°C); needs (kWh) and percentage of energy saving for each unit (air-conditioning, heating and lighting); daylight (lux).

The results are given for a glazing with or without blinds.

Calculations have been carried out using a dynamic simulation software for an entire year with a time interval of five minutes. These simulations have been carried out and their results incorporated into a database. The user selections draw directly from this database. It enables an estimate of the impact of various parameters and helping the user in the choice of the optimal technical solution.

IV.1.2. Impact of the location

Figure 17 below shows the energy needs for heating, air-conditioning and lighting for a 20 m² office space in various European cities. The office space is equipped with clear double glazing (glazing C according to EN 14501) and is south facing. The glazed surface represents 80% of the façade.

The blind is installed externally and its colour is "dark neutral".

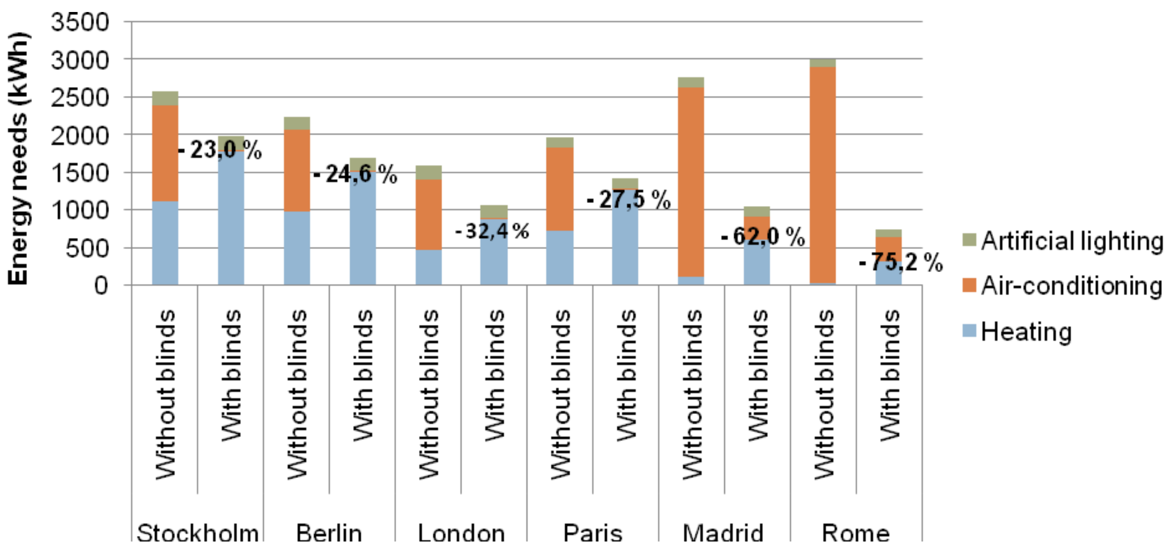


FIGURE 17 – ENERGY NEEDS FROM TEXTINERGIE® FOR VARIOUS EUROPEAN CITIES

The use of an external blind consistently leads to major energy savings in all cases.

It can be seen that heating needs are higher when the blind is installed. This is due to a lack of free solar energy entering into the room when the blind is extended.

Indeed, the principle of operation of the blind is based on the visual comfort of the occupant: the blind rolls down when the natural light on a sensor placed on a desk reaches 500 lux in summer and 900 lux in winter. Therefore, the shading may be extended during sunny days in winter thereby limiting the free heating of the room.

The principle of operation also assumes that artificial lighting is only activated when the solar protection device is fully retracted and the daylight level is insufficient. Therefore, the presence of the blind does not have any impact on the artificial light needs.

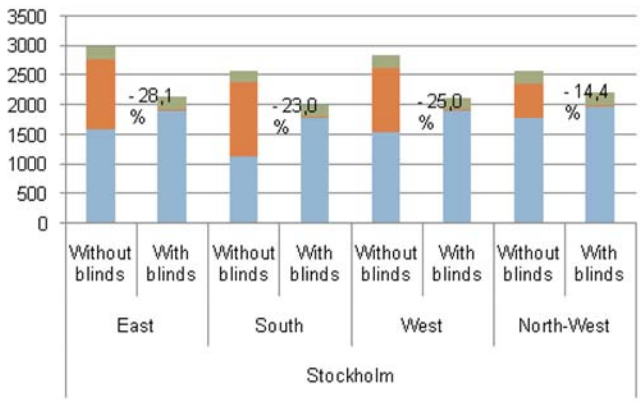
However, as the air-conditioning energy needs are significant, the total results are still very positive and lead to major energy savings.

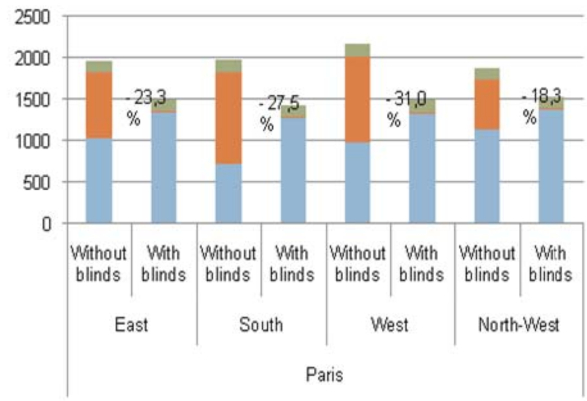
IV.1.3. Impact of the orientation

Figure 18 below presents the impact of the office orientation for three European countries: Stockholm, Paris and Rome.

As expected, results are optimum for the east, west and south exposed façades. However, the orientation for which the energy saving rate is maximised varies depending on the city: it is the east façade for Stockholm (-28,1%), the west façade for Paris (-31%) and the south orientation for Rome (-75,2%).

Although, results are lower, the use of blinds on the north-west exposed façade still results in energy savings for the three cities.





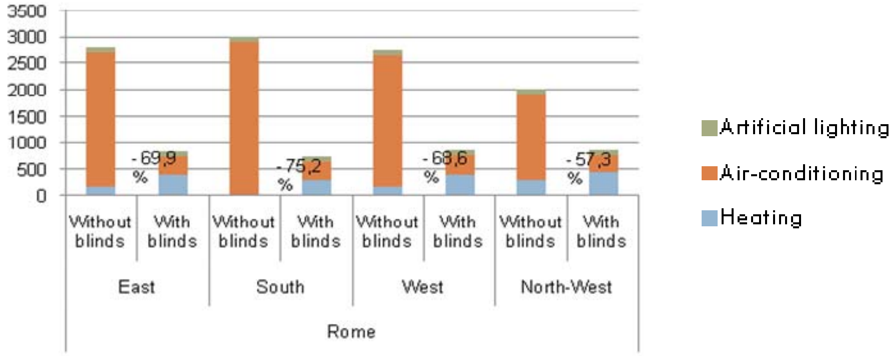


FIGURE 18 – ENERGY NEEDS FROM TEXTINERGIE® FOR VARIOUS ORIENTATION IN THREE EUROPEAN CITIES

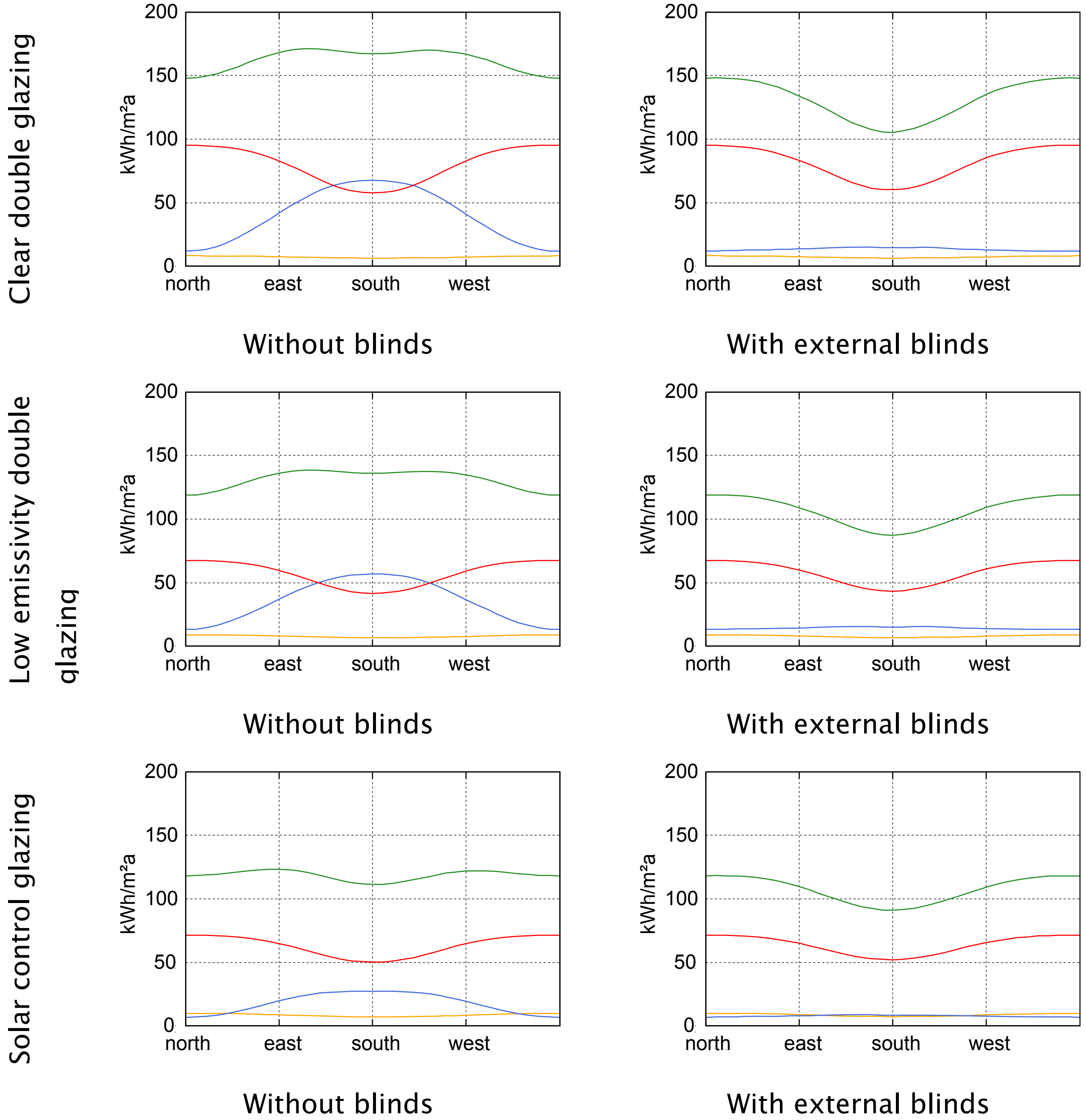
IV.2.ES-SO and REHVA guidebook

In 2010, ES-SO and REHVA (Federation of European Heating, Ventilation and Air-conditioning Associations) have jointly published a guidebook on solar shading[1]. This guidebook contains reference to energy demand calculations carried out on a model office in three European cities (only two are presented here). The software EnergyPlus™ has been used for the calculations. The details of the parameters used for the calculations are available in the ES-SO & REHVA guidebook.

IV.2.1. Stockholm

Figure 19 shows the annual energy demand for different orientations for the model office in Stockholm.

[1] "Solar Shading, how to integrate solar shading in sustainable buildings"



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 (see the ES-SO / REHVA guidebook for the detailed calculation method)

FIGURE 19 - ANNUAL ENERGY BALANCE FOR THE MODEL OFFICE IN STOCKHOLM

The energy demand 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. This effect is clearly stronger for glazing with higher g-values.

The situation becomes markedly different when external solar shading is installed, as shown in the right column of Figure 19. The annual energy demand for cooling is significantly 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 day-lighting and passive solar heating. It can be seen that the primary energy demand in absolute terms is the lowest for the low emissivity glazing combined with solar shading.

Figure 20 shows the cooling load as a function of window orientation for three different glazing types. 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.

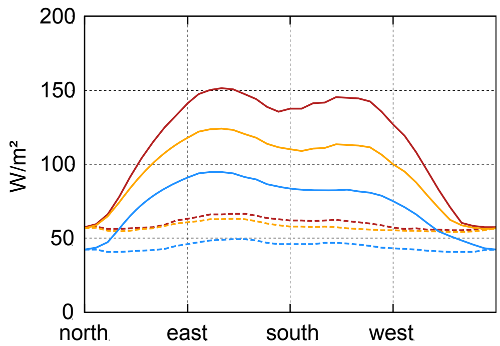


FIGURE 20 - COOLING LOAD AS A FUNCTION OF THE FAÇADE ORIENTATION

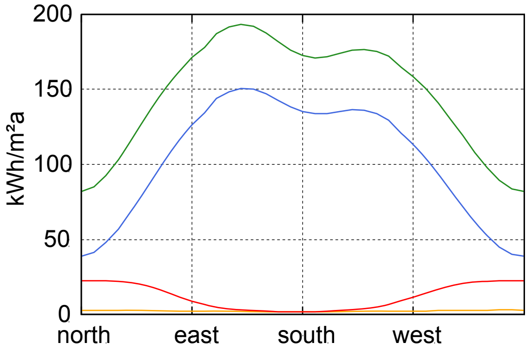
IV.2.2. Madrid

Figure 21shows the energy demand as a function of the orientation of the office in Madrid. In this case, the energy demand 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.

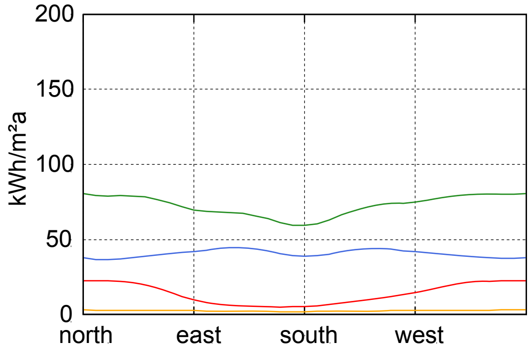
Solar shading substantially reduces the primary energy demand for other than-north orientations. In this case the lowest primary energy requirement is attained with a combination of solar control glazing and exterior solar shading.

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 demand for an office fitted with solar control glazing and solar shading is about 30% lower than for the same office fitted with solar control glazing only.

Clear double glazing

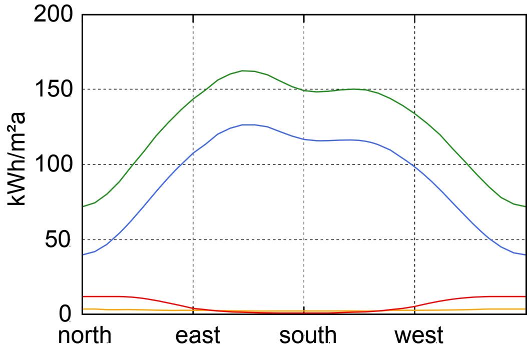


Without blinds

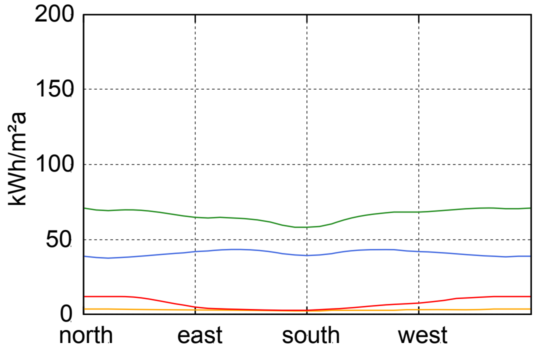


With external blinds

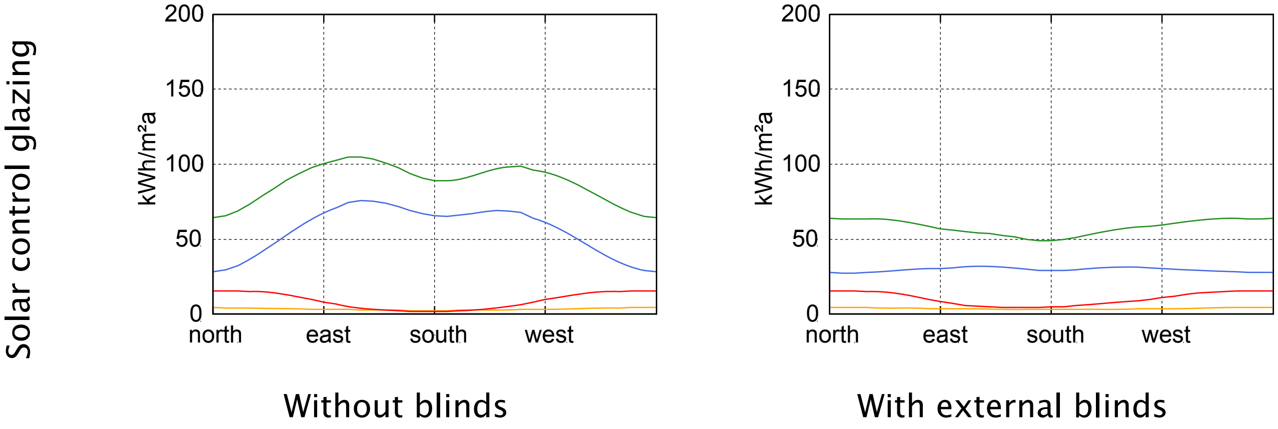
Low emissivity double glazing



Without blinds



With external blinds



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 (see the ES-SO / REHVA guidebook for the detailed calculation method)

FIGURE 21- ANNUAL ENERGY BALANCE FOR THE MODEL OFFICE IN MADRID

IV.2.3.

V. HOW BLINDS AND SHUTTERS IMPROVE THE VISUAL AND THERMAL COMFORT OF A BUILDING

The previous chapter presented the impact of solar shading on the energy demand of cooled office premises. But these products also play a major role in the internal thermal and visual comfort of the occupants. This chapter presents results of studies concerning this important consideration in building design.

V.1. Impact of shutters on summer comfort

In 2010, a study has been carried by the Engineering Office TBC for the French Association of Blinds and Shutters Manufacturers (SNFPSA).

According to the results of thermal simulations carried out with the calculation software Comfie+Pleïade[2] in a typical dwelling for three locations in France, the use of roller shutters in warm conditions reduces the maximum temperature by up to 6°C.

Figure 22 shows the maximum temperature achieved in the dwelling for different operating modes of roller shutters:

- A clock mode: roller shutters are extended from 8h to 18h,
- An external temperature mode: roller shutters are 50% extended if the outdoor temperature is over 23°C and completely extended if the outdoor temperature is over 26°C,
- An “light level” mode: roller shutters are fully extended if the incident luminance is above 10 000 Lux

[2] Pleiades + Comfie used the calculation system Comfie developed by the Energetic Centre of the Engineering School “Mines ParisTech”.

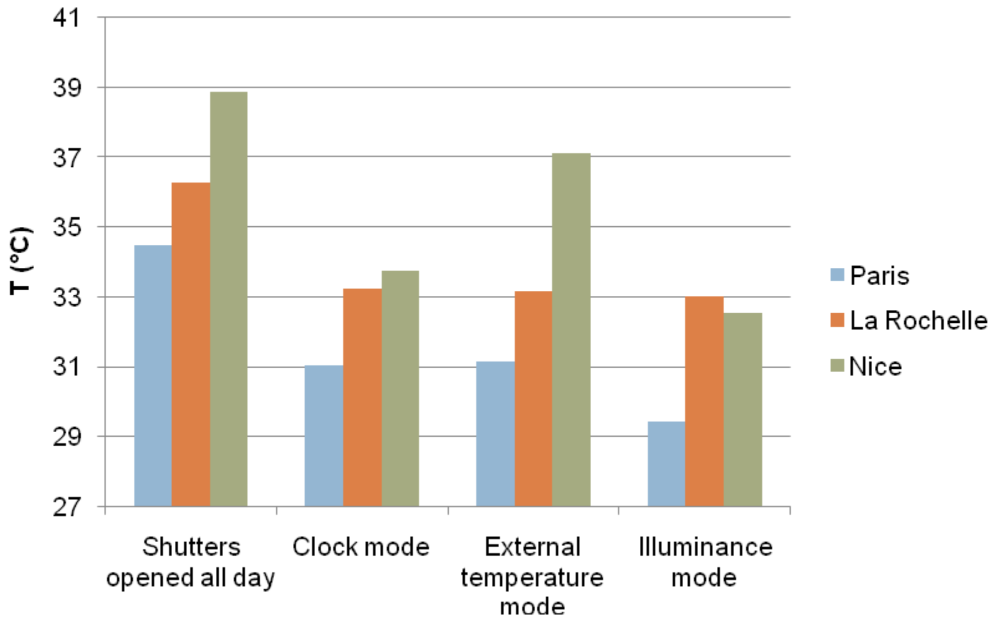


FIGURE 22 – MAXIMUM TEMPERATURE FOR DIFFERENT OPERATING MODES OF ROLLER SHUTTERS

Detailed results are shown in the Table 9 below.

TABLE 9 – MAXIMUM TEMPERATURE FOR DIFFERENT OPERATING MODES OF ROLLER SHUTTERS

	Paris	La Rochelle	Nice
Shutters opened all day	34,46°C	36,26°C	38,89°C
Clock mode	-3,41°C	-3,04°C	-5,13°C
External temperature mode	-3,31°C	-3,10°C	-1,78°C
Light level mode	-5,05°C	-3,23°C	-6,37°C

The use of roller shutters during warm days reduces the maximum temperature in all cases.

The light level operating mode gives the best compromise as it is the most efficient in terms of limitation of overheating but also as it allows the occupants to benefit from daylight when the incident luminance is lower than 10 000 Lux or when the façade is not exposed.

The period of discomfort is defined as the time where the internal temperature is either under 16°C or over 27°C. It is then possible to define a rate of discomfort defined as the ratio of the number of hours where the house is occupied and the temperature is either under 16°C or over 27°C and the total number of hours of occupancy.

Table 10 presents the results of the calculation of the rate of discomfort for three locations and operating modes considered. In practice, it should be noted that as the heating is activated at 19°C, these values only consider the period when the temperature is over 27°C.

TABLE 10 – RATE OF DISCOMFORT FOR DIFFERENT OPERATING MODES OF ROLLER SHUTTERS

	Paris	La Rochelle	Nice
Shutters opened all day	**19,6 %**	**23,6 %**	**39,1 %**
Clock mode	4,1 % (– 15,5 %)	6,9 % (– 16,7 %)	30,4 % (– 8,7 %)
External temperature mode	14,9 % (– 4,7 %)	18,1 % (– 5,5 %)	39,0 % (– 0,1 %)
Light level mode	4,3 % (–15,3 %)	5,8 % (– 17,8 %)	27,6 % (– 11,5 %)

The light level mode is the best option to reduce the rate of discomfort (between 11% and 18% depending on the climatic area). The clock mode provides similar results but again, would not consider the daylight level available that could be seen as uncomfortable for the occupants.

The external temperature mode is the least effective, especially in the Nice area where there is no benefit. It should be noticed that the Nice area is the warmest in France and that additional provisions (such as the thermal inertia of the building) should be taken to achieve a reasonable level of comfort.

V.2. Impact of solar shading on visual comfort

As it relies on a personal perception, visual comfort varies from one person to another. It is a subjective issue. Nevertheless, there is no doubt that daylight is usually preferred to artificial lighting as the primary source of light.

However, situations causing visual discomfort can easily arise in a naturally-lit office. Occasionally, the light may be too bright or the contrasts too great. To fully harvest the benefits of daylight, it needs to be controlled.

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.

Figure 23 presents the luminance level in an office when the solar shading is extended or retracted. It shows that solar shading significantly reduces the luminance ratios avoiding an important difference of luminance between the computer screen and the surroundings that would create a visual discomfort.

Without solar shading — With solar shading

FIGURE 23 – LUMINANCE LEVEL WITH AND WITHOUT SOLAR SHADING IN AN OFFICE (PHOTOS SOMFY)

The ES-SO and REHVA guidebook published in 2010 (see IV.2) presents a summary of scientific research showing 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 occupants 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% reduction of absenteeism. [Thay 1995]
- Direct sun penetration into classrooms, especially through unshaded east or south facing windows, is associated with negative student performance. [Hesh 2003b]
- Students with adequate natural daylight in their classrooms showed 20% faster progress in maths 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, wellbeing and productivity. However, adaptive control of daylight is needed to guarantee the conditions of good visual comfort at all times.

Bibliography

(1) European Standards

EN 14501 “Blinds and shutters – Thermal and visual comfort – Performance characteristics and classification”

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 13363-1 “Solar protection devices combined with glazing – Calculation of solar and light transmittance – Simplified method”

EN 13363-2 “Solar protection devices combined with glazing – Calculation of total solar energy transmittance and light transmittance – Detailed calculation method”

EN ISO 10077-1 “Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – General”

EN 410 “Glass in building – Determination of luminous and solar characteristics of glazing”

(2) Guidebooks

“Guide de la Fermeture et de la Protection Solaire », 2010, co-edited by SEBPTP and Metal’Services

“Solar Shading, how to integrate solar shading in sustainable buildings”, 2010, edited by REHVA, 40 rue de Washington, 1050 BRUSSELS, BELGIUM; info@rehva.eu

(3) Research

“Création d'un outil d'aide au choix optimisé du vitrage du bâtiment selon des critères physiques, écologiques et économiques, pour un meilleur confort visuel et thermique”, Magali Bodart, UCL, Avril 2002.

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[CMU 2004] Guidelines for High Performance Buildings 2004
http://cbpd.arc.cmu.edu/ebids/images/group/cases/Daylighting.pdf

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[Hesh 2003b] Heschong, L., Windows and Classrooms: A Study of Student Performance and the Indoor Environment. Report prepared for the California Energy Commission, 2003.

[Thay 1995] Thayer, Burke Miller, Daylighting & Productivity at Lockheed, Solar Today, Vol.9, 1995.

(4) Informative links

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

Textinergie tool: www.textinergie.org

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

EUROPEAN SOLAR-SHADING ORGANIZATION

Energy Savings & Comfort

The Energy Performance of Buildings Directive ('EPBD') and in particular its stringent 2010 Recast version, requires that, from 2020 onward, all new buildings in Europe shall be 'nearly zero-energy'. This goal is achievable only through the optimisation of the building envelope.

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 guide book 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 then highlights the standardised calculation methods that are used to evaluate the thermal and visual characteristics of blinds and shutters. Finally, from technical studies and research, it provides an overview of the impact of solar shading on the energy consumption of buildings and the occupants comfort.

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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