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1. Introduction

A method is presented for calculating the effect of solar shading systems, as illustrated in Figure 1, on the solar transmittance of glazing. The solar factor defined in EN 410 is of limited use for this purpose, as it assumes that the direct component of solar radiation is perpendicular to the glazing. In contrast, the solar processors implemented in BISTRA (2D) and VOLTRA (3D) account for the actual position of the sun, allowing the calculation of a transient solar factor that varies with solar position.



Figure 1. Example solar shading systems.

2. Target of the simulation

The solar factor g is defined in EN 410 as the solar radiation passing the solar shading and the glazing divided by the incident solar radiation. It has two components: a direct transmittance and a secondary heat transfer towards the inside caused by the solar absorption in the glazing.

In real conditions, both components depend on

- the outside and inside temperature
- the angle dependent solar reflection of the glazing.

Therefore in real conditions, the solar factor isn't a constant value.

By assuming standard conditions

- equal outside and inside temperature

- incident solar radiation that is perpendicular to the glazing,

the solar factor becomes a constant value.

The programs BISTRA and VOLTRA allow simulating the solar shading and the glazing in real climate conditions, typically given as hourly values of temperature and global and diffuse solar radiation. The target of the simulation is to calculate the sum of both the direct solar transmittance and the secondary heat transfer to the inside and to compare it to the incident solar radiation. As in the EN 410 standard we will use equal outside and inside temperatures.

3. 2D analysis of a vertical shading system

BISTRA data [shading 2.bst](#), [shading 1.bst](#), [shading 0.bst](#)

A vertical shading system with a double glazing is shown in Figure 3. It is located in Trappes (Paris) and has a south orientation. The thermal analysis is done for the 8th September. The climate data for Trappes are shown in Figure 4.

The file [shading 2.bst](#) contains the complete data in BISTRA format. The major data part is given in Figure 3. We will discuss here some data highlights only.

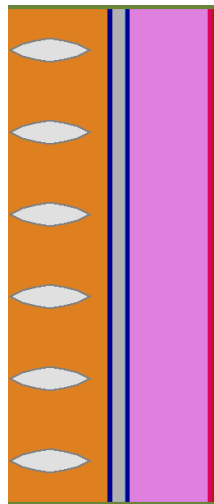


Figure 2. Vertical section of a shading system.

Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ϵ_1 / ϵ_2 [- / -]	λ [W/mK]	ρ [kg/m ³]	c [J/kgK]	θ [°C]	h [W/m ² K]	q [W/m ²]	θ_a [°C]	h_c [W/m ² K]	P_c [W/m]	θ_r [°C]	Sun	ρ_s [-]	Specular [%]	τ_s [-]	Standard
8	MATERIAL				aluminium alloys		160.000	0.90	2800	880								0.60	0	0.00	
12	MATERIAL				black high conductive		160.000	0.90	1									0.00	0	0.00	
18	MATERIAL				glazing pane 2		1.000	0.84	2500	750								0.29	0	0.79	
26	MATERIAL				glazing pane 1		1.000	0.84	2500	750								R01	0	0.84	
29	MATERIAL				coating on pane 2		1.000	0.04	2500	1000								0.29	0	0.79	
174	BC_FREE	CONVEC	HOR		interior (forced at 25°C)			1.2	1000			0		3.15	0						NIHIL
182	BC_SIMPL	NIHIL			interior forcing					T01	10000.00	0					NO				NIHIL
188	BC_SKY	NIHIL			exterior (summer)							0	T01	6.00		T01	YES				NIHIL
190	BC_FREE	NIHIL			interior (forced at 25°C)			1.2	1000			0		10000.00	0						NIHIL
191	MATERIAL				adiabatic		0.000	0.00	1	1								1.00	0	0.00	
193	TRANSMAT	NIHIL			argon		0.017		1.7	519											NIHIL
240	EQUIMAT	NIHIL			cavity in metal		0.200	0.90	1.2	1000											NIHIL

Figure 3. BISTRA data [shading 2.bst](#).

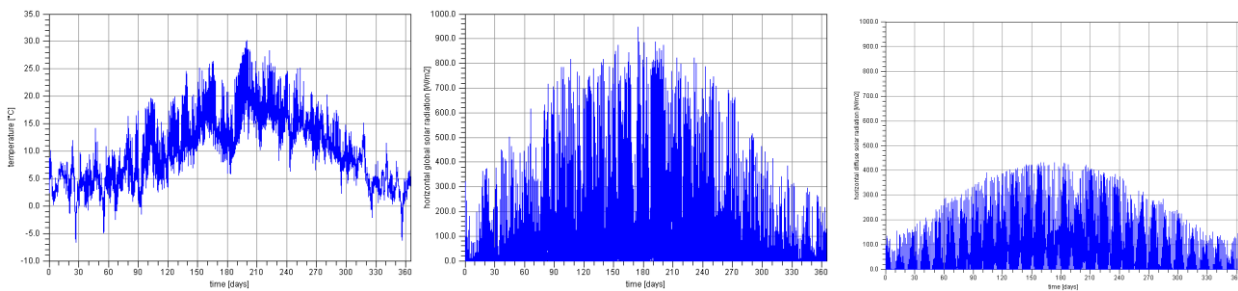


Figure 4. Temperature, horizontal global and diffuse solar radiation for Trappes (Paris).

- 6 elements are considered (a total height of 0.60 m). On top and at the bottom an adiabatic material layer (colour 191) is applied. In that way the edge effects are limited.
- The **outdoors** is defined as a BC_SKY type using a convective surface heat transfer coefficient $h_{ec} = 6 \text{ W/m}^2\text{K}$ corresponding to a summer condition. The outdoors air and sky temperature T01 (Figure 3, columns θ_a and θ_r) is a time function (file Trappes.FTE). The outdoors is defined as the 'sun' zone (Figure 3, column Sun). Also the solar radiation data are time functions (files Trappes.FSG and Trappes.FSD). The orientation of the façade is defined in the Solar Data window. A horizon with a height of 5° in all directions is defined in the Sun Obstacles window.

By using the BC_SKY type the reflection of the solar radiation striking the shading elements is taken into account. It should be emphasised that this reflection is considered as diffuse in this example (processed using view factors). However, for the BISTRA examples this can be adjusted to specular reflection if desired.

- The **indoors** is defined in a somewhat complex way, in order to derive the direct transmittance and the secondary heat transfer. At the right (colour 182) a boundary condition of the type BC_SIMPL with a temperature T01 (indoors temperature equal to outdoors temperature) and a very high global surface coefficient ($h_i = 10000 \text{ W/m}^2\text{K}$) is defined. In this way, the highly conductive black plate (colour 12) left of it will have almost the same temperature. Between the double glazing and the very conductive plate an air cavity with a boundary condition of the type BC_FREE is applied. It is built up using 2 colours: index 174 in contact with the glazing and index 190 in contact with the very conductive plate. For the colour 174 the convective heat transfer coefficient will be calculated as a function of temperature difference between the air and the glazing surface (subtype CONVEC). For the colour 190 a very high convective surface coefficient ($h_c = 10000 \text{ W/m}^2\text{K}$) is applied. This will force an air cavity temperature almost equal to the indoor temperature (function T01).

By this approach the heat flowing into the indoor environment (colour 182) will be equal to the sum of the direct solar transmittance and the secondary heat transfer.

- The **material properties** thermal conductivity λ , density ρ and specific heat c were taken from ISO 10456. The double glazing cavity gas is argon with $\lambda = 0.017 \text{ W/mK}$ (EN 673).

- The **long wave emissivity** ε of all ¹ material surfaces is 0.9, except for the glazing surfaces that have a long wave emissivity $\varepsilon = 0.837$ according to EN 673 . A low emissivity coating with $\varepsilon = 0.037$ is applied on side 3 of the double glazing (colour 29).
- The internal **double glazing** has a U-value $U = 1.1 \text{ W/m}^2\text{K}$ and a solar factor $g = 0.56$.

The solar properties of the glazing panes assumed are listed in Table 1. These data are used for the properties of the glazing panes and glazing cavities (colours 18, 26, 29, 193): thermal conductivity λ , density ρ and specific heat c , long wave emissivity, solar reflectance ρ_s and solar transmittance τ_s .

No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m ² K/W]	ρ [kg/m ³]	c [J/kgK]	Nu [-]	hrb [W/m ² K]	τ_s [-]	ε_{1lr} [-]	ρ_{1s} [-]	α_{1s} [-]	ε_{2lr} [-]	ρ_{2s} [-]	α_{2s} [-]
1	Planilux 6mm	NORMAL		0.006	1.000	0.006	2500	850	-	-	0.784	0.84	0.07	0.15	0.84	0.07	0.15
2	argon	GAS		0.015	0.017	0.743	1.7	519	1.02	5.15	-	-	-	-	-	-	-
3	Planitherm ULTR	NORMAL		0.006	1.000	0.006	2500	850	-	-	0.562	0.04	0.29	0.15	0.84	0.21	0.23

Table 1. Double glazing properties.

It should be emphasised that the definition of the solar transmittance as defined in BISTRA and VOLTRA is different to the more commonly used definition as used in glazing technology.

In BISTRA and VOLTRA the solar transmittance is the one after deduction of reflection:

$$\tau_{s-BISTRA-VOLTRA} = \frac{\tau_s}{1-\rho_s} \quad [\text{Eq. 1}]$$

The Physibel Toolbox app 'Glass property converter' can be used as a tool to derive the solar property values; apps.physibel.be

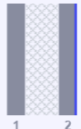
No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m ² K/W]	ρ [kg/m ³]	c [J/kgK]	Nu [-]	hrb [W/m ² K]	τ_s [-]	ε_{1lr} [-]	ρ_{1s} [-]	α_{1s} [-]	ε_{2lr} [-]	ρ_{2s} [-]	α_{2s} [-]
1	Planilux 6mm	NORMAL		0.006	1.000	0.006	2500	850	-	-	0.784	0.84	0.07	0.15	0.84	0.07	0.15
2	argon	GAS		0.015	0.017	0.743	1.7	519	1.02	5.15	-	-	-	-	-	-	-
3	Planitherm ULTR	NORMAL		0.006	1.000	0.006	2500	850	-	-	0.562	0.04	0.29	0.15	0.84	0.21	0.23

Glass Radiation Properties

Manufacturer Data

Glazing Type

Double



Layer	τ	ρ_1	α_1	ε_1	ρ_2	α_2	ε_2
1	0.784	0.07	0.146	0.84	0.07	0.146	0.84
2	0.562	0.29	0.148	0.04	0.21	0.228	0.84

Physibel Data



Colour	τ_{Physibel}	ρ	ε
1	0.8430	0.0700	0.8400
2	0.8430	0.0700	0.8400
3	0.7915	0.2900	0.0400
4	0.7114	0.2100	0.8400

Visit the [documentation](#) to learn more.

Figure 5. Glass property converter: apps.physibel.be

¹ Only for material surfaces that are in direct contact with a BC_FREE, BC_SKY or TRANSMAT type the value of the long wave emissivity is taken into account in the simulation.

- The **external glazing reflection** is assumed to be **angle dependent**. The function reference R01 (Figure 3, row colour 10) refers to the function [glass reflection angle func 0p070.FRF](#) (Figure 6). Again the spreadsheet mentioned above can be used to derive typical functions.

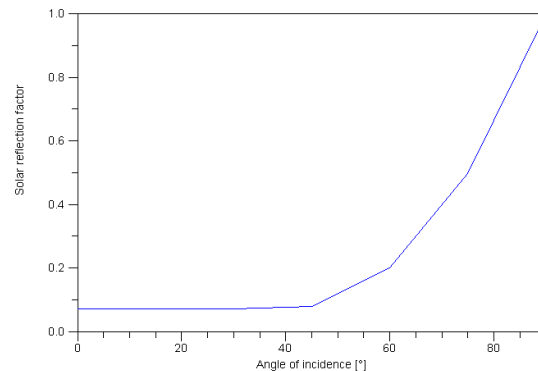


Figure 6. Angular dependent solar reflectance of the external glazing.

- The **solar transmittance** of opaque materials of course is $\tau_s = 0$.
The blinds are assumed to have a light colour: **solar reflectance** $\rho_s = 0.6$ (and thus $\alpha_s = 0.4$).
The black highly conductive plate absorbs 100 %: $\rho_s = 0.0$ (and thus $\alpha_s = 1.0$).
The adiabatic layers on top and at the bottom reflects 100 %: $\rho_s = 1.0$ (and thus $\alpha_s = 0.0$).
- The following **calculation parameters** are defined:
 - o time step = 10'
 - o start-up calculation duration = 0 days (the inertia is limited)
 - o calculation duration = 1 day
 - o day number 251 (8 September)
 - o non-linear radiation model.

Figure 7 shows the simulated temperature course at 3 different times (9:00, 13:00, 17:00).

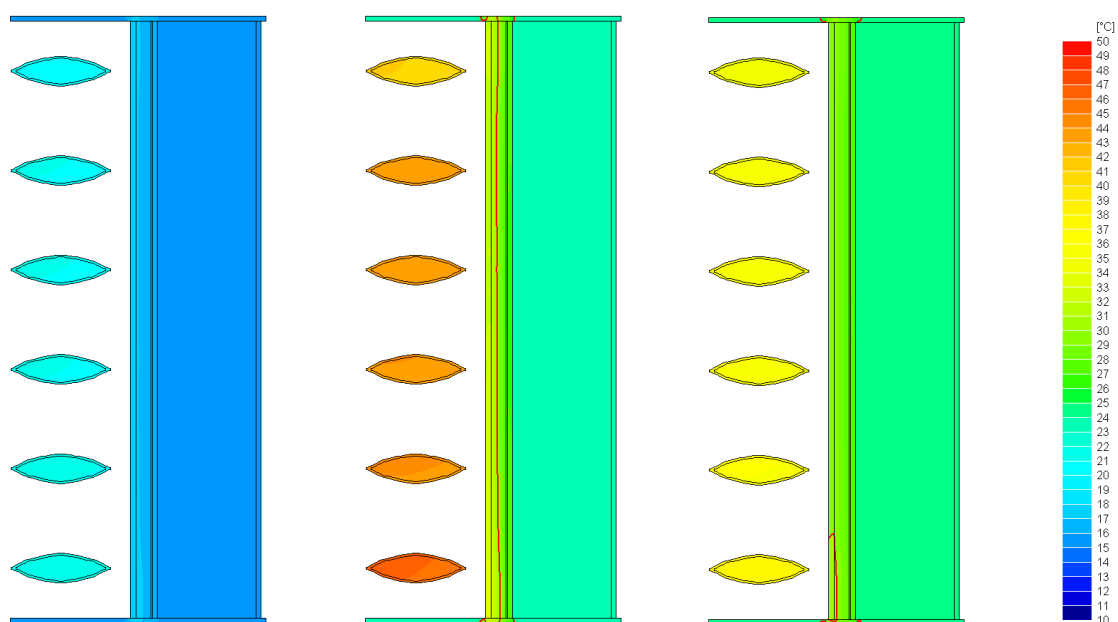


Figure 7. Temperature course at 09:00, 13:00, 17:00.

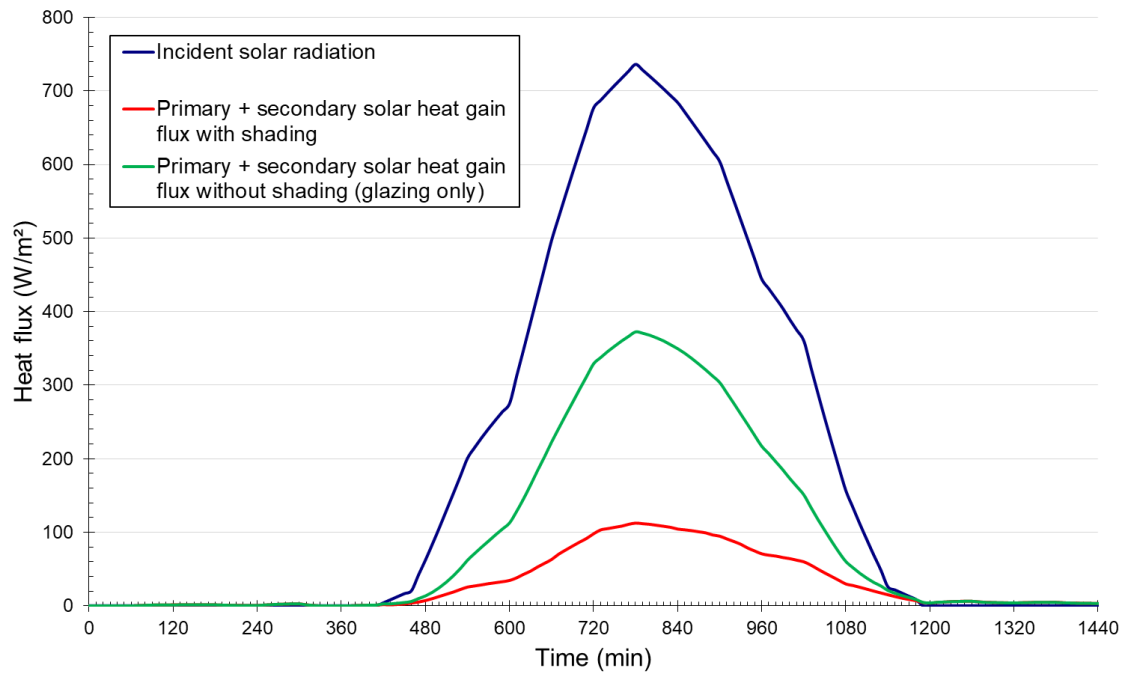


Figure 8. Incident solar radiation flux and solar heat gain flux for the glazing without and with shading device as a function of time (south orientation).

Figure 8 shows the heat gain flux (sum of primary and secondary heat gains) as a function of time. The same graph shows the incident solar radiation (obtained using the BISTRA data [shading_0.bst](#))² and the heat gain flux of the glazing without shading device (obtained using the BISTRA data [shading_1.bst](#)).

Figure 9 shows the results for a west oriented façade. The results were obtained using the BISTRA data [shading_0_ouest.bst](#), [shading_1_ouest.bst](#) and [shading_2_ouest.bst](#). As could be expected the graph clearly shows the lower effectiveness of the shading device for west orientations.

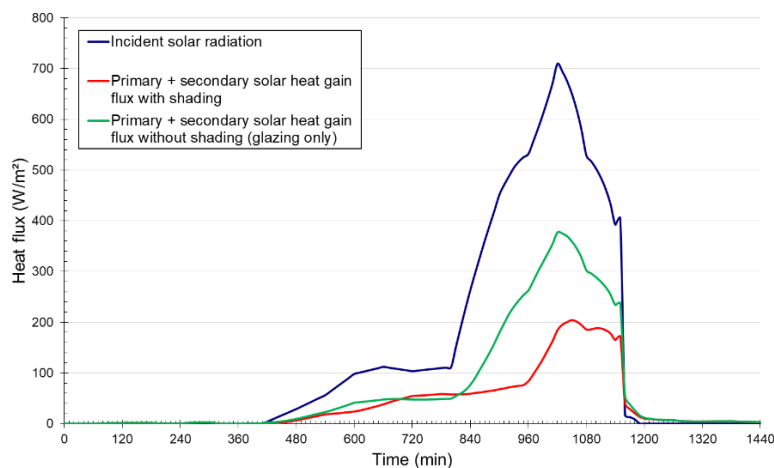


Figure 9. Incident solar radiation flux and solar heat gain flux for the glazing without and with shading device as a function of time (west orientation).

² Alternatively, a report definition for the total irradiance can be selected for the outer glass (colour 18) (Etot) in [shading_1.bst](#).

4. 3D analysis of an overhang

VOLTRA data [shading_3D_2.vtr](#)

An overhang in a façade with a double glazed wooden window in. It is located in Trappes (Paris) and has a south orientation. The thermal analysis is done for the 8th September.

The file [shading_3D_2.vtr](#) contains the complete data in VOLTRA format. The major data part is given in Figure 10. We will discuss here some data highlights only.

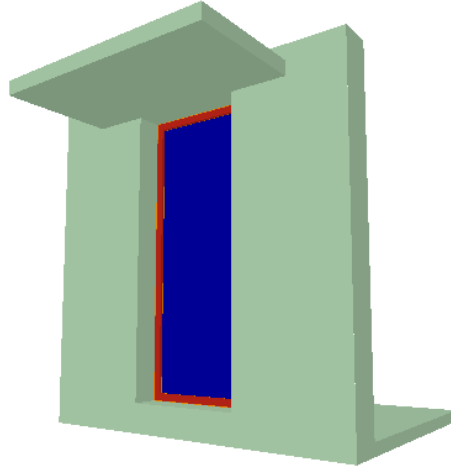


Figure 10. External view of window and overhang.

Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ϵ_1 / ϵ_2 [- / -]	λ [W/mK]	ρ [kg/m ³]	c [J/kgK]	θ [°C]	h [W/m ² K]	q [W/m ²]	ϵ_a [°C]	h_c [W/m ² K]	P_c [W]	θ_r [°C]	Sun	ρ_s [-]	τ_s [-]	Standard
8	MATERIAL				aluminium		160.000	0.90	2800	880								0.10	0.00	
12	MATERIAL				timber (700 kg/m ³)		0.180	0.90	700	1600								0.10	0.00	
18	MATERIAL				glazing pane 2		1.000	0.84	2500	750								0.21	0.71	
26	MATERIAL				glazing pane 1		1.000	0.84	2500	750								R01	0.84	
29	MATERIAL				coating on pane 2		1.000	0.04	2500	750								0.29	0.79	
60	MATERIAL				EPDM		0.250	0.90	1150	1000								0.10	0.00	
86	MATERIAL				polysulfide		0.400	0.90	1700	1400								0.10	0.00	
105	MATERIAL				mol. sieve		0.100	0.90	700	1000								0.10	0.00	
170	BC_SIMPL	NIHIL			exterior					T01	13.50	0					YES			NIHIL
174	BC_SKY	NIHIL			interior (normal)							0	20.0	2.50		20.0	NO			
177	MATERIAL				light concrete		0.150	0.90	400	850								0.40	0.00	
192	TRANSMAT	NIHIL			argon		0.017		1.7	519										
240	EQUIMAT	CAVITY	HOR	Yx	cavity (CEN)	0.90 / 0.90	0.046	0.90	1.2	1008										EN6946

Figure 11. VOLTRA data [shading_3D_2.vtr](#).

- The **outdoors** is defined as a BC_SIMPL type (instead of the BC_SKY type in the 2D analysis above) with a global surface heat transfer coefficient $h_e = 13.5$ W/m²K. The outdoors temperature T01 (Figure 3, column θ) is a time function (file Trappes.FTE). The outdoors is defined as the 'sun' zone (Figure 3, column Sun). Also the solar radiation data are time functions (files Trappes.FSG and Trappes.FSD). The orientation of the façade is defined in the Solar Data window. A horizon with a height of 5° in all directions is defined in the Sun Obstacles window.
- The **indoors** is defined in a simpler way compared to the 2D analysis above. The type BC_SKY is used, with a constant air temperature and a constant radiation temperature, both equal to 20 °C. A convective heat transfer coefficient $h_c = 2.5$ W/m²K is applied. This approach doesn't allow a quantitative analysis of the primary and secondary solar heat gains as in the 2D analysis above. Only a qualitative evaluation is intended here.

- The **material and surface properties** thermal conductivity λ , density ρ , specific heat c , long wave emissivity ϵ are as in the 2D analysis above.
- The **double glazing** is identical to the one in the 2D analysis above. Also the aluminium glazing edge is considered now. Angle dependent solar reflection is applied.
- The **calculation parameters** are identical to the ones in the 2D analysis above.
- The simulation requires the calculation of **3D view factors**. For the grid as used in the transient simulation, the view factor calculation requires a lot of computer memory. In order to rationalise, the view factors are clustered with a maximum of 1000 view factor faces per zone:

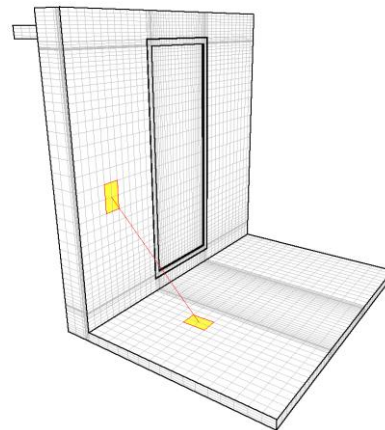
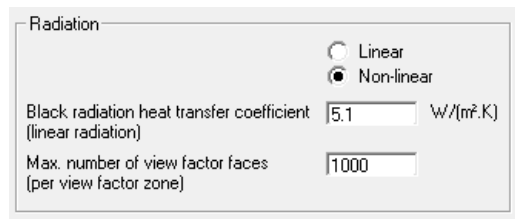
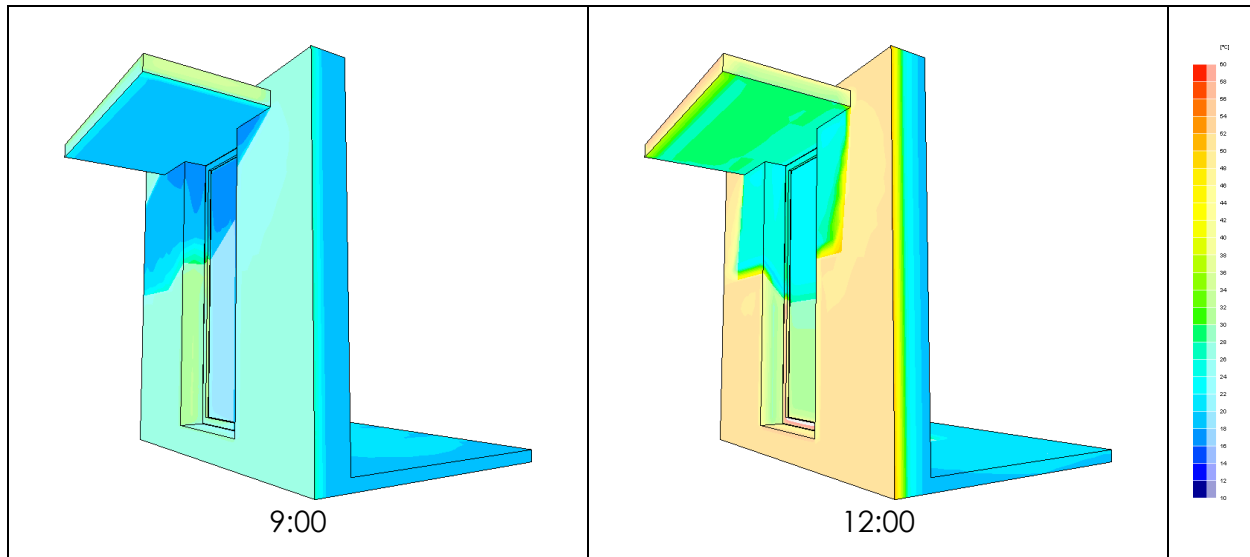


Figure 12. View factor calculation principle.



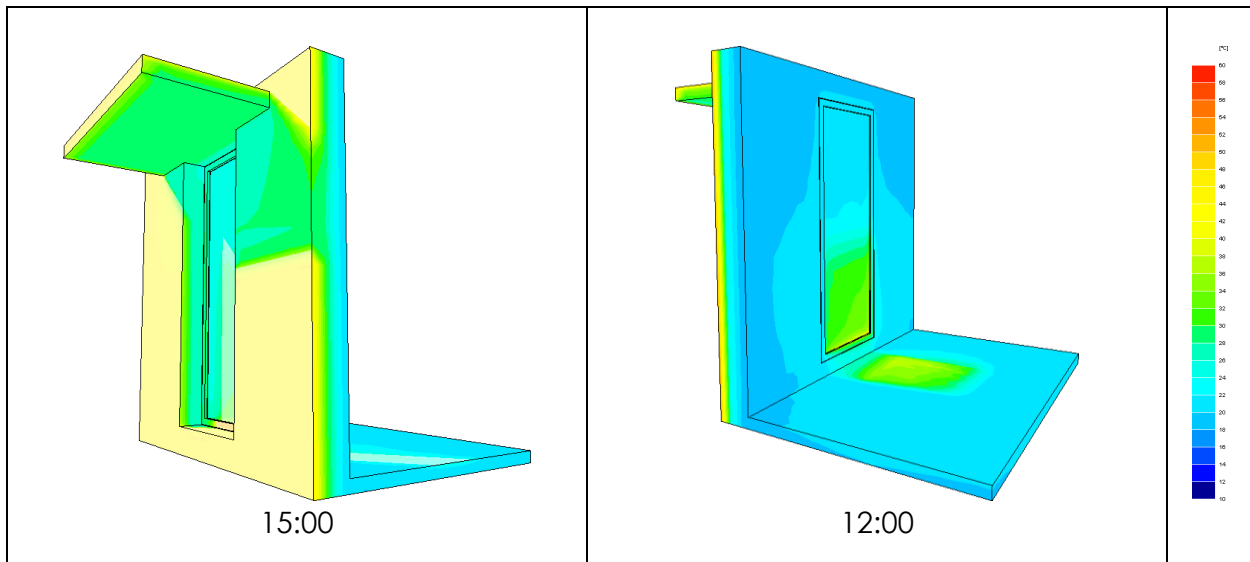


Figure 13. Temperature course at 09:00, 12:00, 15:00 (3 external views, 1 internal view).

Figure 13 shows the simulated temperature course at 3 different times (9:00, 12:00, 15:00). The results only allow a qualitative evaluation (comparing situations with and without overhang). A quantitative evaluation (amounts of incoming solar heat) requires the definition of a box just behind the glazing, similar to the one in the 2D analysis above.

5. References

EN 410:2011 Glass in building - Determination of luminous and solar characteristics of glazing

EN ISO 10456: 2007 Building materials and products -- Hygrothermal properties -- Tabulated design values and procedures for determining declared and design thermal values

EN 673:2024 Glass in building – Determination of thermal transmittance (U value) – Calculation method

EN ISO 13792: 2005 Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling - Simplified methods