C1 – THERMAL ANALYSIS OF THE BUILDING ENVELOPE IN SUMMER CONDITIONS PART 1: OPAQUE CONSTRUCTIONS

1. Introduction

Determining the maximum temperature within the building envelope is key to assessing potential damage and degradation risks. Such thermal analyses can be carried out using various Physibel software tools. Depending on the desired accuracy, models can range from simplified approaches to more detailed simulations, as illustrated in several case studies here.

2. Theoretical background

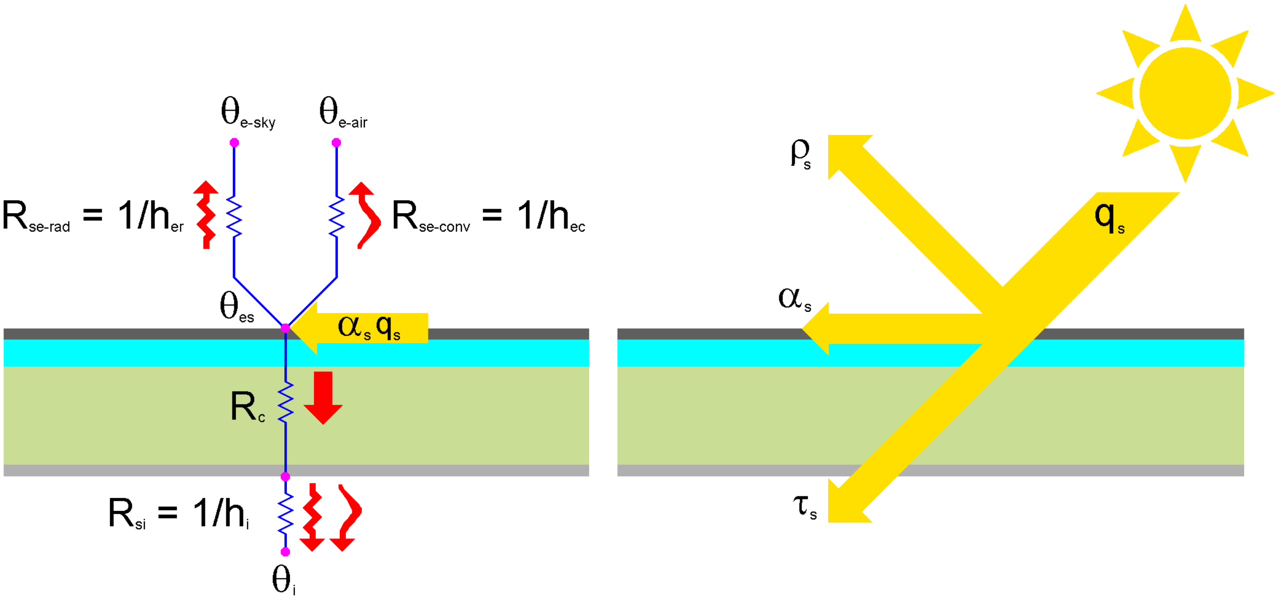

Figure 1 Heat transfer flows in a construction subject to solar radiation

Figure 1 displays the heat transfer flows in a construction subjected to solar radiation.

Solar radiation (the sum of direct solar radiation, diffuse solar radiation and ground reflected radiation) striking a surface, is divided in 3 components (reflection, absorption and solar transmission) that are proportional to the surface properties.

- ρ_s the solar reflectance [-]
- α_s the solar absorptance [-]
- τ_s the solar transmittance factor [-].

$\tau_s = 0$ in case of an opaque element.

From the law of conservation of energy it follows:

$$\rho_s + \alpha_s + \tau_s = 1 \tag{1}$$

The absorbed solar heat $\alpha_s q_s$ will heat up the surface. From the surface heat will flow

- by heat transmission (q_t) to the interior
- by convection (q_s) to the exterior
- by long wave radiation (q_r) to the exterior

The external surface temperature θ_{es} can be derived from the thermal equilibrium equation:

$$\alpha_s q_s = q_t + q_c + q_r \tag{2}$$

The transmission heat transfer q_t equals to:

$$q_t = \frac{\theta_{es} - \theta_i}{R_c + 1/h_i} \tag{3}$$

with θ_i internal resultant temperature [°C]

R_c construction thermal resistance [m²K/W]

h_i global internal surface heat transfer coefficient [W/m²K]

The convective heat transfer q_c equals to:

$$q_c = \frac{\theta_{es} - \theta_{e-air}}{1/h_{ec}} \tag{4}$$

with θ_{e-air} external air temperature [°C]

h_{ec} external convective surface heat transfer coefficient [W/m²K]

The long wave radiation heat transfer q_r equals to:

$$q_r = \frac{\theta_{es} - \theta_{e-sky}}{1/h_{er}} \tag{5}$$

with θ_{e-sky} external sky temperature [°C]

h_{er} external long wave surface heat transfer coefficient [W/m²K]

A simplification is to replace the 2 external parallel resistances by 1 resistance, assuming that the external sky temperature equals the external air temperature. In that way, the global surface heat transfer equals to:

$$q_c + q_r = \frac{\theta_{es} - \theta_{e-air}}{1/h_e} \tag{6}$$

with h_e external global surface heat transfer coefficient [W/m²K]

3. Boundary conditions

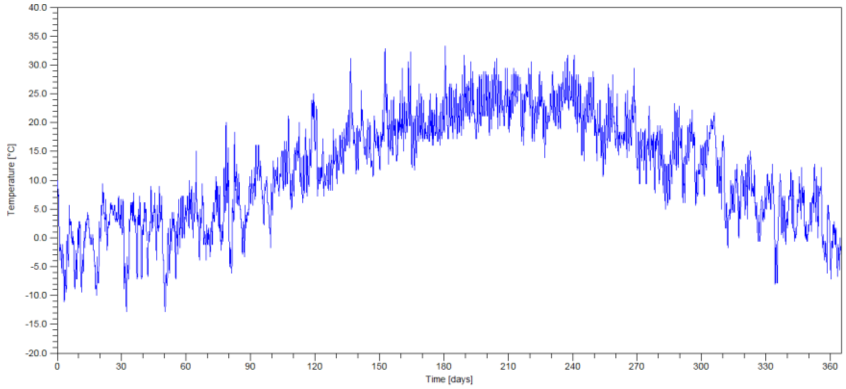

Figure 2 Temperature for New York City

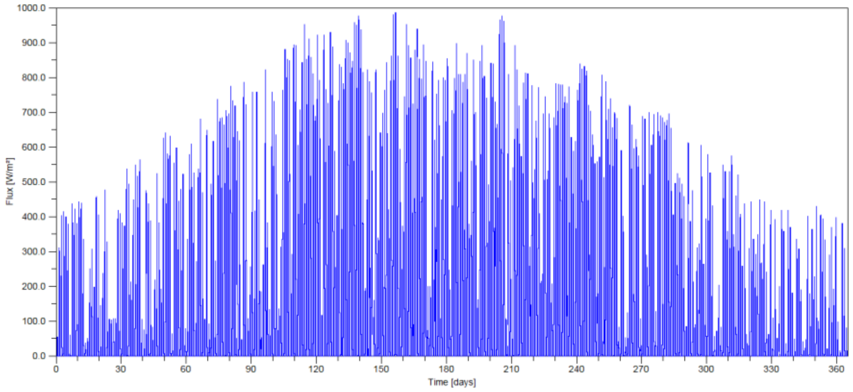

Figure 3 Horizontal global solar radiation for New York City

Outdoors

Hourly values of air temperature, global (and diffuse) solar radiation and sky temperature on a yearly basis can be retrieved from databases. It is assumed further that the sky temperature equals the air temperature[1]. Figure 2Figure 3 show such values for New York City. Such functions can be used in a transient analysis (programs BISTRA and VOLTRA). In a steady state analysis (programs BISCO, TRISCO, SOLIDO) one value of the air temperature and of the incident solar radiation is required. From the graphs it can be read that for a horizontal surface in New York City:

$$\theta_{e-air} = 33.3°\mathrm{C} \qquad\qquad q_s = 985\ \mathrm{W/m^2} \qquad\qquad (7)$$

are maximum values. These values will be used in the steady state analysis.

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[1] The sky temperature is normally equal or lower than the air temperature. Assuming a sky temperature equal to the air temperature is a conservative in regard of the purpose of the thermal analysis, i.e the knowledge of maximum temperatures.

Indoors

The indoor temperature course depends on multiple parameters. In the case studies a constant indoor temperature will be used:

$$\theta_i = 25°\text{C} \quad (8)$$

4. Surface Properties

In the first instance, the case studies concern opaque constructions, i.e. the solar transmittance factor $\tau_s = 0$. The solar absorptance depends mainly on the colour of the surface. Table 1 (from EN ISO 52016-1) gives values of the solar absorptance that may be used when no specific values are available.

	light colour Category 1	intermediate colour Category 2	dark colour Category 3
α_S	0.3	0.6	0.9

Table 1 Solar absorptance factors (EN ISO 52016-1)

5. Surface heat transfer coefficients

Indoors

Table 2 (from ISO 6946: 2017) gives values for the indoor surface heat transfer coefficient h_i.

	upwards heat transfer	horizontal heat transfer	downwards heat transfer
h_i [W/m2K]	10.0	7.7	5.9

Table 2 Indoor surface heat transfer coefficients (ISO 6946)

Outdoors convection

Both forced (due to the wind) and natural (due to temperature difference) convection occur at the external surface. For summer calculations, EN ISO 52022-3 recommends:

$$h_{ec} = 8\ \text{W/m}^2\text{K} \quad (9)$$

A more physical approach is to use a h_{ec}-value based on the temperature difference between air and surface (assuming no forced convection due to wind) (EN ISO 6946 Table D.2)[2]:

for horizontal heat flow $h_{ec} = 1.46\Delta\theta^{1/3}$ [W/m^{2}K] (10)

for upwards heat flow $h_{ec} = 2.28\Delta\theta^{1/3}$ [W/m^{2}K] (11)

for downward heat flow $h_{ec} = 0.18\Delta\theta^{0.187}$ [W/m^{2}K] (11)

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[2] Other relations are available in the literature.

Outdoors long wave radiation

For summer calculations, EN ISO 13789 recommends:

$$\mathrm{h_{er}} = 4{,}14\ \mathrm{W/m^2K} \tag{12}$$

A more physical approach is to calculate the radiation surface heat transfer coefficient:

$$\mathrm{h_r} = \varepsilon \mathrm{h_{rb}} \qquad \mathrm{h_{rb}} = \sigma\left(\mathrm{T_{sky}^2} + \mathrm{T_{es}^2}\right)\left(\mathrm{T_{sky}} + \mathrm{T_{es}}\right) \approx 4\sigma \mathrm{T_m^3} \tag{13}$$

with ε long wave emissivity [-]

$\mathrm{h_{rb}}$ black radiation heat transfer coefficient [W/m²K]

σ Stefan-Boltzmann constant ($5.67\ 10^{-8}$ W/m²K⁴)

$\mathrm{T_{sky}}$ absolute temperature of the sky [K]

$\mathrm{T_{es}}$ absolute temperature of the surface [K]

$\mathrm{T_m}$ mean temperature [K]

Table 3 gives the values of $\mathrm{h_{rb}}$ for different values of $\mathrm{T_m}$.

T_m [°C]	0	10	20	30	40	50
$\mathrm{h_{rb}}$ [W/m²K]	4.63	5.15	5.72	6.33	6.98	7.67

Table 3 Values of $\mathrm{h_{rb}}$ for different values of $\mathrm{T_m}$

The Physibel software (with RADCON module installed) allows both an automatic iterative calculation of Eq. 13 (this is called non-linear radiation), and the specification of a $\mathrm{h_{rb}}$-value from Table 3 (this is called linear radiation). The non-linear radiation model results in the more correct result. The linear radiation model results in correct results as long as the $\mathrm{h_{rb}}$-value is correctly estimated.

Outdoors convection and radiation

The global external heat transfer coefficient $\mathrm{h_e}$ (see Eq. 6) is the sum of the convective and radiation surface coefficient. For summer calculations (with low wind velocity) this could lead to:

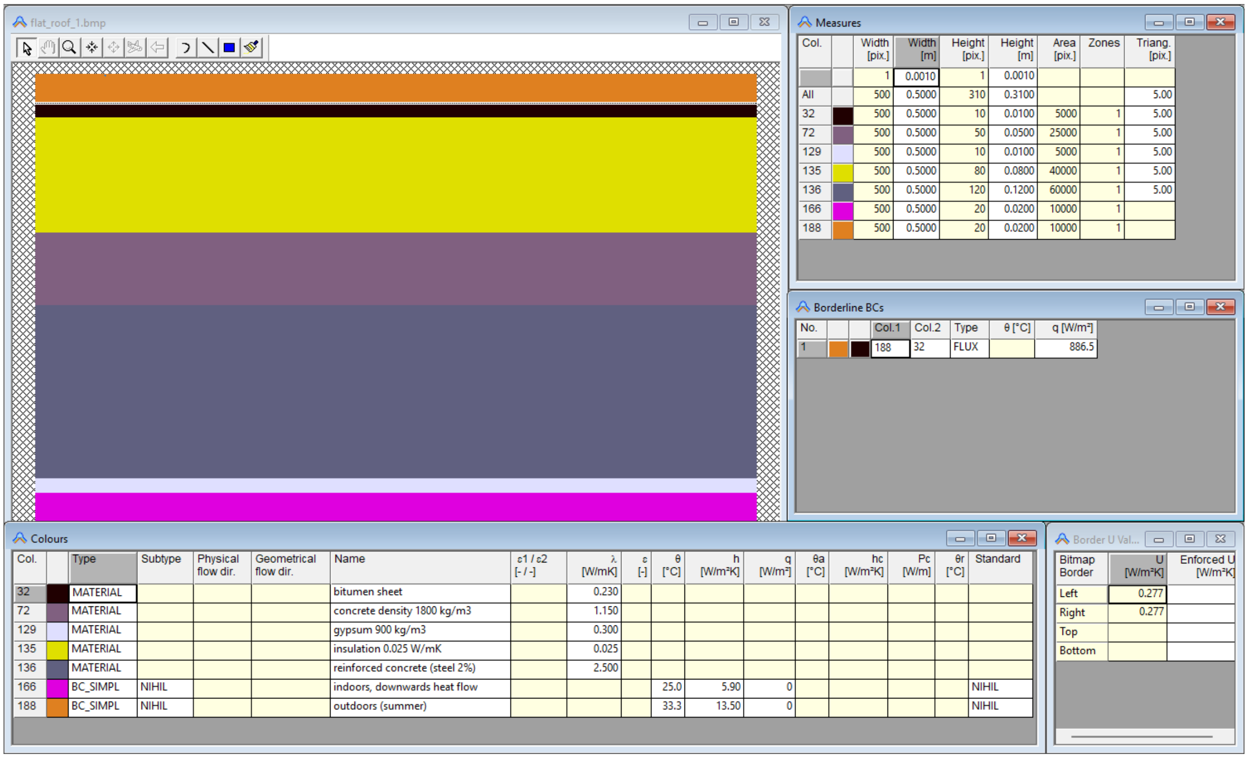
$$\mathrm{h_e} = \mathrm{h_{ce}} + \mathrm{h_{re}} = 8\frac{\mathrm{W}}{\mathrm{m^2K}} + 4.14\frac{\mathrm{W}}{\mathrm{m^2K}} = 12.14\ \mathrm{W/m^2K} \tag{14}$$

A commonly used value in practice is 13.5 W/m²K; this value was previously specified in EN ISO 13792. This standard has been withdrawn and replaced by ISO 52016-1:2017 and ISO 52017-1:2017. This value will also be used in the example cases in this document.

6. Case study A1. Flat roof, 1D steady state simplified approach

BISCO data flat_roof_1.bsc

TRISCO data flat_roof_1.trc



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		1	0.0010	1	0.0010			
All		500	0.5000	310	0.3100			5.00
32	⬛	500	0.5000	10	0.0100	5000	1	5.00
72	🟪	500	0.5000	50	0.0500	25000	1	5.00
129	⬜	500	0.5000	10	0.0100	5000	1	5.00
135	🟨	500	0.5000	80	0.0800	40000	1	5.00
136	🟦	500	0.5000	120	0.1200	60000	1	5.00
166	🟪	500	0.5000	20	0.0200	10000	1	
188	🟧	500	0.5000	20	0.0200	10000	1	

No.			Col.1	Col.2	Type	θ [°C]	q [W/m²]
1	🟧	⬛	188	32	FLUX		886.5

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [- / -]	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W/m]	θr [°C]	Standard
32	⬛	MATERIAL				bitumen sheet		0.230									
72	🟪	MATERIAL				concrete density 1800 kg/m3		1.150									
129	⬜	MATERIAL				gypsum 900 kg/m3		0.300									
135	🟨	MATERIAL				insulation 0.025 W/mK		0.025									
136	🟦	MATERIAL				reinforced concrete (steel 2%)		2.500									
166	🟪	BC_SIMPL	NIHIL			indoors, downwards heat flow				25.0	5.90	0					NIHIL
188	🟧	BC_SIMPL	NIHIL			outdoors (summer)				33.3	13.50	0					NIHIL

Bitmap Border	U [W/m²K]	Enforced U [W/m²K]
Left	0.277	
Right	0.277	
Top		
Bottom		

Figure 4 BISCO data flat_roof_1.bsc

The case study concerns a flat roof with a black surface, located in New York City. Although this case easily can be calculated by hand, as the heat flow is 1D, the programs BISCO/TRISCO are used to solve it. Figure 4 shows the BISCO data for a flat roof. A simplified steady state approach is used:

-Indoors: temperature = 25 °C (Eq. 8)

global surface heat transfer coefficient $\mathrm{h_i}$ = 5.9 W/m2K (Table 2)

-Outdoors: temperature = 33.3 °C (Eq. 7)

global surface heat transfer coefficient $\mathrm{h_i}$ = 13.5 W/m2K (Eq. 14)

absorbed solar radiation = 0.9 x 985 W/m2 = 886.5 W/m2 (Eq. 7 and Table 1).

The absorbed solar radiation is entered as a "borderline boundary condition".

Figure 5 shows the temperature course found. The external surface temperature is 97.45 °C.

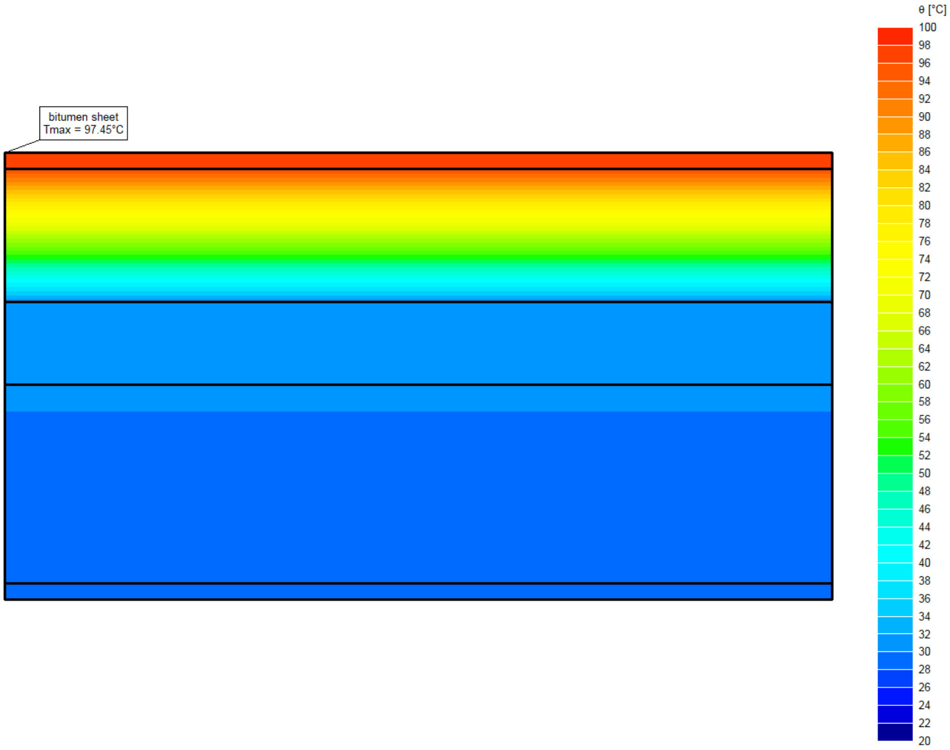
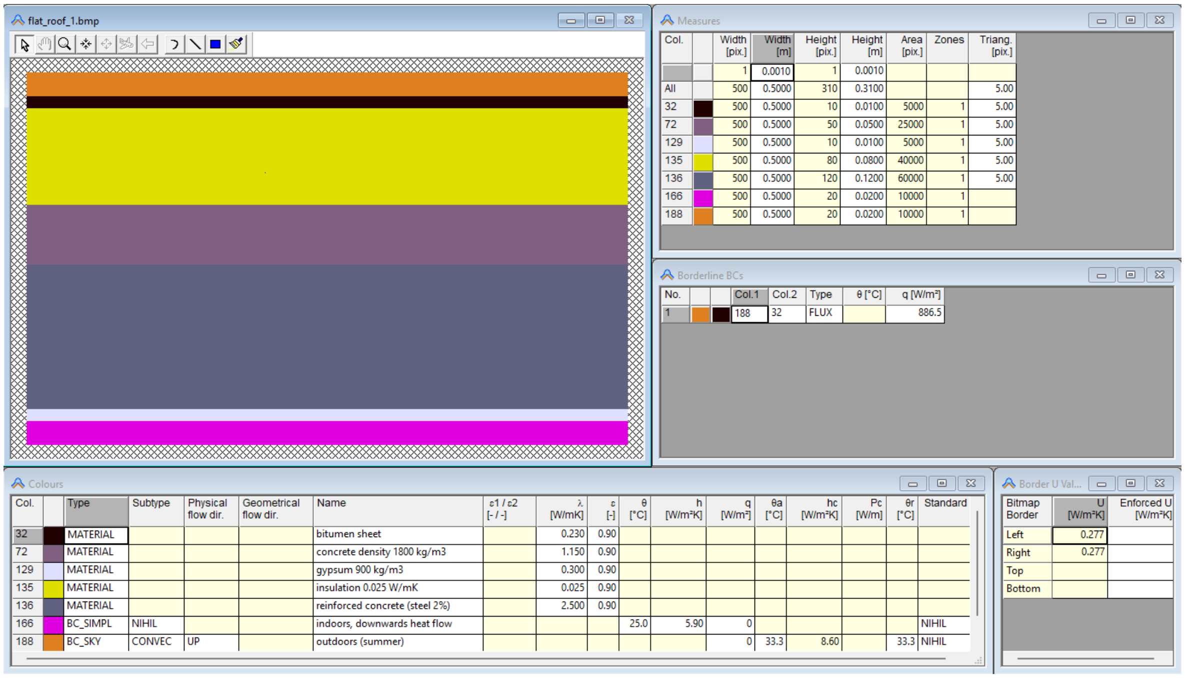


Figure 5 Temperature course

7. Case study A2. Flat roof, 1D steady state detailed approach

BISCO data [flat_roof_1_RADCON.bsc]

VOLTRA data [flat_roof_1_RADCON.trc]



Col.		Width [pix.]	Width [m]	Height [pix.]	Height [m]	Area [pix.]	Zones	Triang. [pix.]
		1	0.0010	1	0.0010			
All		500	0.5000	310	0.3100			5.00
32	■	500	0.5000	10	0.0100	5000	1	5.00
72	■	500	0.5000	50	0.0500	25000	1	5.00
129	■	500	0.5000	10	0.0100	5000	1	5.00
135	■	500	0.5000	80	0.0800	40000	1	5.00
136	■	500	0.5000	120	0.1200	60000	1	5.00
166	■	500	0.5000	20	0.0200	10000	1	
188	■	500	0.5000	20	0.0200	10000	1	

No.			Col.1	Col.2	Type	θ [°C]	q [W/m²]
1	■	■	188	32	FLUX		886.5

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [-/-]	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W/m]	θr [°C]	Standard
32	■	MATERIAL				bitumen sheet		0.230	0.90								
72	■	MATERIAL				concrete density 1800 kg/m3		1.150	0.90								
129	■	MATERIAL				gypsum 900 kg/m3		0.300	0.90								
135	■	MATERIAL				insulation 0.025 W/mK		0.025	0.90								
136	■	MATERIAL				reinforced concrete (steel 2%)		2.500	0.90								
166	■	BC_SIMPL	NIHIL			indoors, downwards heat flow				25.0	5.90	0					NIHIL
188	■	BC_SKY	CONVEC	UP		outdoors (summer)						0	33.3	8.60		33.3	NIHIL

Bitmap Border	U [W/m²K]	Enforced U [W/m²K]
Left	0.277	
Right	0.277	
Top		
Bottom		

Figure 6 BISCO data [flat_roof_1_RADCON.bsc]

At the external surface, the heat transfer by convection and radiation is considered separately. Therefore the outdoors boundary condition is taken as a BC_SKY type (Figure 6) with

- air temperature = sky temperature = 33.3 °C (Eq. 7)
- convective heat transfer coefficient calculated iteratively according to Eq. 11. This is forced by applying the Subtype: "CONVEC" and Physical flow dir.: "UP" to the colour 188. In the window Calculation Parameters, "recalculate before each iteration cycles" and "Use solution temperatures" are specified.
- long wave emission of the external surface = 0.9. In the window Calculation Parameters, non-linear radiation is specified.

Figure 7 shows the temperature course found. The external surface temperature is 86.94 °C.

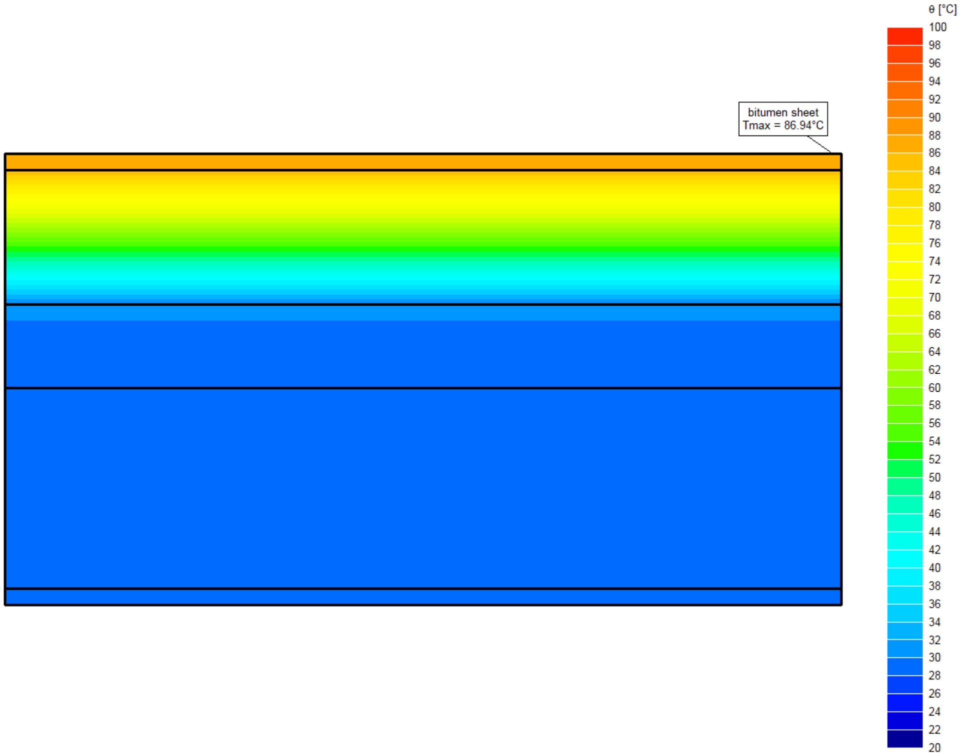
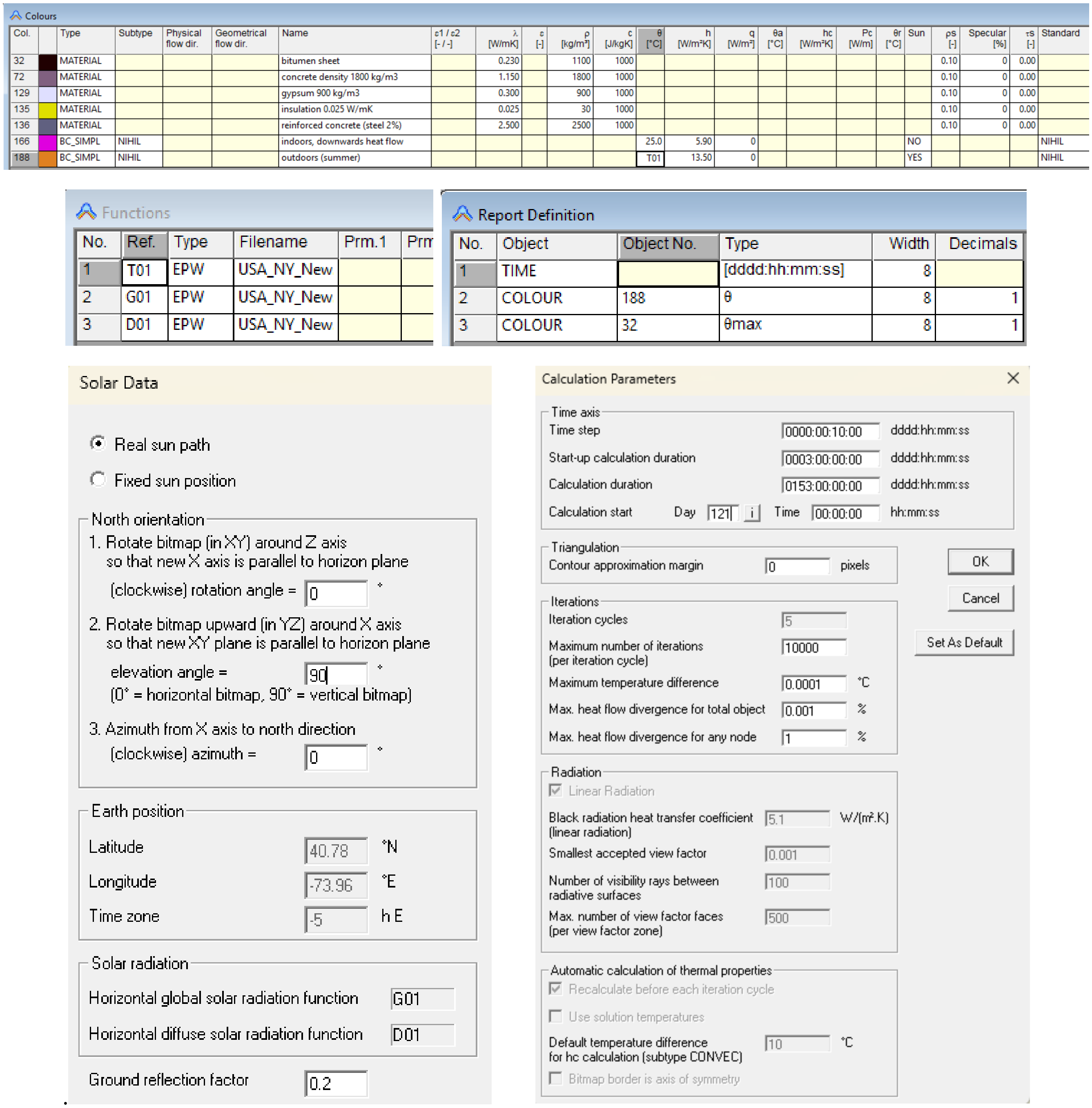


Figure 7 Temperature course

8. Case study A3. Flat roof, 1D transient simplified approach

BISTRA data flat_roof_1_transient.bst

VOLTRA data flat_roof_1_transient.vtr



Colours

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [- / -]	λ [W/mK]	ε [-]	ρ [kg/m³]	c [J/kgK]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W/m]	θr [°C]	Sun	ρs [-]	Specular [%]	τs [-]	Standard
32	⬛	MATERIAL				bitumen sheet		0.230		1100	1000									0.10	0	0.00	
72	🟪	MATERIAL				concrete density 1800 kg/m3		1.150		1800	1000									0.10	0	0.00	
129	⬜	MATERIAL				gypsum 900 kg/m3		0.300		900	1000									0.10	0	0.00	
135	🟨	MATERIAL				insulation 0.025 W/mK		0.025		30	1000									0.10	0	0.00	
136	⬛	MATERIAL				reinforced concrete (steel 2%)		2.500		2500	1000									0.10	0	0.00	
166	🟪	BC_SIMPL	NIHIL			indoors, downwards heat flow						25.0	5.90	0					NO				NIHIL
188	🟧	BC_SIMPL	NIHIL			outdoors (summer)						T01	13.50	0					YES				NIHIL

Functions

No.	Ref.	Type	Filename	Prm.1	Prm
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2	G01	EPW	USA_NY_New		
3	D01	EPW	USA_NY_New		

Report Definition

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1	TIME		[dddd:hh:mm:ss]	8	
2	COLOUR	188	θ	8	1
3	COLOUR	32	θmax	8	1

Solar Data

● Real sun path

○ Fixed sun position

North orientation

1. Rotate bitmap (in XY) around Z axis so that new X axis is parallel to horizon plane
   (clockwise) rotation angle = 0 °
2. Rotate bitmap upward (in YZ) around X axis so that new XY plane is parallel to horizon plane
   elevation angle = 90 °
   (0° = horizontal bitmap, 90° = vertical bitmap)
3. Azimuth from X axis to north direction
   (clockwise) azimuth = 0 °

Earth position

Latitude: 40.78 °N

Longitude: -73.96 °E

Time zone: -5 h E

Solar radiation

Horizontal global solar radiation function: G01

Horizontal diffuse solar radiation function: D01

Ground reflection factor: 0.2

Calculation Parameters

Time axis

Time step: 0000:00:10:00 dddd:hh:mm:ss

Start-up calculation duration: 0003:00:00:00 dddd:hh:mm:ss

Calculation duration: 0153:00:00:00 dddd:hh:mm:ss

Calculation start Day 121 Time 00:00:00 hh:mm:ss

Triangulation

Contour approximation margin: 0 pixels

Iterations

Iteration cycles: 5

Maximum number of iterations (per iteration cycle): 10000

Maximum temperature difference: 0.0001 °C

Max. heat flow divergence for total object: 0.001 %

Max. heat flow divergence for any node: 1 %

Radiation

☑ Linear Radiation

Black radiation heat transfer coefficient (linear radiation): 5.1 W/(m².K)

Smallest accepted view factor: 0.001

Number of visibility rays between radiative surfaces: 100

Max. number of view factor faces (per view factor zone): 500

Automatic calculation of thermal properties

☑ Recalculate before each iteration cycle

☐ Use solution temperatures

Default temperature difference for hc calculation (subtype CONVEC): 10 °C

☐ Bitmap border is axis of symmetry

Figure 8 BISTRA data flat_roof_1_transient.bst

Compared to the steady state case studies, the absorbed solar radiation doesn't need to be defined as a borderline boundary condition. The program BISTRA contains a solar processor, and the absorbed solar radiation is calculated at each time step from the horizontal global and diffuse radiation functions defined (New York City), the solar reflection factor of the surface, the orientation of the construction element as defined in the BISTRA data windows (Figure 8). For the heat transfer by radiation and convection from the roof surface to the outdoor environment a simplified approach is used (Eq. 14). The transient thermal behaviour is simulated from the 1st May until the 30th September.

Figure 9 shows the evolution of the outdoors and roof surface temperature. The maximum roof surface temperature is 93°C and occurs on 24 July. The file [flat_roof_1_transient_24_July.mp4]() contains an animation of the temperature course on that day.

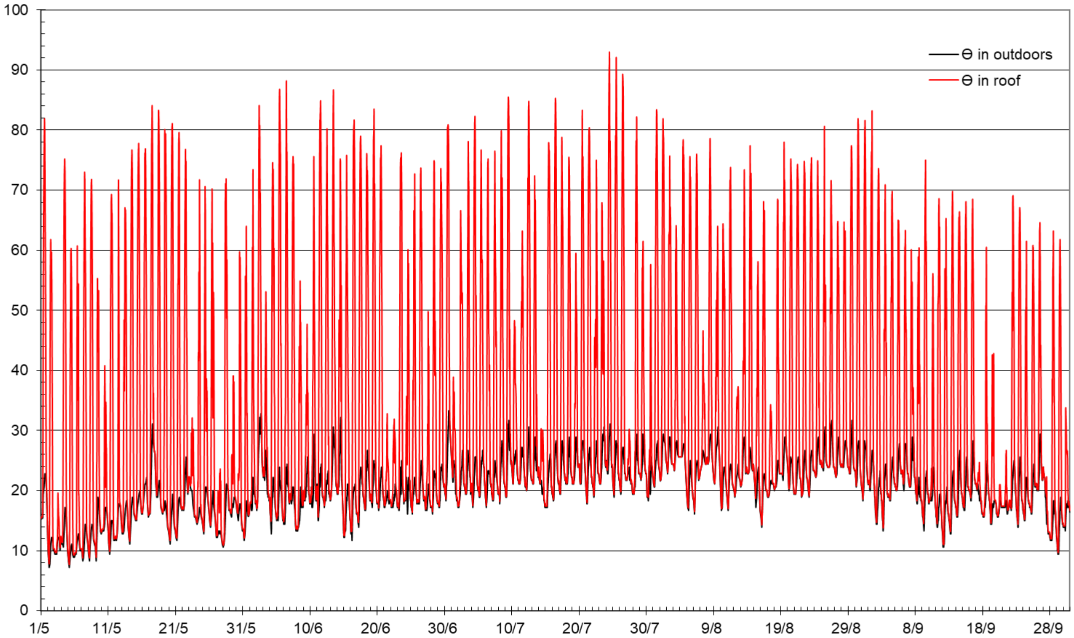
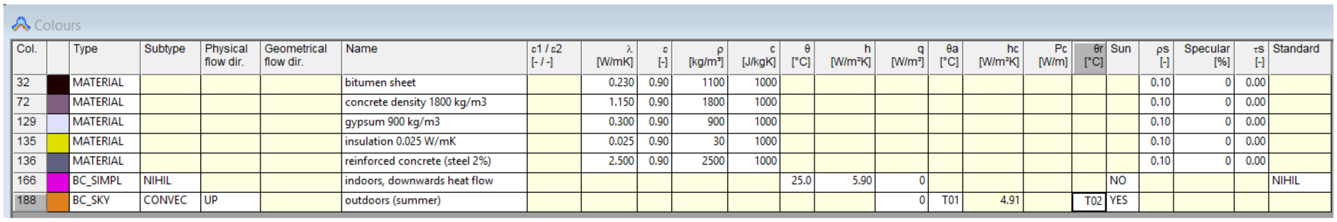


Figure 9 Outdoors and roof surface temperatures [°C].

9. Case study A4. Flat roof, 1D transient detailed approach

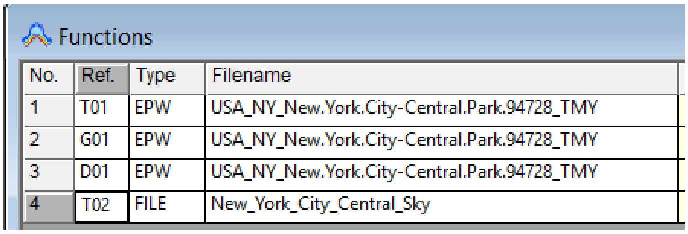
BISTRA data flat_roof_1_RADCON_transient.bst

VOLTRA data flat_roof_1_RADCON_transient.vtr



Colours

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [- / -]	λ [W/mK]	ε [-]	ρ [kg/m^3]	c [J/kgK]	θ [°C]	h [W/m^{2}K]	q [W/m^2]	θa [°C]	hc [W/m^{2}K]	Pc [W/m]	θr [°C]	Sun	ρs [-]	Specular [%]	τs [-]	Standard
32	■	MATERIAL				bitumen sheet		0.230	0.90	1100	1000									0.10	0	0.00	
72	■	MATERIAL				concrete density 1800 kg/m3		1.150	0.90	1800	1000									0.10	0	0.00	
129	■	MATERIAL				gypsum 900 kg/m3		0.300	0.90	900	1000									0.10	0	0.00	
135	■	MATERIAL				insulation 0.025 W/mK		0.025	0.90	30	1000									0.10	0	0.00	
136	■	MATERIAL				reinforced concrete (steel 2%)		2.500	0.90	2500	1000									0.10	0	0.00	
166	■	BC_SIMPL	NIHIL			indoors, downwards heat flow						25.0	5.90	0					NO				NIHIL
188	■	BC_SKY	CONVEC	UP		outdoors (summer)								0	T01	4.91		T02	YES				



Functions

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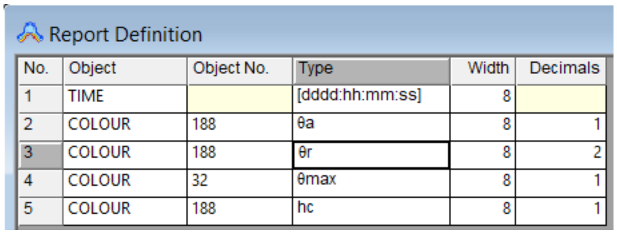
2	G01	EPW	USA_NY_New.York.City-Central.Park.94728_TMY
3	D01	EPW	USA_NY_New.York.City-Central.Park.94728_TMY
4	T02	FILE	New_York_City_Central_Sky



Report Definition

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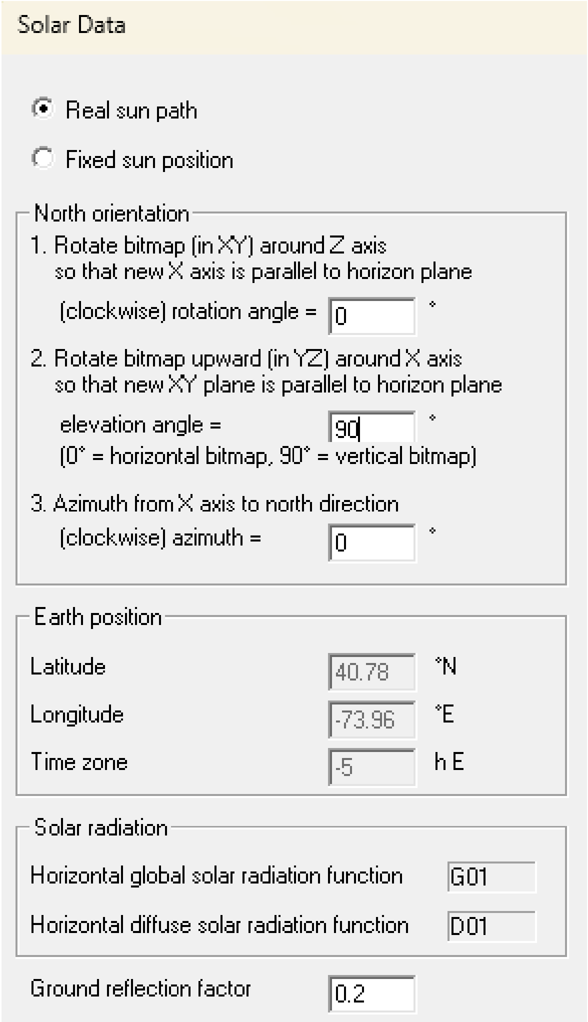
3	COLOUR	188	θr	8	2
4	COLOUR	32	θmax	8	1
5	COLOUR	188	hc	8	1



Solar Data

● Real sun path

○ Fixed sun position

North orientation

1. Rotate bitmap (in XY) around Z axis so that new X axis is parallel to horizon plane

(clockwise) rotation angle = 0 °

2. Rotate bitmap upward (in YZ) around X axis so that new XY plane is parallel to horizon plane

elevation angle = 90 °

(0° = horizontal bitmap, 90° = vertical bitmap)

3. Azimuth from X axis to north direction

(clockwise) azimuth = 0 °

Earth position

Latitude 40.78 °N

Longitude -73.96 °E

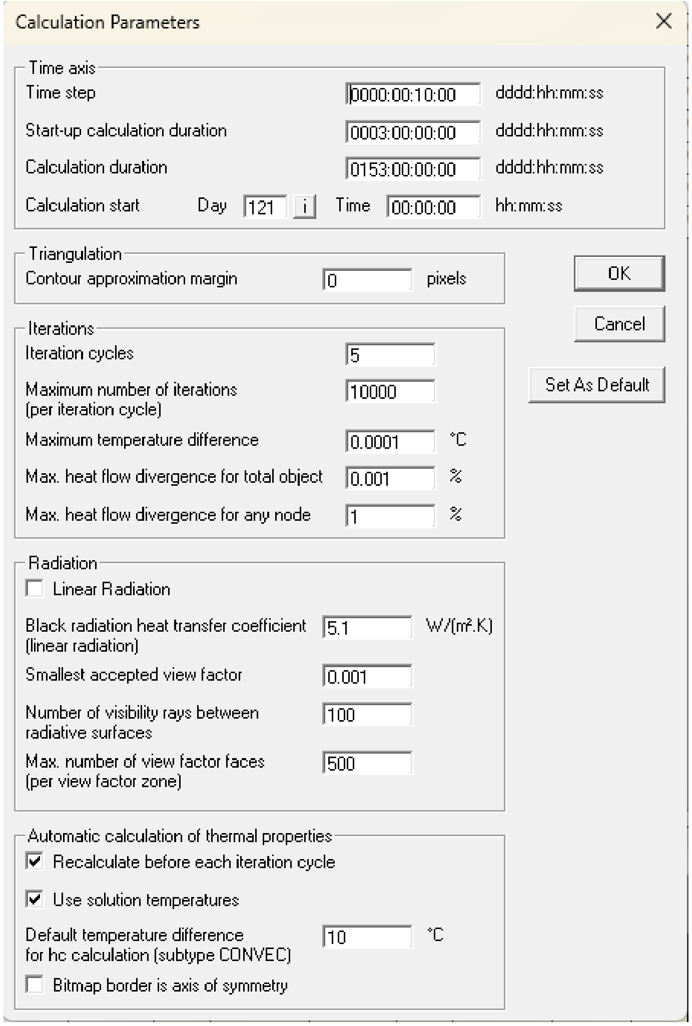
Time zone -5 h E

Solar radiation

Horizontal global solar radiation function G01

Horizontal diffuse solar radiation function D01

Ground reflection factor 0.2



Calculation Parameters

Time axis

Time step 0000:00:10:00 dddd:hh:mm:ss

Start-up calculation duration 0003:00:00:00 dddd:hh:mm:ss

Calculation duration 0153:00:00:00 dddd:hh:mm:ss

Calculation start Day 121 Time 00:00:00 hh:mm:ss

Triangulation

Contour approximation margin 0 pixels

Iterations

Iteration cycles 5

Maximum number of iterations (per iteration cycle) 10000

Maximum temperature difference 0.0001 °C

Max. heat flow divergence for total object 0.001 %

Max. heat flow divergence for any node 1 %

Radiation

☐ Linear Radiation

Black radiation heat transfer coefficient (linear radiation) 5.1 W/(m²K)

Smallest accepted view factor 0.001

Number of visibility rays between radiative surfaces 100

Max. number of view factor faces (per view factor zone) 500

Automatic calculation of thermal properties

☑ Recalculate before each iteration cycle

☑ Use solution temperatures

Default temperature difference for hc calculation (subtype CONVEC) 10 °C

☐ Bitmap border is axis of symmetry

Figure 10 BISTRA data flat_roof_1_RADCON_transient.bst

In the detailed radiation transient approach, a similar procedure is followed as in the simplified transient case. The key difference lies in the treatment of heat transfer at the external surface, where convection and radiation are considered separately. Consequently, the outdoor boundary condition is defined as a BC_SKY type, allowing for distinct air and sky temperatures.

The air temperature is directly obtained from the EPW file, whereas the sky temperature must be generated through a preprocessing step. Using the F9 – Preparing sky temperature and convective surface heat transfer coefficient from EPW file Physibel software format document available in the Physibel Knowledge Base, a corresponding .FTE file containing the sky temperature can be created. This file is then imported as a T02 function and assigned to θ_r in the colours window.

Figure 10 illustrates the BISTRA data windows used for this setup. The transient thermal behaviour is simulated over the period from 1st May to 30th September.

Figure 11 shows the evolution of the outdoors and roof surface temperature and of the convective heat transfer coefficient[3]. The maximum roof surface temperature is 80.4 °C and occurs on 25 July. The file flat roof 1 RADCON transient 25 July.mp4 contains an animation of the temperature course on that day.

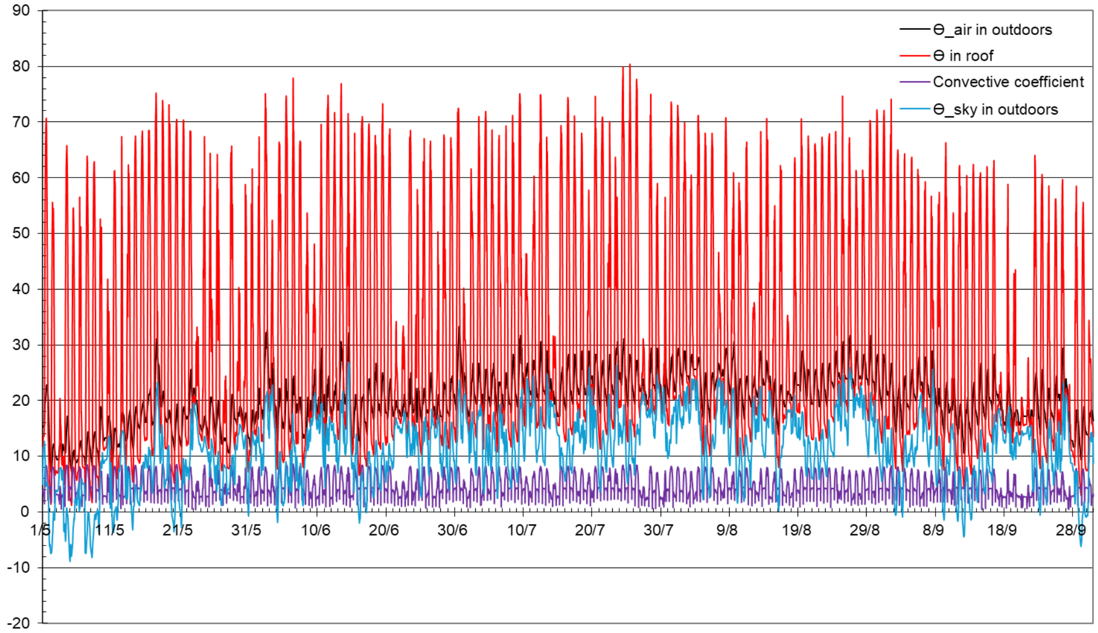


Figure 11 Outdoors air, sky and roof surface temperatures [°C] and convective heat transfer coefficient [W/m²K]

Case studies A1-A2-A3-A4 (Flat roof): summary and discussion

The steady state and simplified approach (case study A1) leads to the highest roof surface temperature: 97.5°C.

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[3] The convective heat transfer coefficient is only due to natural convection. No forced convection due to the wind is considered.

A steady state detailed approach (case study A2) results in a roof surface temperature of 86.9 °C.

A transient simplified approach (case study A3) results in a roof surface temperature of 93 °C.

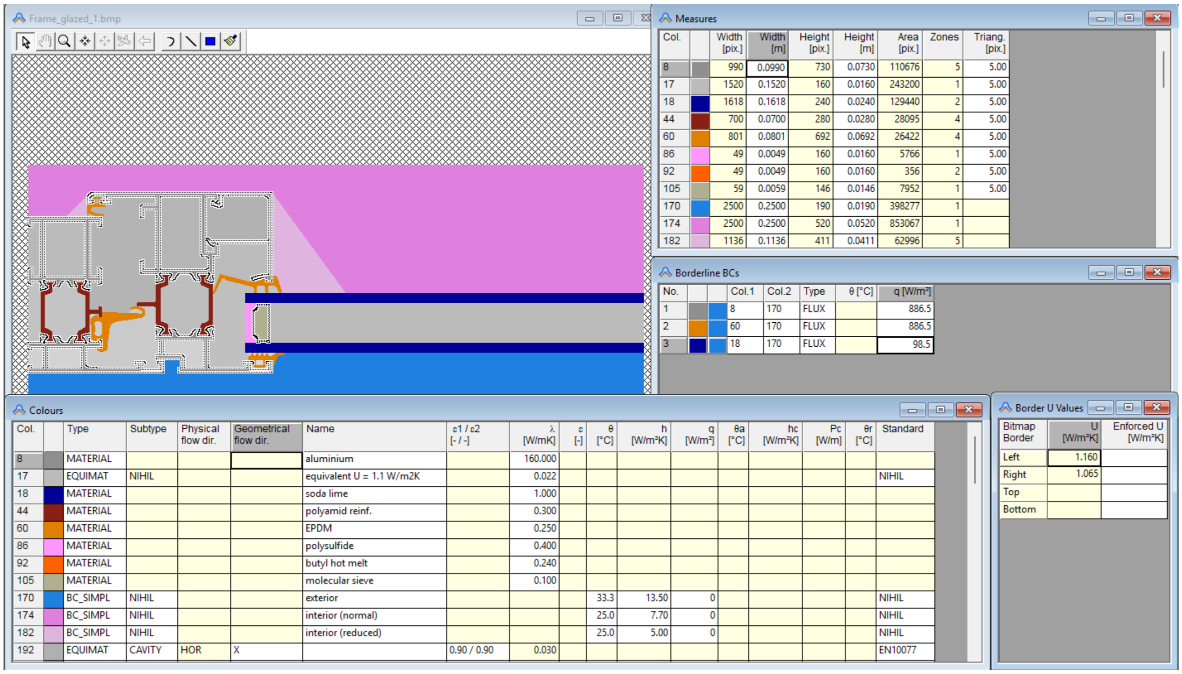
The transient detailed approach (case study A4) leads to the lowest roof surface temperature: 80.4 °C.

Table 4 Results

Example flat roof	**BC_SIMPL (global surface coefficient)**	**BC_SKY (detailed radiation)**
Steady-state	97.5°C (Case A1)	86.9°C (Case A2)
Transient	93°C (Case A3)	80.4°C (Case A4)

10. Case study B1. Window frame, 2D steady state simplified approach

BISCO data [Frame_glazed_1.bsc]



Measures

Col.		Width [pix.]	Width [m]	Height [pix.]	Height [m]	Area [pix.]	Zones	Triang. [pix.]
8	■	990	0.0990	730	0.0730	110676	5	5.00
17	■	1520	0.1520	160	0.0160	243200	1	5.00
18	■	1618	0.1618	240	0.0240	129440	2	5.00
44	■	700	0.0700	280	0.0280	28095	4	5.00
60	■	801	0.0801	692	0.0692	26422	4	5.00
86	■	49	0.0049	160	0.0160	5766	1	5.00
92	■	49	0.0049	160	0.0160	356	2	5.00
105	■	59	0.0059	146	0.0146	7952	1	5.00
170	■	2500	0.2500	190	0.0190	398277	1	
174	■	2500	0.2500	520	0.0520	853067	1	
182	■	1136	0.1136	411	0.0411	62996	5	

Borderline BCs

No.			Col.1	Col.2	Type	θ [°C]	q [W/m²]
1	■	■	8	170	FLUX		886.5
2	■	■	60	170	FLUX		886.5
3	■	■	18	170	FLUX		98.5

Colours

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [-/-]	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W/m]	θr [°C]	Standard
8	■	MATERIAL				aluminium		160.000									
17	■	EQUIMAT	NIHIL			equivalent U = 1.1 W/m2K		0.022									NIHIL
18	■	MATERIAL				soda lime		1.000									
44	■	MATERIAL				polyamid reinf.		0.300									
60	■	MATERIAL				EPDM		0.250									
86	■	MATERIAL				polysulfide		0.400									
92	■	MATERIAL				butyl hot melt		0.240									
105	■	MATERIAL				molecular sieve		0.100									
170	■	BC_SIMPL	NIHIL			exterior				33.3	13.50	0					NIHIL
174	■	BC_SIMPL	NIHIL			interior (normal)				25.0	7.70	0					NIHIL
182	■	BC_SIMPL	NIHIL			interior (reduced)				25.0	5.00	0					NIHIL
192	■	EQUIMAT	CAVITY	HOR	X		0.90 / 0.90	0.030									EN10077

Border U Values

Bitmap Border	U [W/m²K]	Enforced U [W/m²K]
Left	1.160	
Right	1.065	
Top		
Bottom		

Figure 12 BISCO data [Frame_glazed_1.bsc]

The case study concerns a dark coloured window frame, vertically positioned, south oriented and located in New York City. It is assumed that the maximal incident solar radiation on a vertical south oriented surface is about 985 W/m² [4]. The frame is glazed. In this case the solar transmittance through the glazing is not considered. It is simply assumed that the external pane of the glazing

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[4] Little higher solar incidence may occur in wintertime (in combination with lower temperature). Higher solar incidence may occur due to reflections by water, snow and glazings. The maximum solar incidence on a surface can be calculated using the programs BISTRA and VOLTRA.

absorbs 10 % of the incident solar radiation. Figure 12 shows the BISCO data. A simplified steady state approach is used:

-Indoors: temperature = 25 °C (Eq. 8)

global surface heat transfer coefficient hi = 7.7 or 5.0 W/m2K (EN 10077-2)

-Outdoors: temperature = 33.3 °C (Eq. 7)

global surface heat transfer coefficient hi = 13.5 W/m2K (Eq. 14)

absorbed solar radiation (frame and EPDM) = 0.9 x 985 W/m2 = 886.5 W/m2

absorbed solar radiation (glazing) = 0.1 x 985 W/m2 = 98.5 W/m2 (Eq. 7 and Table 1).

The absorbed solar radiation is entered as a “borderline boundary condition”.

Figure 13 gives the temperature course found. The maximum external surface temperature is 85.19 °C.

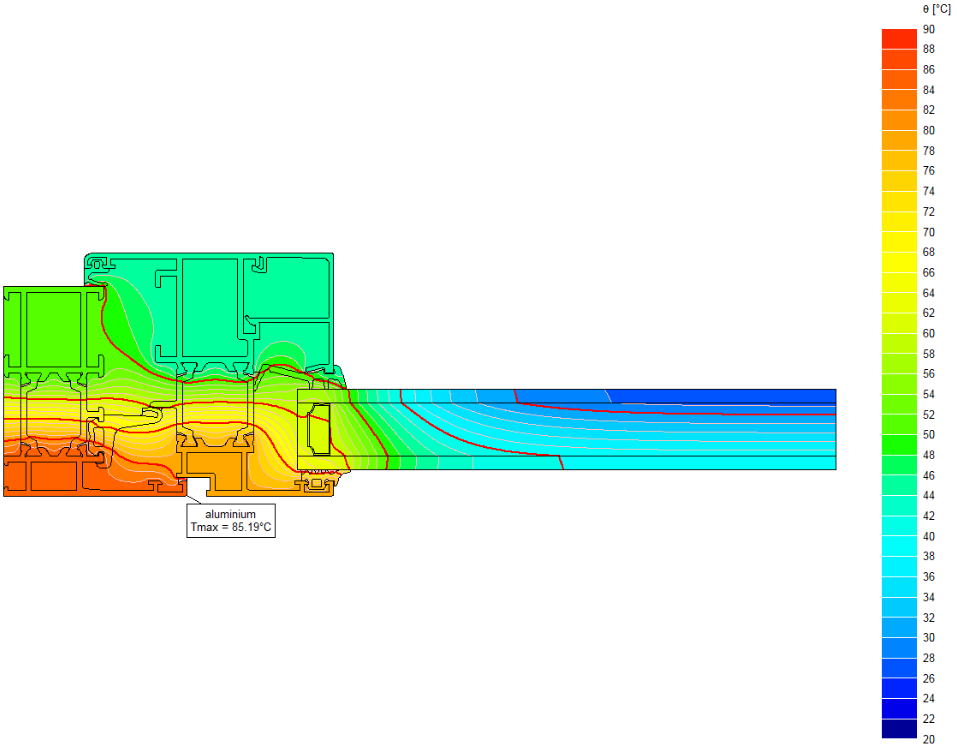
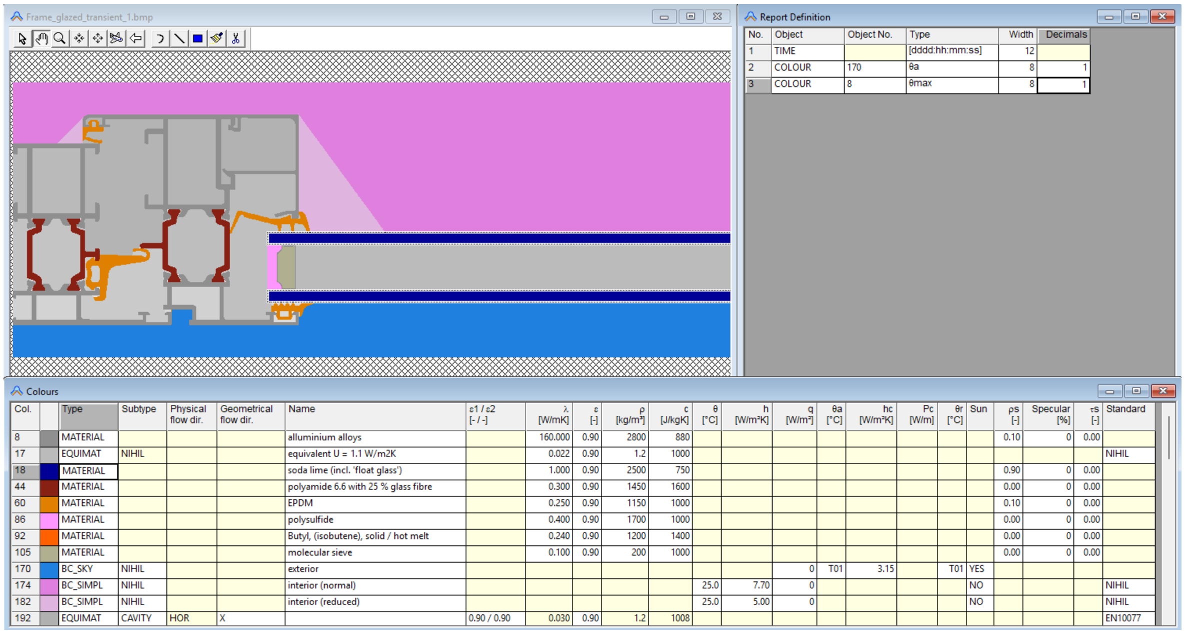


Figure 13 Temperature course

11. Case study B2. Window frame, 2D transient detailed approach

BISTRA data Frame_glazed_transient_1.bst



No.	Object	Object No.	Type	Width	Decimals
1	TIME		[dddd:hh:mm:ss]	12	
2	COLOUR	170	θa	8	1
3	COLOUR	8	θmax	8	1

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [-/-]	λ [W/mK]	ε [-]	ρ [kg/m³]	c [J/kgK]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W/m]	θr [°C]	Sun	ρs [-]	Specular [%]	τs [-]	Standard
8	■	MATERIAL				alluminium alloys		160.000	0.90	2800	880									0.10	0	0.00	
17	■	EQUIMAT	NIHIL			equivalent U = 1.1 W/m2K		0.022	0.90	1.2	1000												NIHIL
18	■	MATERIAL				soda lime (incl. 'float glass')		1.000	0.90	2500	750									0.90	0	0.00	
44	■	MATERIAL				polyamide 6.6 with 25 % glass fibre		0.300	0.90	1450	1600									0.00	0	0.00	
60	■	MATERIAL				EPDM		0.250	0.90	1150	1000									0.10	0	0.00	
86	■	MATERIAL				polysulfide		0.400	0.90	1700	1000									0.00	0	0.00	
92	■	MATERIAL				Butyl, (isobutene), solid / hot melt		0.240	0.90	1200	1400									0.00	0	0.00	
105	■	MATERIAL				molecular sieve		0.100	0.90	200	1000									0.00	0	0.00	
170	■	BC_SKY	NIHIL			exterior								0	T01	3.15		T01	YES				
174	■	BC_SIMPL	NIHIL			interior (normal)						25.0	7.70	0					NO				NIHIL
182	■	BC_SIMPL	NIHIL			interior (reduced)						25.0	5.00	0					NO				NIHIL
192	■	EQUIMAT	CAVITY	HOR	X		0.90 / 0.90	0.030	0.90	1.2	1008												EN10077

Figure 14 BISTRA data Frame_glazed_transient_1.bst

The detailed approach doesn't concern the glazing. Again we only assume solar absorption in the outer glass pane (solar absorption of 10%). Part II of this document will focus on transparent construction elements.

Compared to the steady state case studies, the absorbed solar radiation doesn't need to be defined as a borderline boundary condition. The program BISTRA contains a solar processor, and the absorbed solar radiation is calculated at each time step from the horizontal global and diffuse radiation functions defined (New York City), the solar reflection factor of the surface, the orientation of the construction element as defined in the BISTRA data windows (Figure 14). The transient thermal behaviour is simulated for the 24th September.

Figure 15 shows the temperature course at 12:30. The maximum external surface temperature is 61.3 °C.

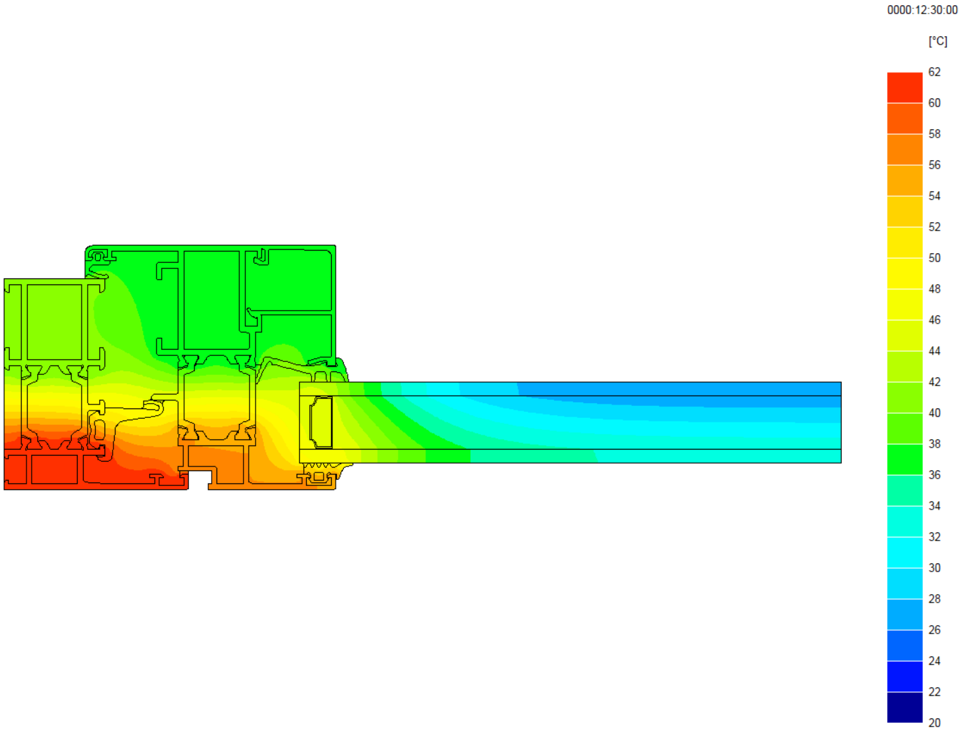


Figure 15 Temperature course at 12.30

12. References

- EN ISO 52016-1(2017) : Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures. ISO 6946: 2017. Building components and building elements – Thermal resistance and thermal transmittance - Calculation methods
- ISO 52022-3:2017 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
- ISO 10077-2:2017. Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 2: Numerical method for frames)