Tutorial

Calculating the temperatures in window frame during a sunny day: getting started with BISTRA

BST Tutorial a

1. Introduction

alu_1_frame_glazed.bsc
alu_1_frame_glazed_dynamic.bst

This tutorial explains how to calculate the temperatures occurring in a glazed window frame during a sunny day with BISTRA. The tutorial uses the geometrical model of the window frame and glazing discussed in the BISCO tutorials BSCa[1] and BSCb[2].

Key elements:

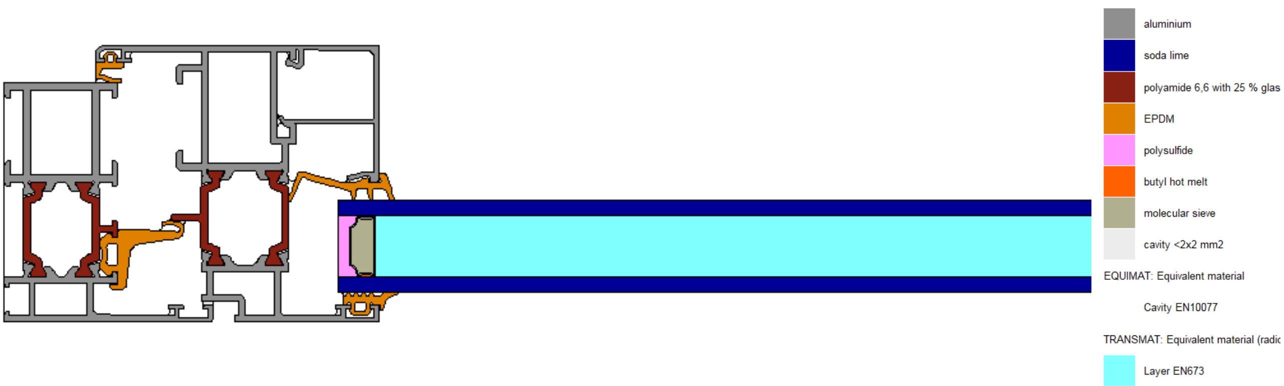
- Weather data (EPW-format) as boundary conditions
- Thermal properties
- Defining glass properties
- Definition of solar data and sun obstacles
- Graphic output and text output

2. Case study data

This tutorial starts with the horizontal section of an aluminium window frame with double glazing resulting from a DXF file in the BISCO tutorials BSCa and BSCb. The window is located in Brussels (with Uccle climate data) and is oriented to the West. The simulation will be conducted for June 16th, a sunny day with high solar load on a West oriented wall.

At the inside an environment constant air and radiative temperature of 25°C is assumed.

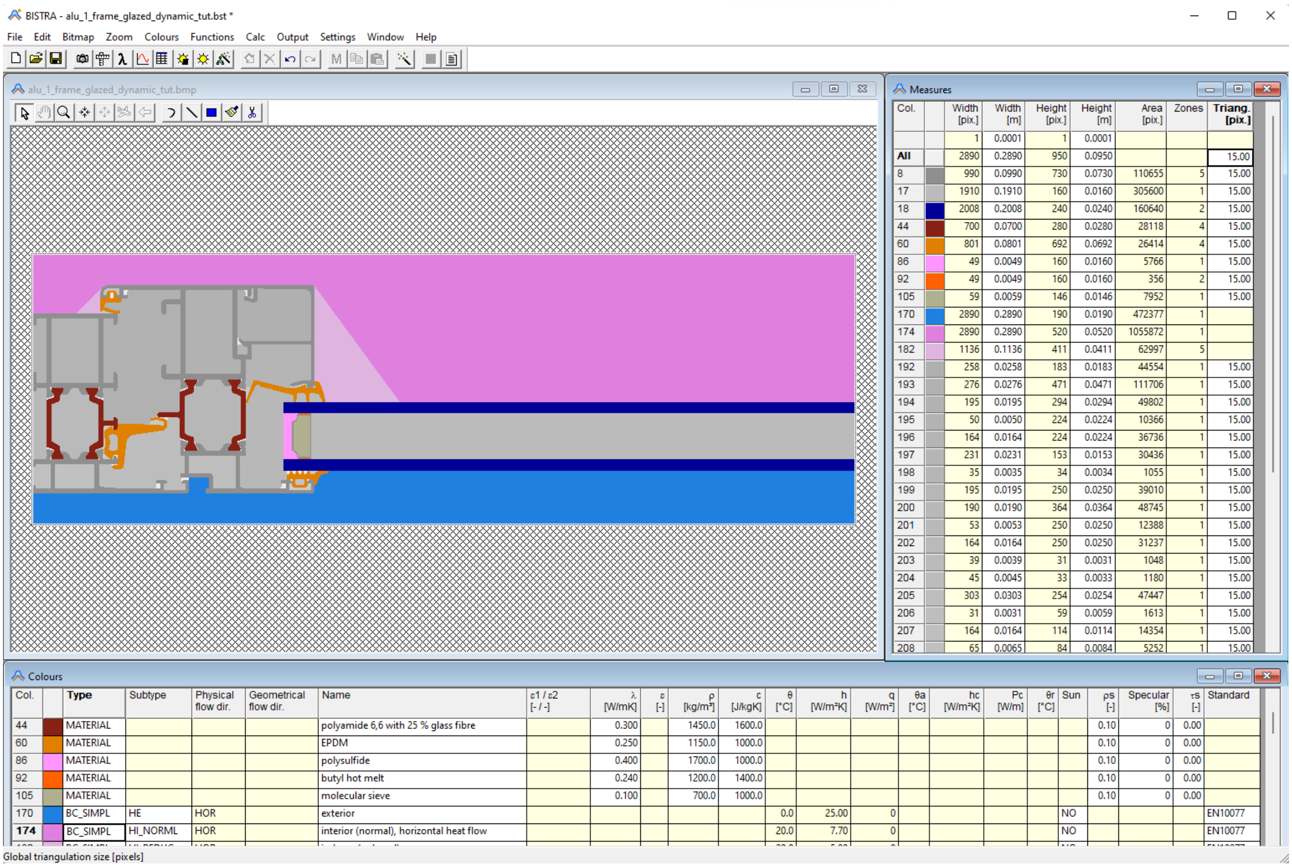
The tutorials illustrates how to calculate the dynamic temperature field, the maximum temperature within the frame and glazing panes and the maximum temperature differences in the two glazing panes during this day.



[1] BISCO Tutorial BSCa-Thermal transmittance of a window profile according to EN ISO 10077-2
[2] BISCO Tutorial BSCb - Linear thermal transmittance of a glazing spacer according to EN ISO 10077-2

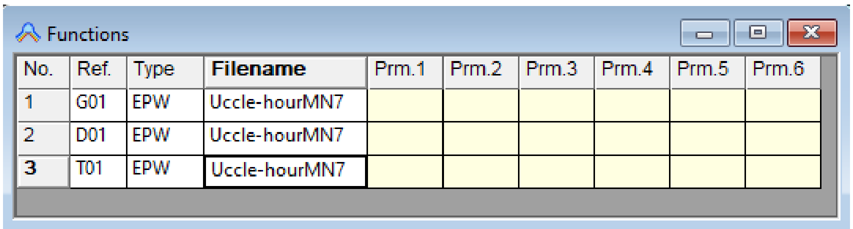
3. Getting started

- Start BISTRA and open the BISCO file alu_1_frame_glazed.bsc from the directory ...\Documents\Physibel\Bistra5\Tutorials, using the menu command *File → Open...*.
  Note: The extension of a BISTRA data file is .bst, but BISTRA can also read BISCO data files (with extension .bsc, chosen from the field "Files of type" in the "Open" dialog box).
- The bitmap size of alu_1_frame_glazed.bmp is 2890 x 950 pixels, with a pixel size of 0.1 mm.
- The triangulation size in BISCO tutorial BSCb was set to 5 pixels. For this dynamic simulation a somewhat bigger triangulation size is recommended. Adjust the global triangulation size to 15 pixels (top right in Measures Window)
- Save the BISTRA file under a different name: *File → Save as...*
  (e.g. alu_1_frame_glazed_dynamic.bst)



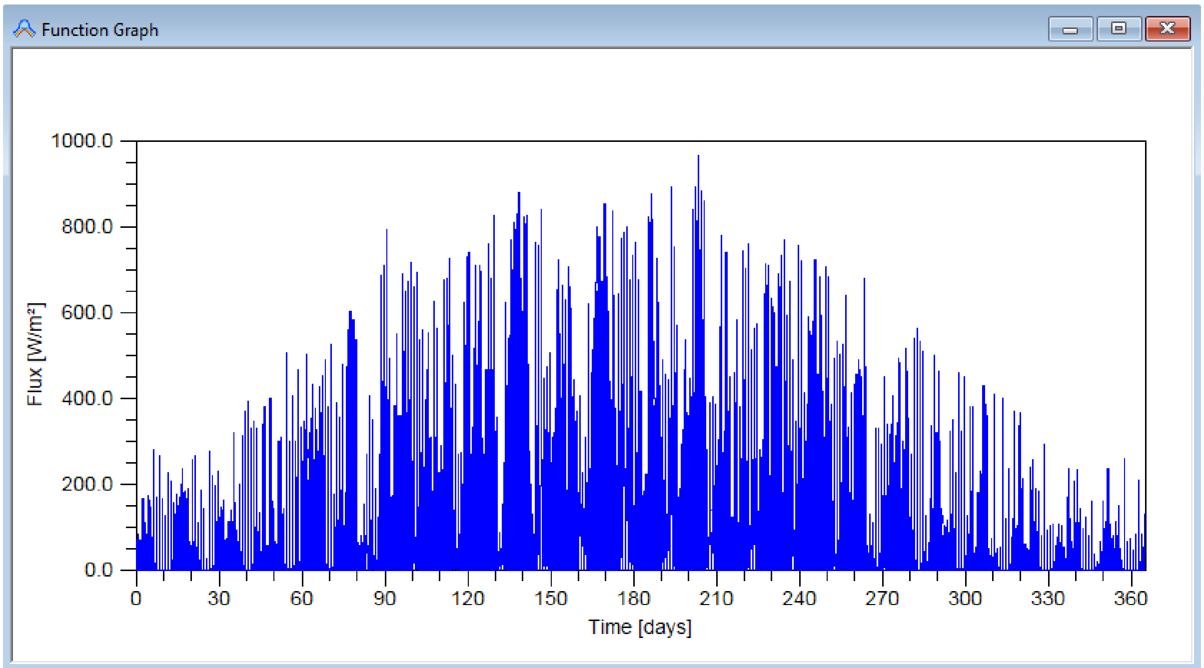
4. Weather data

- Open the **Functions window** (*Edit → Functions*).
- Add a new Function: *Edit → Insert Row.*
- For this tutorials we will create 3 functions for which we use the Type EPW:
  - G01: horizontal global solar radiation
  - D01: horizontal diffuse solar radiation
  - T01: temperature

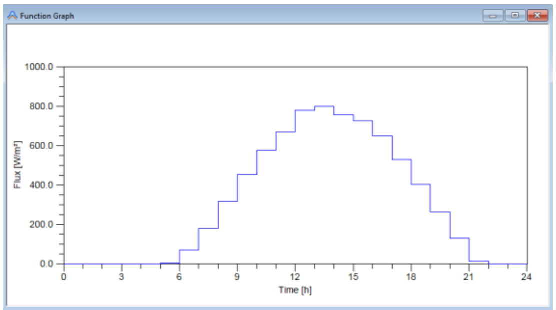


No.	Ref.	Type	Filename	Prm.1	Prm.2	Prm.3	Prm.4	Prm.5	Prm.6
1	G01	EPW	Uccle-hourMN7						
2	D01	EPW	Uccle-hourMN7						
3	T01	EPW	Uccle-hourMN7						

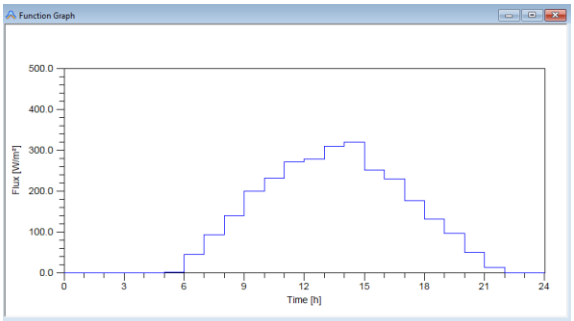
- The first function with reference G01 refers to the horizontal global solar radiation data for Uccle.
- A function reference consists of a letter which refers to the function type (here "G" = horizontal global solar radiation) and a two-digit sequence number.
- The **Function Graph window** shows the current function G01.
  The time axis shows all days of the year with the origin (abscissa 0) at day number 167 (= June 16th), as defined in the Calculation Parameters dialog box (*Edit → Calc Parameters...*, day number at start of calculation = 167, see section 0).

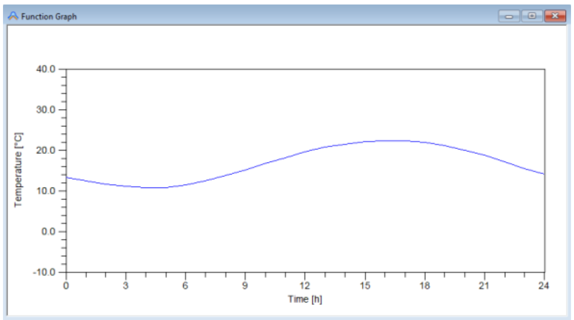


- *Functions → X Scale...* and select "Calculation time" as scope.



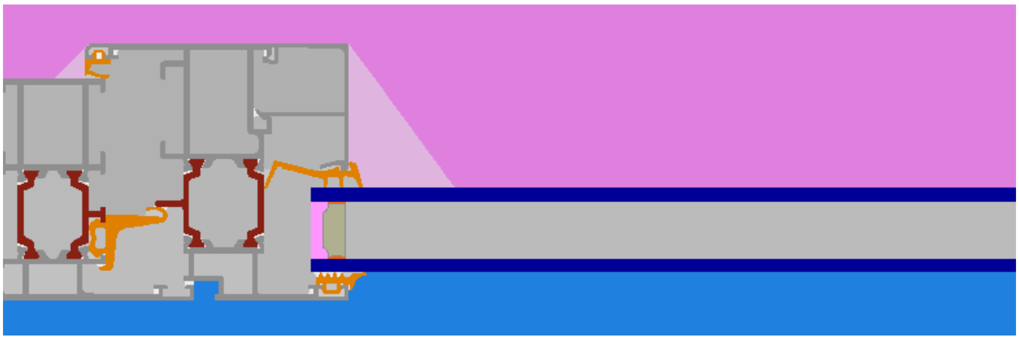
- The function "D01" is used for the creation of the horizontal diffuse solar radiation data of Uccle (see picture below left). The function "T01" shows the air temperature of Uccle (see picture below right).



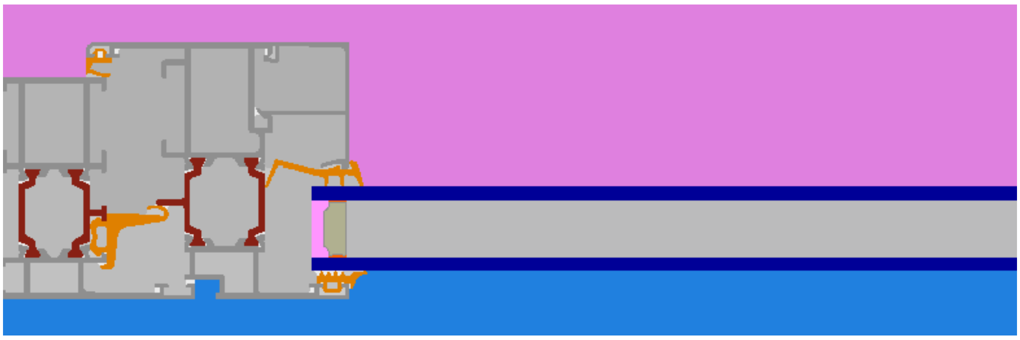


5. Boundary conditions

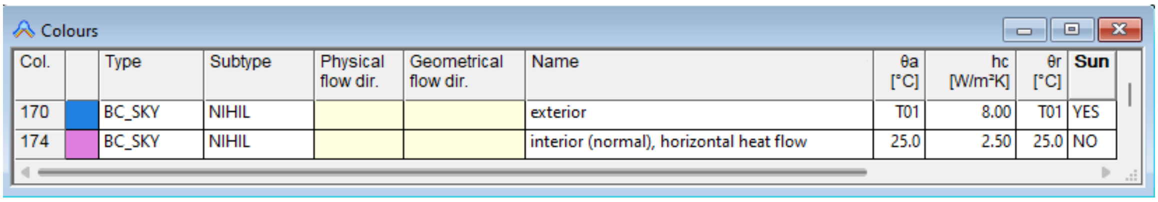
- In the **Colours window** boundary conditions can be defined. When loading the alu_1_frame_glazed.bsc 3 boundary conditions with the type BC_SIMPL (global surface coefficient) are included (according to the rules defined in EN ISO 10077-2):
  - Colour 174: 20°C h=7.7 W/(m².K)
  - Colour 182: 20°C h=5 W/(m².K) (reduced surface coefficient in corners)
  - Colour 170: 0°C h=25 W/(m².K)



- For the dynamic calculations including solar radiation the boundary conditions will be switched to the type BC_SKY, taking into account detailed radiation. For this reason there is no need anymore to use the reduced global surface coefficient linked to colour 182.
- To change colour 182 to colour 174: Activate Colour 182 by selecting it with a left mouse click in the bitmap or select the corresponding row in the **Colours window**. *Bitmap → Change Colour... (F5)* and fill in 174 and press OK.



- The inside environment is located at the top of the bitmap (colour number 174). It is modelled as type BC_SKY with constant air temperature and radiative temperature (= 25°C). The convective heat transfer coefficient hc = 2.5 W/(m².K) (cf. EN ISO 13792). The zone is marked as non-solar zone (sun = NO, in column "Sun" in **Colours window**).
- The outside environment is located at the bottom of the bitmap (colour number 170). It is modelled as BC_SKY with air temperature and radiation temperature referring to the function with reference T01 as defined in the **Functions window.** The convective heat transfer coefficient hc = 8.0 W/(m².K) (cf. EN ISO 13792). The zone is marked as solar zone (sun = YES, in column "Sun" in Colours window).



Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	θa [°C]	hc [W/m²K]	θr [°C]	Sun
170		BC_SKY	NIHIL			exterior	T01	8.00	T01	YES
174		BC_SKY	NIHIL			interior (normal), horizontal heat flow	25.0	2.50	25.0	NO

- It is important to switch the type BC_SIMPL to BC_SKY. The BISTRA solar processor then considers reflected solar radiation. If it was BC_SIMPL, all reflected radiation would be lost (because no detailed radiation is considered for BC_SIMPL).
- If the object surface is transparent (see following section 6.a), the amount of transmitted radiation is calculated from the remainder of solar radiation (after subtraction of reflection) and the transmission factor of the object colour in contact to the solar zone, and transferred to the opposite side of all adjacent transparent layers (colours of type MATERIAL or EQUIMAT). The zone at this other side should be a view factor zone (type BC_FREE, BC_SKY, BC_NOSKY, TRANSMAT), otherwise (type BC_SIMPL, BC_FRE_S) the transmitted radiation is lost.

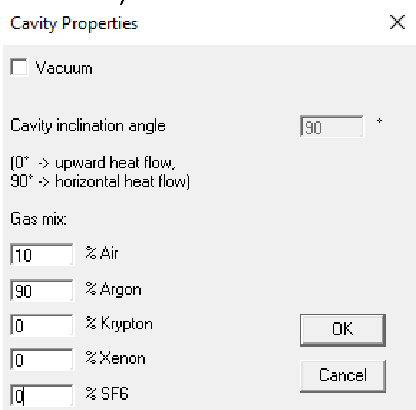
6. Thermal material properties

The **Colours window** also defines the material properties of the different colours in the bitmap. BISTRA materials (and equivalent materials) have, in addition to BISCO materials, thermal capacity properties (material density ρ in kg/m^3 and specific heat c in J/(kg.K)), and radiative properties. Special attention is given in this section to the properties of the glazing cavity and the radiative properties of the glazing panes.

a. Glass cavity according to EN 673

The glazing cavity (colour 17) is as a 90% filled argon space modelled with the type TRANSMAT (with gas properties in line with EN 673).

- Change the Type of Colour 17 in the **Colours window** to TRANSMAT.
- Change the corresponding standard (last column) to EN 673.
- Make sure that the geometrical (heat) flow direction is Y.
- The thermal conductivity field in the **Colours window** will turn red.
- Double click in this thermal conductivity field to define the cavity's properties:



- The equivalent thermal conductivity (considering convection) will now be calculated according to EN 673.
  Note: With a TRANSMAT type the infrared radiation across the cavity is calculated separately via view factors (see following paragraph)

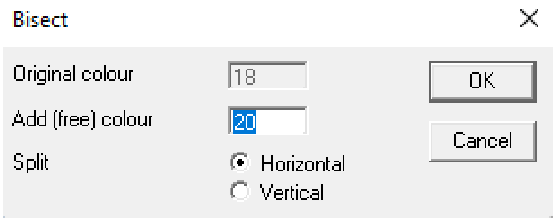
Colours

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	λ [W/mK]	ρ [kg/m³]	c [J/kgK]	Standard
17		TRANSMAT	LAYER	HOR	Y	90%Argon 10%Air	0.019	1.7	567.0	EN673

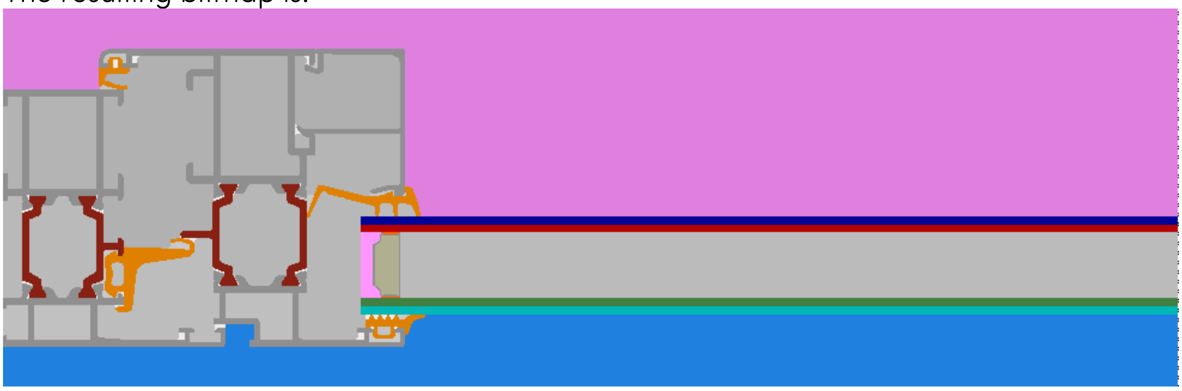
b. Radiative properties of double glazing

The cavity of the double glazing is modelled with TRANSMAT, which is a view factor zone. So the solar properties (reflection and transmission factors) on each side of the individual outer and inner panes must be considered. Therefore, we first split the colour used for the glass (colour 18) in 4 different colours by using the functions '*Bitmap → Split Zones…*' and '*Bitmap → Bisect…*'.

- First split glass (colour 18) in two separate colours: Select colour 18 and split in two  separate zones (*Bitmap → Split Zones…*).
- To further split each glass pane in two colours: select the function Bisect *Bitmap → Bisect…*  and click on the corresponding glass colours with a horizontal split.



- The resulting bitmap is:

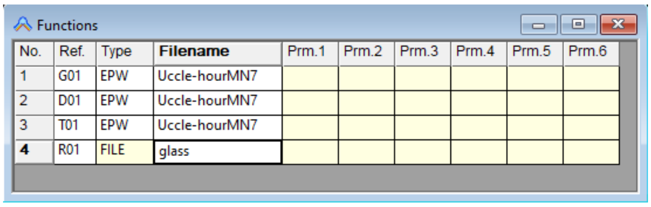


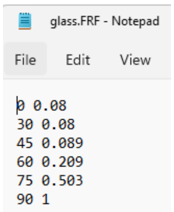
The next step is linking the radiative properties of the glass to the corresponding side of the glass via the bitmap colours in the **Colours window**.

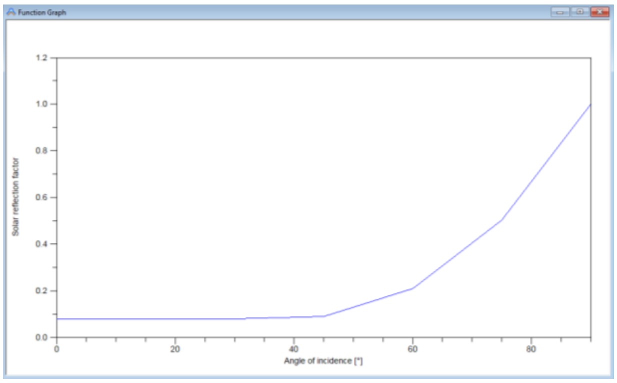
The double glazing unit consisting of two panes of 4 mm enclosing 16 mm space filled with argon (90%) with following properties is considered:

	Side 1				Side 2			
	τ_0	ρ_0	α_0	ε_{IR}	τ_0	ρ_0	α_0	ε_{IR}
Glass 1 (outside)	0.83	0.08	0.09	0.837	0.83	0.08	0.09	0.837
Glass 2 (inside)	0.58	0.30	0.12	0.04	0.58	0.24	0.18	0.837

The subscript 0 refers to the incident angle = 0°, i.e. at normal angle of incidence. At the outer surface of the outer pane (glass 1, side 1) we consider an angle dependent reflection factor at the solar zone, defined by a function referred to by "R01" (cf. **Functions window**).







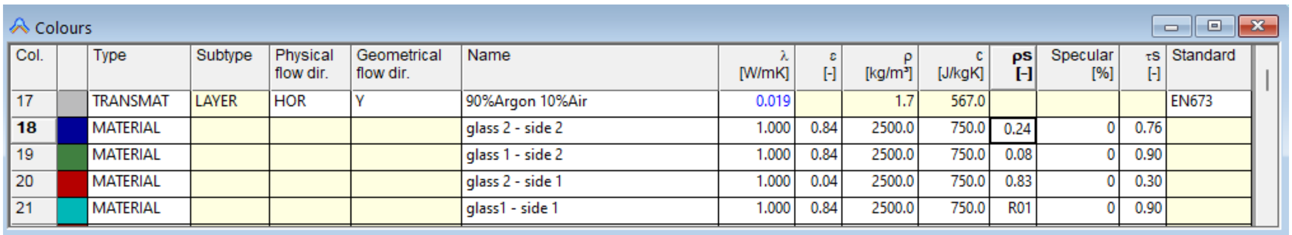
The function R01 is defined by the following points: ρ_0 = ρ30 = 0.08, ρ_{45} = 0.089, ρ_{60} = 0.209, ρ_{75} = 0.503, ρ_{90} = 1.0. All other points are linearly interpolated (as shown in the function graph). The function file 'glass.FRF' is a simple text file (see above figure).

The input value τ_s in BISTRA is the transmission factor after subtraction of the reflection factor.

From $\rho_0 + \tau_0 + \alpha_0 = 1$ and $\tau_s + \alpha_s = 1$ (which holds after subtraction of the reflection factor ρ_s) follows:

$\tau_0 = (1 - \rho_0) \times \tau s$ or $\tau s = \frac{\tau_0}{1-\rho_0}$ and $\rho_0 = \rho_s$

	Colour number	τ_s	ρ_s	ε_{IR}
Glass 1, side 1	21	0.90	0.08 (via R01)	0.837
Glass 1, side 2	19	0.90	0.08	0.837
Glass 2, side 1	20	0.83	0.30	0.04
Glass 2, side2	18	0.76	0.24	0.837



Note: If the cavity of the double glazing was modelled with EQUIMAT (equivalent material), then the solar properties of the global glazing system should be used at the outer and inner surface of the double glazing, because within adjacent material layers no separate reflection and transmission calculations are executed. The solar properties of adjacent material layers are thus not taken into account (their impact should be included in the solar properties of the first adjacent layer hit by the solar radiation). These solar properties of the glazing system as a whole are usually available from the glazing manufacturers.

7. Solar data

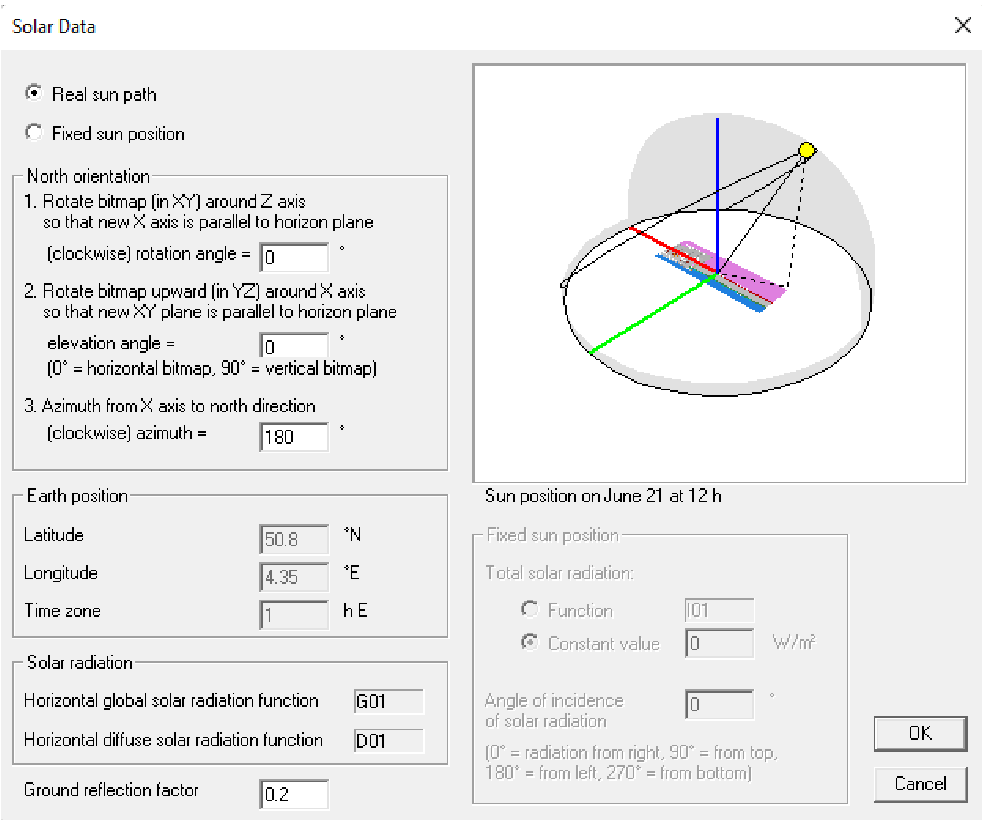
Upon opening the Solar Data dialog box (*Edit → Solar Data...*), the user can choose to simulate a real sun path or perform a simplified simulation with a fixed sun position. A real sun path is selected for this tutorial. 

The bitmap must then be positioned into the horizontal coordinate system ("North orientation"). This is a 3D coordinate system with the local horizon as fundamental plane XY. The X axis points to the north, the Y axis points to the west, the Z axis points to the zenith. The coordinate transformation (from 2D bitmap XY into 3D horizontal coordinate system XYZ) is defined in the Solar Data dialog box.

The first two angles define the transformation from the bitmap X_bY_b into a horizontal coordinate system XYZ without paying attention to the north direction within the local horizon plane.

For a bitmap in a horizontal plane, i.e. representing a horizontal section view (as our example) the first two angles equal 0°.

The third angle defines the north direction within the local horizon plane. Change the value to 180° to orientate the façade to the West.



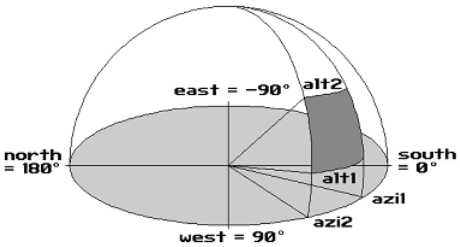
The position of the bitmap in the horizontal coordinate system can be checked within the Solar Data dialog box (for the sun position on June 21 at 12h). It is possible rotate the figure with the left mouse.

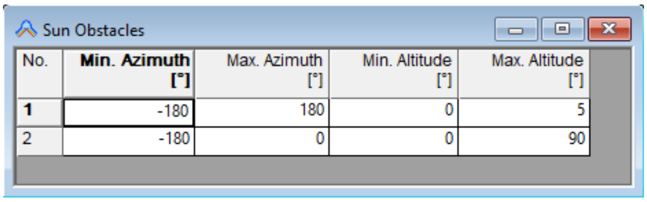
The geographical location (latitude, longitude and time zone) are copied from these climate data files, and the input is not required in the Solar Data dialog box (the corresponding input fields are greyed).

8. Sun Obstacles

A sun obstacle is a spherical region on the sky hemisphere in the horizontal coordinate system in which the sun is blocked by other objects. Sun obstacles are defined in the **Sun Obstacles window** (*Edit → Sun Obstacles*).

A new row can be inserted in the **Sun Obstacles window** via *Edit → Insert Row* .




Sun Obstacles

No.	Min. Azimuth [°]	Max. Azimuth [°]	Min. Altitude [°]	Max. Altitude [°]
1	-180	180	0	5
2	-180	0	0	90

Each sun obstacle is a spherical rectangle defined by a minimum and maximum azimuth (clockwise angle with origin in the south, and ranging from –180° up to 180°) and minimum and maximum altitude (between 0° and 90°).

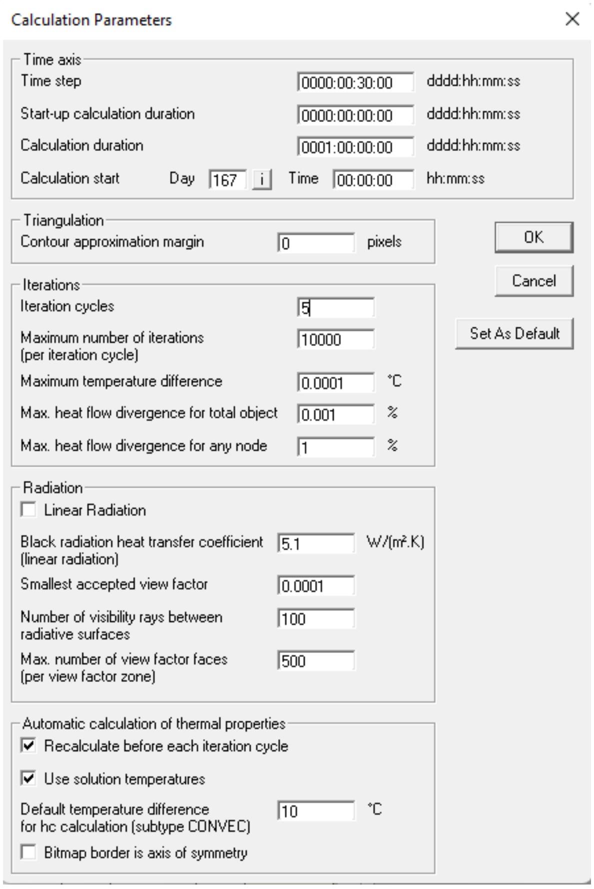
The first sun obstacle is a zone around the horizon up to 5° high. This obstacle is by default present for each new BISTRA data file to avoid numerical rounding errors for low sun positions.

The second sun obstacle corresponds to the interior side of the building casting a shadow.

9. Calculation parameters

The following dynamic calculation parameters are set in the Calculation Parameters dialog box (opened with *Edit → Calc Parameters...*):

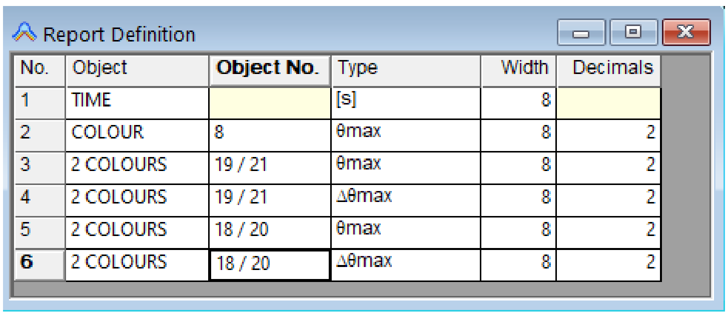
- Time step interval: 30 minutes.
- Start-up calculation duration (to get dynamic start values): 0 seconds (i.e. no start-up).
- Calculation duration: 1 day.
- Day number at start of calculation: 167 (= 16th June), which marks the starting point in the weather data files (which contain 1 year of 365 days).



10. Report definition

The **Report Definition window** (*Edit → Report Definition*) contains the report items that will be included in the text report output. Adding a new row to define an output: *Edit → Insert Row*

The text report tabulates the report values at a regular time step interval (here every time step, cf. setting in *Calc → Report Frequency...*).


Report Definition

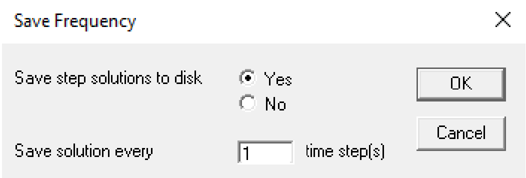
No.	Object	Object No.	Type	Width	Decimals
1	TIME		[s]	8	
2	COLOUR	8	θmax	8	2
3	2 COLOURS	19 / 21	θmax	8	2
4	2 COLOURS	19 / 21	Δθmax	8	2
5	2 COLOURS	18 / 20	θmax	8	2
6	2 COLOURS	18 / 20	Δθmax	8	2

Include following items:

- Time, using the format seconds (s).
- Maximum temperature (θ_{max}) of the window frame (colour 8)
- Maximum temperature (θ_{max}) in the inner glass pane (colours 18/20).
- Maximum temperature difference ($\Delta\theta_{max}$) in the inner glass pane (colours 18/20).
- Maximum temperature (θ_{max}) in the outer glass pane (colours 19/21).
- Maximum temperature difference ($\Delta\theta_{max}$) in the outer glass pane (colours 19/21).

11. BISTRA calculation

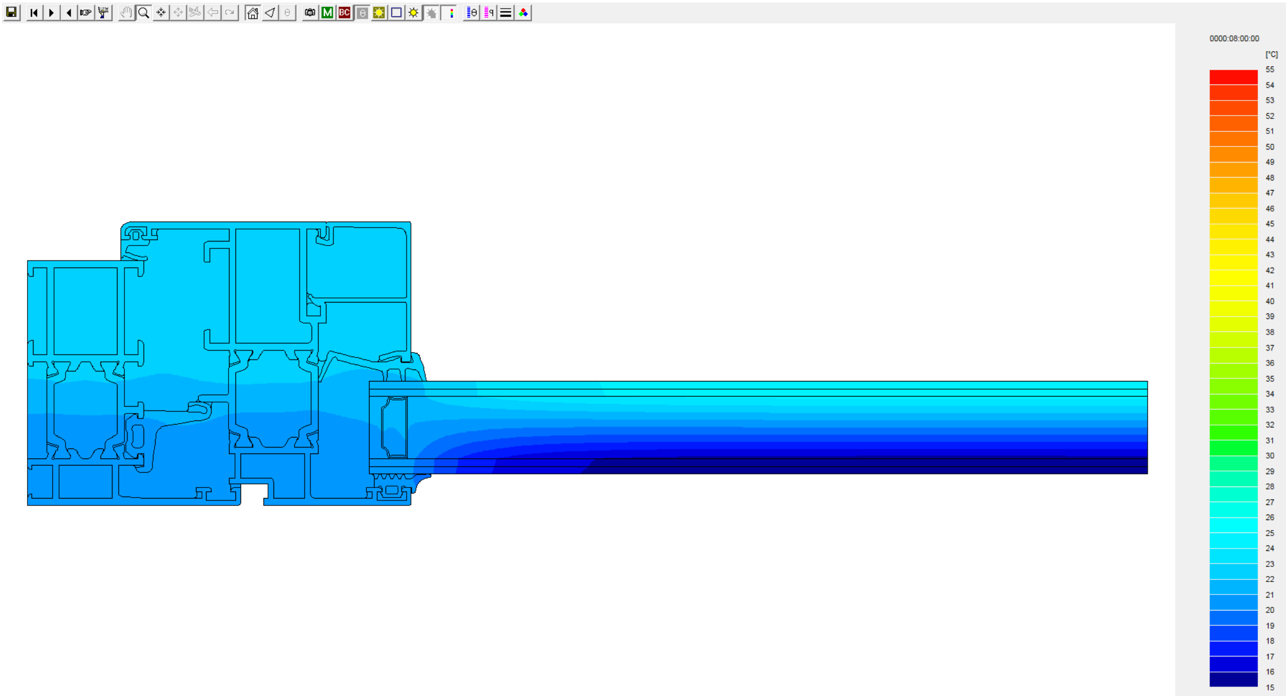
- Before starting the calculation, request that step solutions (.sol files and .sfx files) are saved during the calculation, so that afterwards graphic animations can be made in the graphic output section (*Output → Graphic Output*).
  For this example every single .sol file has a file length of 128 Kbytes, a single .sfx file 15.5Kbytes.
  Open the Save Frequency dialog box with *Calc → Save Frequency...* to view the settings.



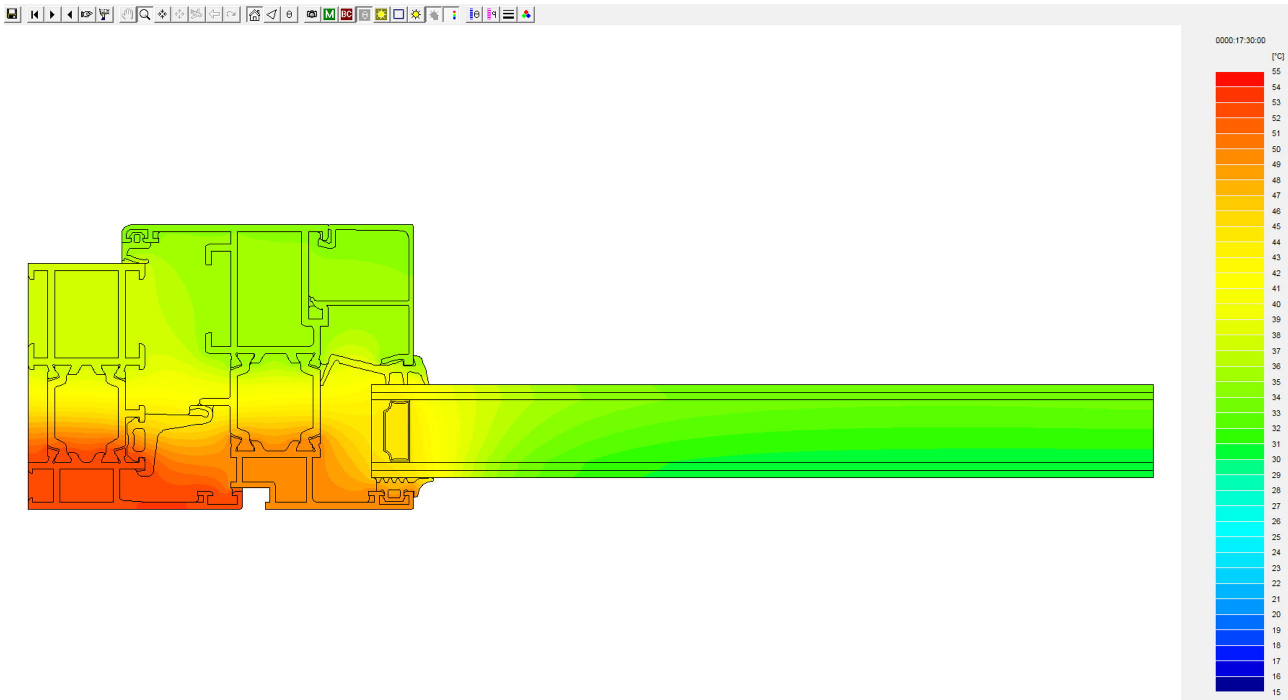
- Now start the BISTRA calculation with *Calc → Calc System.*
  If a triangulation file (wooden_frame.tri) for the given BISTRA data file (alu_1_frame_glazed_dynamic.bst) already exists, the user is asked to recalculate the triangulation. A recalculation of the triangulation can be necessary after a triangulation size is modified (in the **Measures window**) or a bitmap colour is modified.
- After the triangulation the iterative solution starts.
  During the calculation a calculation monitor is displayed showing the progress (with current time step, current iteration step, stopping criteria, number of nodes, triangles, view factors).
- For the given example, with time steps every 30 minutes and a global triangulation size of 15 pixels, the calculation will take about 15-30 seconds. When the simulation is finished the calculation monitor will disappear.
- After the calculation, output is available through the submenus via *Output → Graphic Output* or *Output → Text Output.*

12. Graphic output

- Go to *Output → Graphic Output*
- Select the view option *View → Fill Temperatures.*
- The temperature range (15°C – 55°C) and the temperature increment (1°C) can be changed in the Temperature Range dialog box, opened with *Settings → Temperature Range....*
- Get the results at the time step at 8 a.m. (*Animate → Go To...*, enter 0000:08:00:00).

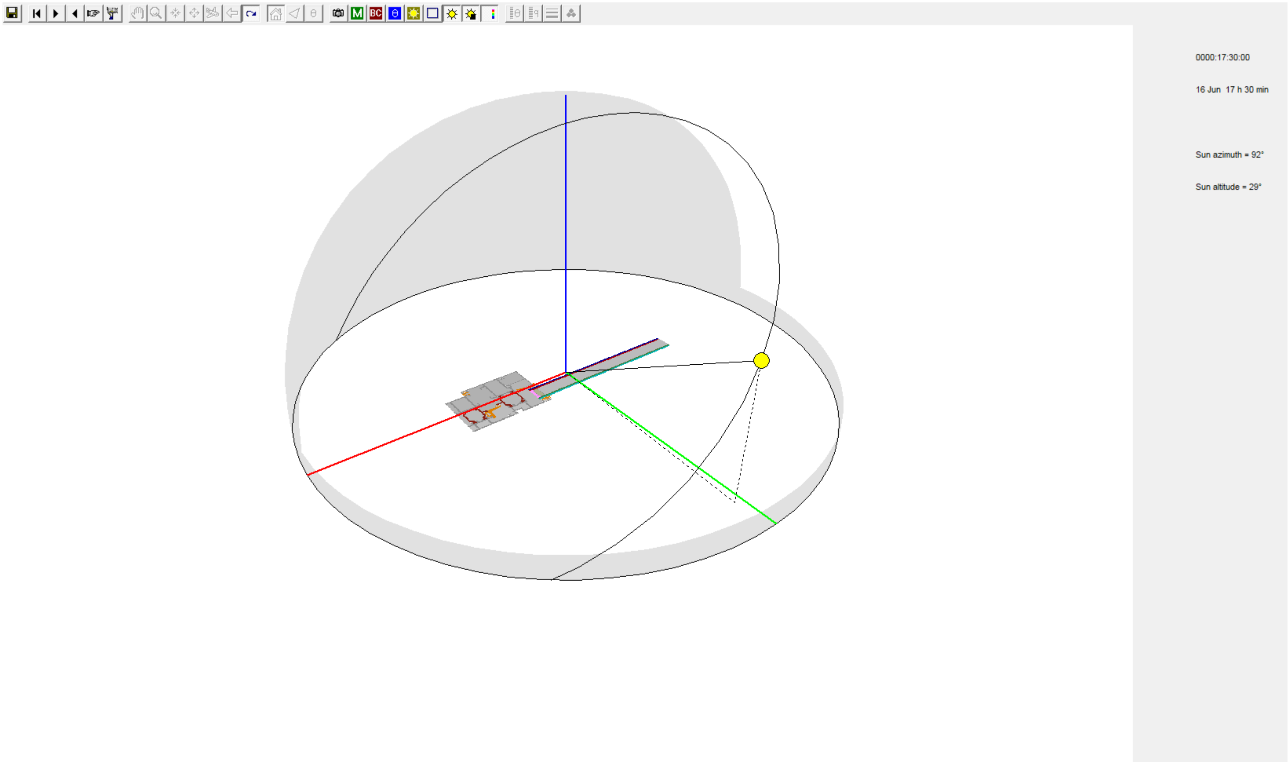


- At 17.30h we get high temperatures on the West facade.

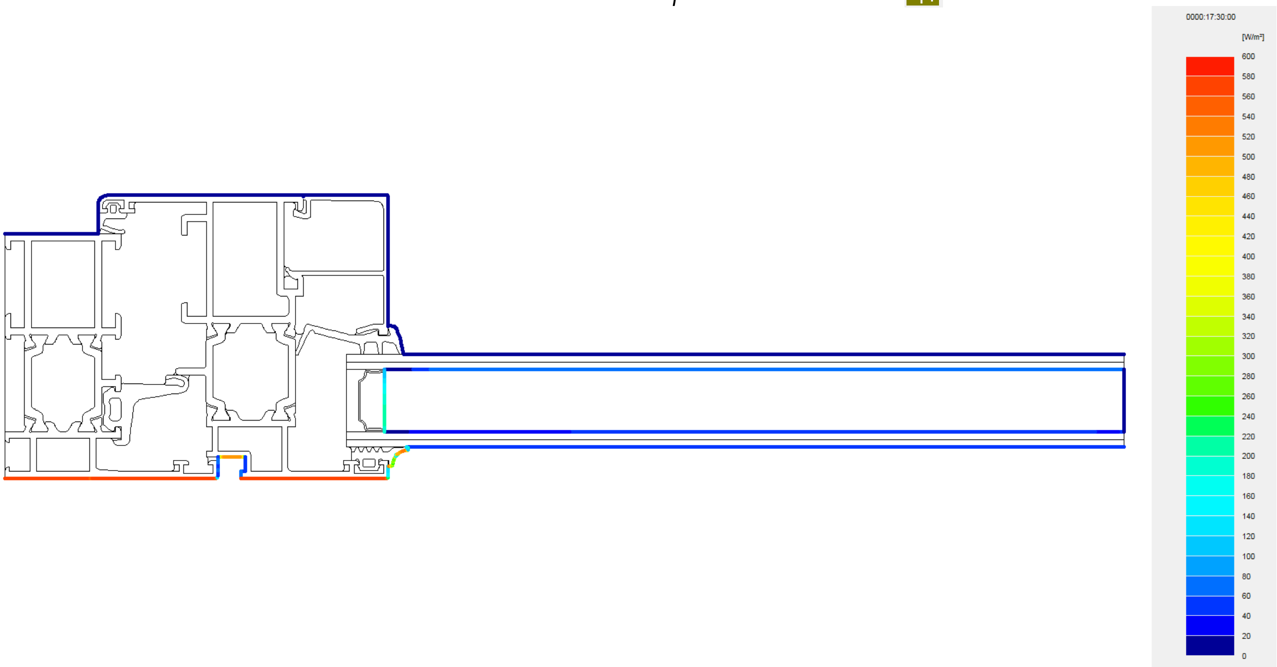


- Move the mouse over the image to get the temperature at the mouse point displayed in the status bar at the bottom of the BISTRA window.

- To visualise the sun position: *View → Sun position*

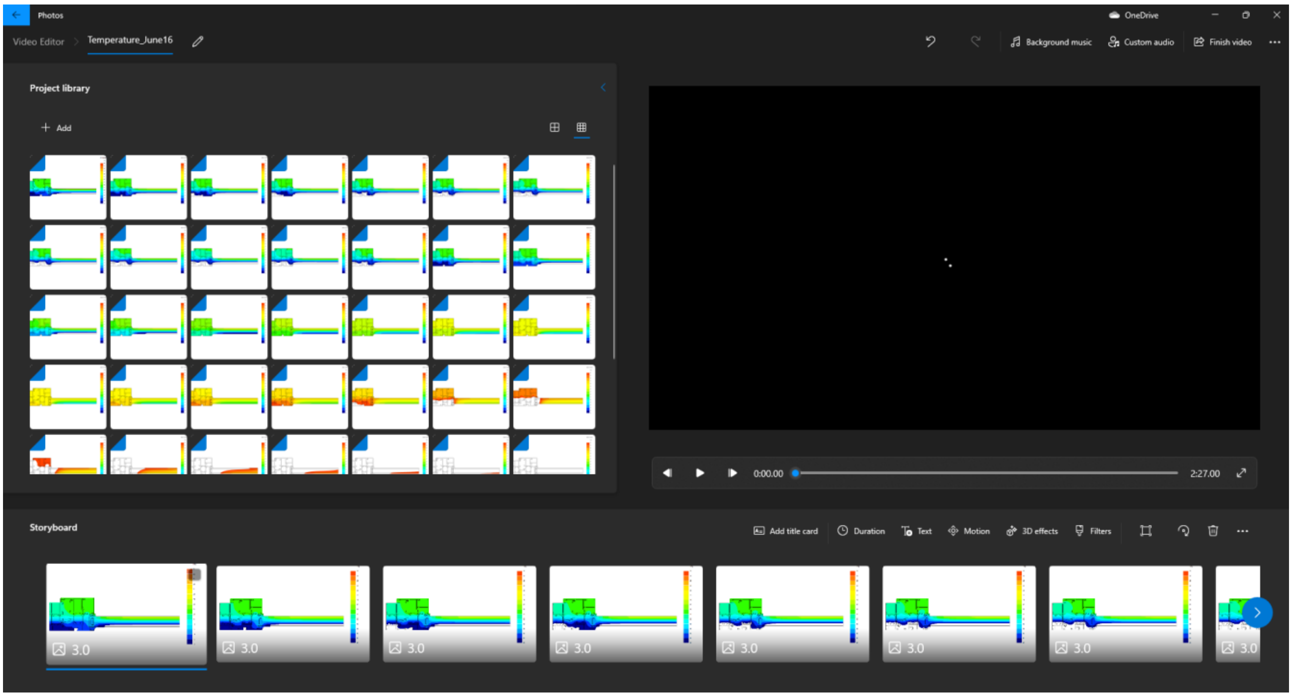


- The absorbed solar radiation: *View → Absorped Solar Fluxes*



- Go to *File → Exit* to quit the **Graphic Output window**.

- To make an animation of the field temperatures with Windows Video Editor:
    - *Prepare the animatin images in BISTRA:*
        - *View → Fill Temperatures.*
        - *File → Save Animation Images…*
    - Open Windows Video Editor, start new video project (e.g. Temperature_June16)
        - Add the generated Animation Images to the Project library in Video Editor and drag them thereafter to the storyboard.
        - Select all images in the storyboard and adjust the duration.
        - Finish video to export in .mp4



13. Text output

- Go to *Output → Text Output*
- Select *View → Time Step Results*, and *Edit → Go To...*, enter 0000:12:00:00. The text window shows the time step results at 12 a.m.

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BISTRA Calculation Results

BISTRA data file: alu_1_frame_glazed_dynamic.bst
Number of nodes = 7667
Number of viewfactors = 0

Time step 0000:12:00:00

Heat flow divergence for total object = 7.45974e-07 %
Heat flow divergence for worst node = 0.778641 %

Col. Type       Name                            tmin      tmax        ta   flow in  flow out
                                                [°C]      [°C]      [°C]     [W/m]     [W/m]
   8 MATERIAL   aluminium                      26.19     29.28
  17 TRANSMAT   90%Argon_10%Air                21.92     27.82                 3.64      0.01
  18 MATERIAL   glass_2_-_side_2               26.29     27.58
  19 MATERIAL   glass_1_-_side_2               21.90     27.92
  20 MATERIAL   glass_2_-_side_1               26.31     27.69
  21 MATERIAL   glass1_-_side_1                21.86     27.99
  44 MATERIAL   polyamide_6,6_with_25_%_g      26.23     29.25
  60 MATERIAL   EPDM                           26.19     29.25
  86 MATERIAL   polysulfide                    27.57     27.89
  92 MATERIAL   butyl_hot_melt                 27.53     27.80
 105 MATERIAL   molecular_sieve                27.77     27.82
 170 BC_SKY     exterior                       21.86     29.28                 2.75      5.07
 174 BC_SKY     interior_(normal),_horizo      26.19     27.19                 0.00      2.68
 192 EQUIMAT                                   26.20     26.22
 193 EQUIMAT                                   26.19     27.74
 194 EQUIMAT                                   26.20     26.23
 195 EQUIMAT                                   26.52     26.54
 196 EQUIMAT                                   26.52     26.54
 197 EQUIMAT                                   26.22     26.79
```

- Select *View → Report Output* to get the report item values per time step for the report items defined in the **Report Definition window** (cf. section 10)

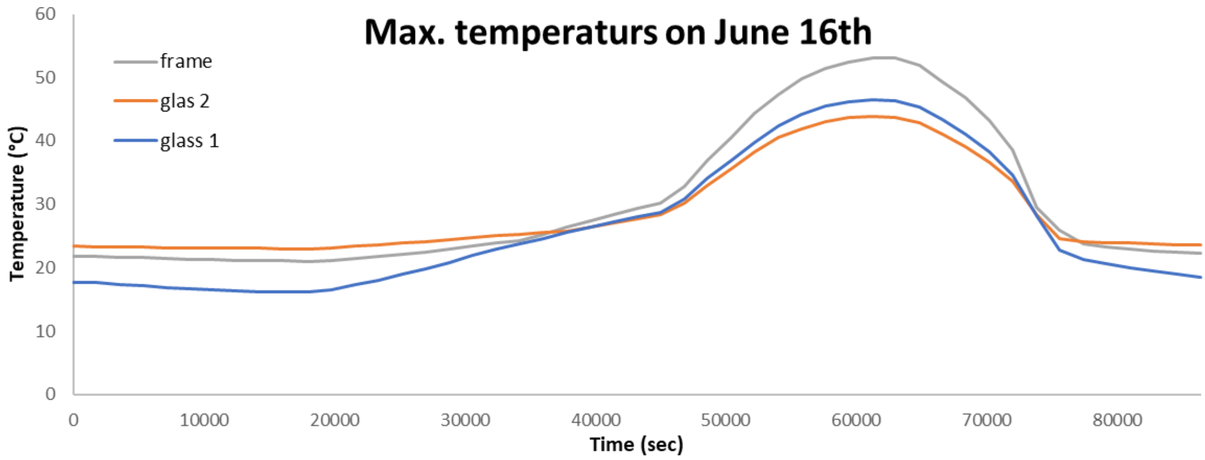
```
File  Edit  View  Settings

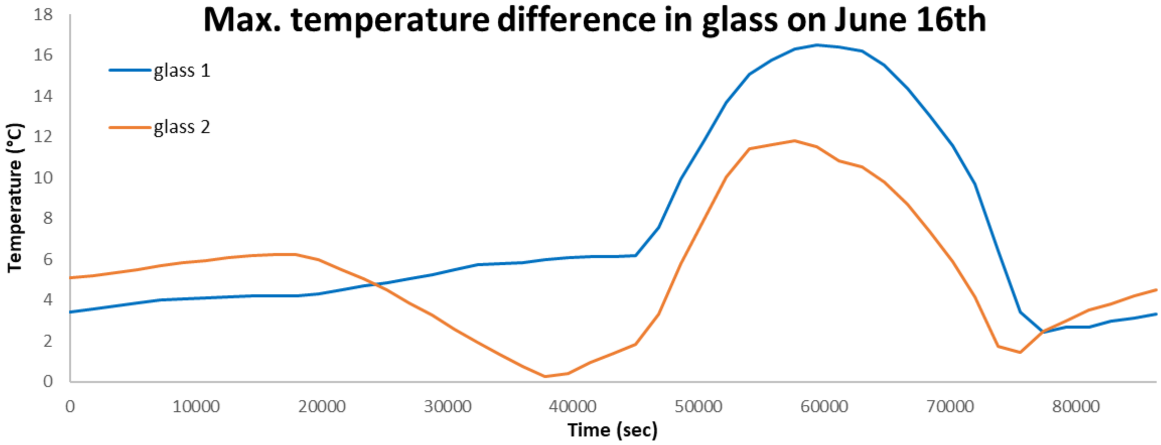
BISTRA data file: alu_1_frame_glazed_dynamic.bst

Column 1: Time [s]
Column 2: Colour 8 (aluminium) - Maximum temperature [°C]
Column 3: Colours 19 (glass 1 - side 2) and 21 (glass1 - side 1) - Maximum temperature [°C]
Column 4: Colours 19 (glass 1 - side 2) and 21 (glass1 - side 1) - Maximum temperature difference [°C]
Column 5: Colours 18 (glass 2 - side 2) and 20 (glass 2 - side 1) - Maximum temperature [°C]
Column 6: Colours 18 (glass 2 - side 2) and 20 (glass 2 - side 1) - Maximum temperature difference [°C]

       0     21.74     17.70      3.41     23.36      5.11
    1800     21.72     17.61      3.54     23.34      5.17
    3600     21.66     17.39      3.72     23.29      5.32
    5400     21.55     17.13      3.85     23.23      5.50
    7200     21.44     16.87      4.00     23.17      5.68
    9000     21.32     16.63      4.06     23.12      5.85
   10800     21.23     16.47      4.11     23.08      5.96
   12600     21.15     16.32      4.17     23.05      6.07
   14400     21.09     16.19      4.22     23.02      6.16
   16200     21.04     16.11      4.21     23.00      6.22
   18000     21.02     16.13      4.19     23.00      6.22
   19800     21.11     16.57      4.29     23.16      5.97
   21600     21.38     17.34      4.51     23.41      5.51
   23400     21.73     18.07      4.68     23.62      5.03
```

- The data can be exported to any spreadsheet application to visualize the results.





- Press the <Esc> key or go to *File* → *Exit* to quit the **Text Output window**.