BISTRA

computer program to calculate
two-dimensional transient heat transfer
in free-form objects

version 5.0

physibel

This manual is intended as a complete reference for the BISTRA application.

Documented software application examples, tutorials & exercises, short practical guides (How To's) and validation cases are accessible via the Physibel Knowledge base (www.physibel.be/en/knowledge).

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CHAPTER A INTRODUCTION

A.1. Program overview

BISTRA is a thermal analysis program for transient heat transfer in two-dimensional free-form objects. BISTRA is the extension for time-dependent boundary conditions of the steady-state program BISCO.
As in BISCO, the geometry is defined by a coloured picture in bitmap format (A.1.1). BISTRA requires data input for the association of the bitmap colours with the physical properties of materials and boundary conditions.
BISTRA calculates a triangulation for the material colours (A.1.2). The system nodes are located in the triangle vertices. The temperatures in the nodes are calculated, from which all heat flows can be derived.
BISCO data files can be taken as starting data in BISTRA.

The time-dependent boundary conditions are described with functions, which can be built-in functions based on variable parameters, external user-defined functions (saved as separate files) based on function values given at a fixed time interval, or standardised weather files
The thermal conductivity and specific heat of any material can refer to temperature dependent functions, which is useful in fire simulations where broad ranges of temperatures can occur. These functions are described in external text files using node points (abscissa: temperature, ordinate: thermal property value), between which linear interpolation is used.

BISTRA contains a solar processor based on direct and diffuse solar radiation weather data. The sun path can be visualised in relation to the object. Solar absorption powers in all nodes per time step are calculated based on solar properties (reflection and transmission factor) of the materials and the solar irradiation data. The effect of shadowing and diffuse and specular reflection can be examined in detail.

BISTRA allows the calculation of ventilation.

BISTRA allows creating time-dependent graphic animations of the temperature field in the studied object. Alphanumeric lists of time functions of temperatures, heat flows, and other variables can be made.

BISTRA always includes the RADCON module (which allows separate calculation of radiation using view factors and convection, see Chapter H), because it is essential for fire simulation or when using the solar processor.

A.1.1. Bitmap (BMP) file

The input of BISTRA needs a 2D raster image (also called bitmap) in colour.
The pixels of this bitmap can have 256 (= 2^8) different colours.
The bitmap is stored in a 256-colours (or 8-bit) BMP file (Microsoft Windows Bitmap).
Each colour in the bitmap will be linked to a different (homogeneous) material or boundary condition, having its own thermal properties.
Each pixel of the bitmap is a square with side equal to a fixed physical length (= pixel size), to be defined in the **Measures window** of BISTRA.

A 256-colours BMP file contains a header section and an image data section.

The header section contains the definition of the 256 possible colour values in the bitmap (called the colour palette). Each colour of the colour palette is defined by its red, green and blue components (or RGB values). Each colour component is an integer between 0 and 255 (having the range of 1 byte), which defines the intensity of that colour (0 = dark, 255 = full intensity). Using this colour system 256 x 256 x 256 different colour values can be created. From this colour space only a subset of 256 colours can be saved in the colour palette.

In BISTRA the individual colour values are shown in the **Colours window**. Each row in this window shows a colour number (between 0 and 255), which is the index into the colour palette, followed by the corresponding colour value from the colour palette.
By default BISTRA shows only the colours present in the actual loaded bitmap (which number is normally smaller than 256). To show all 256 possible colour values of the colour palette execute the command *Colours → List All* (which is only enabled when the **Colours window** is active).
The colour value for each colour number can be edited from the **Colours window** (by editing the RGB values).
A BMP file generated in BiscoDxf or BISCO by default uses the colour palette of the ColourPalette.bmp file of BISCO. BISTRA can load the colour palette of another bitmap into the current bitmap (see B.6, *Bitmap → Load Palette...*).

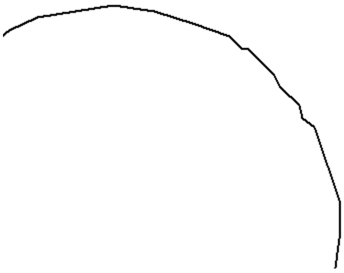
The image data section of a 256-colours BMP file contains the pixel values of the bitmap, row by row (or scanline by scanline). Each pixel value is a colour number (between 0 and 255), which is an index into the colour palette.
BISCO can read either uncompressed or (run-length encoded) compressed 256-colours BMP files. An uncompressed BMP file contains the pixel values of all individual pixels, while a compressed BMP file clusters pixel intervals of equal pixel value.

In BISCO the image data are shown in the **Bitmap window**. When the **Bitmap window** is active, the bitmap coordinates (X and Y) and corresponding pixel value (colour number) of the pixel under the mouse cursor are displayed in the program status bar (at the bottom of the BISTRA application window).

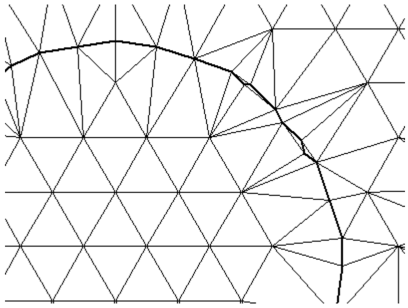
A.1.2. Triangulation

BISTRA has a set of functions to clean up the bitmap up for a thermal calculation (see B.7). The raster image is then converted into a vector image, in which the staircase pixel boundaries are converted to approximated contour lines. The space besides the contour lines are triangulated using a balanced mesh with preferably equilateral triangles.
The desired triangulation mesh size per material colour (defined in the **Measures window**) can be modified to improve the calculation quality without increasing too much the total number of nodes.
In most cases a uniform triangulation mesh size for all materials will yield satisfactory results.
The smaller the triangulation mesh size, the better the final calculation precision.

Bitmap
(composed of pixels)



Vector image
(boundary representation)



Triangulation

The vector representation of the triangulation is also better suited to account for the convective heat transfer, because the length of the contact surface between a material and a boundary condition is more precise than the measurements along the rectangular pixel boundaries.

The complete triangulation information (vertices coordinates, triangle definitions per material colour, edge definitions per boundary condition) is saved into a text file (with same file name as BISTRA file and extension .tri).

The vertices of the triangulation mesh are the nodes of the thermal system.

A.2. BISTRA brief history

BISTRA was first developed in 2005 based on the steady-state program BISCO.

- Version 1.0 was ready in December 2005.
- Version 2.0 (March 2009) included the solar processor based on direct and diffuse solar radiation weather data files.
- Simulation of ventilation flows through different zones following user-defined ventilation paths is possible since version 3.0 (January 2011). The ventilation volume flow rates refer to time dependent functions.
- Further development in version 4.0 (July 2017) to harmonise functions with BISCO v11.0.

The detailed version history can be found on the website:
www.physibel.be/en/products/bistra/versions .

A.3. Technical specifications

- BISTRA is a 64-bit Windows program. BISTRA is installed in C:\Program Files (x86)\Physibel\BISTRA5.
  In this folder the executable file is BISTRA.exe.
- The standard version of BISTRA allows a maximum of 500,000 nodes. An add-on feature to calculate an unlimited amount of nodes is available for purchase (feature Unlimited Nodes). The maximum number of nodes then depends on the RAM installed.
- BISTRA relies on OpenGL for use of hardware accelerated graphics.
- BISTRA is protected by either a hardware key, provided by Physibel, or a software licence (A.4).

The Physibel 64-bit programs need several shared libraries (.dll files) from Microsoft.
The Microsoft Visual C++ 2017 Redistributable Package (x64) is included in the installation files of BISTRA, but can also be downloaded from https://support.microsoft.com/en-us/help/2977003/the-latest-supported-visual-c-downloads.

This package installs mfc140.dll and other files in the directory C:\Windows\SysWOW64, required by 64-bit applications developed with Microsoft Visual C++ 2017.

A.4. Licence

The Physibel applications are protected by a licence, to prevent illegal use of the software. This can be either a hardware licence (Sentinel USB key) or a software licence.

A.4.1. Hardware licence

Perpetual licences are protected by a hardware licence (Sentinel USB key). The licence is locked to this dongle. It is strongly recommended to take a financial assurance for loss of the key by theft or any other incidence.

Before BISTRA can be used, the driver (delivered with purchase) for the hardware key needs to be installed. Administrator rights are needed for this installation. It might be necessary to restart your computer after installing the driver.

During use of BISTRA, the dongle needs to be attached to the computer at all times.

A.4.2. Software licence

Subscription licences are protected by a software licence. After first installation of BISTRA, the user needs to activate the licence using the activation code received upon purchase of the software. When first opening BISTRA, the Software Licence Manager will open automatically and prompt the user to activate the licence, or to register in the network floating database, depending on the licence type. The computer needs to be connected to the internet for this licence activation. Cloud-based floating licences are activated every time when opening the application.

After activation, the Software Licence Manager is available from the menu for stand-alone licences:
Help → Software Licence Manager...

Users with a floating network licence can check out a licence from the database for a maximum period of 3 days.
Help → Check out/in floating licence...

The software licence key for BISTRA is linked to the computer where it was activated. When you want to move the application with a stand-alone licence to another computer, you can deactivate the licence in the Software Licence Manager. The licence can then be reactivated on a new computer.

If the Software Licence Manager is unavailable from the application itself, you can also open it from the command prompt. You need to first change directory to the Program Files folder where the application is installed. Then, open the Software Licence Manager with the following command:
QlmLicenseWizard.exe /settings "BISTRA 5.0.lw.xml"

A.5. User Account Control (UAC)

Administrator rights are necessary to install BISTRA on a computer.

The installation of the application is machine-level, meaning all user accounts can access the application after installation.

Each user account has its own copy of the colour database and accompanying BMP file (see F.2), to work with. These files can be found in the user's application data directory (C:/Users/*username*/Appdata/Roaming/Physibel/BISTRA5/).

In case of a software licence, the licence for BISTRA is linked to the computer, but is stored at the user level. Each user account on a computer has to activate the licence in order to have access to the licence.

A.6. Overview of delivered files and file structure

BISTRA is installed (when the user has accepted the default destination) in the folder C:\Program Files (x86)\Physibel.

The following files are installed

Folder	*File*	*Description*
...\Physibel\BISTRA5	BISTRA.exe	BISTRA (64-bit) program
	*.dll, *.pat, *.rgb	Program resources
	QlmLicenseWizard	Software Licence Manager files
...\Physibel\Materials	*.phm	Material databases
...\Physibel\Manuals	BISTRAManual.pdf	BISTRA manual

The colour database file ColourDatabase.bst and accompanying BMP file (see F.2), together with the parameter file BISTRA.prm (see A.10), are installed in C:/ProgramData/Physibel/BISTRA5 (machine-level), and copied to each user account's application data folder when first opening BISTRA (C:/Users/*username*/AppData/Roaming/Physibel/BISTRA5).

A.7. Logging

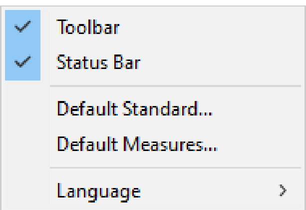
When using BISTRA, information is continuously written to a log file located in the user account's application data folder (C:/Users/*username*/AppData/Roaming/Physibel/BISTRA5). This file contains information that can help for debugging when something went wrong, and also to clarify or elaborate on error or warning messages shown in the application.

A.8. Text convention

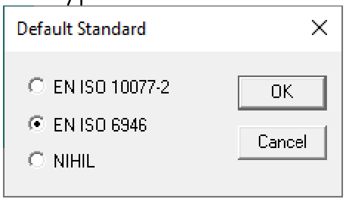
Menu paths are printed in *italic*, with format *Submenu → Command.*
E.g. *File → Open* (Open command in File submenu).

A.9. Program settings

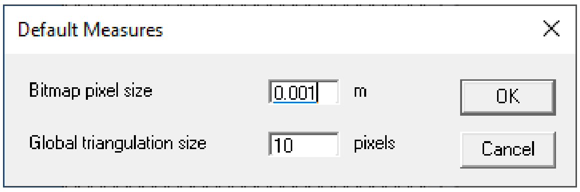
Global program settings are available via the Settings submenu.



- *Settings → Toolbar:* presence of the toolbar giving access to menu commands through icons.
- *Settings → Status Bar*: presence of the status bar at the bottom of the BISTRA application window, containing context depending information.
- *Settings → Default Standard...*: set EN ISO 10077-2, EN ISO 6946 or NIHIL as default standard for the definition of colour types.



- *Settings → Default Measures...*: set the default bitmap pixel size and global triangulation size (see B.9).



- *Settings → Language*: the selected language (English, Dutch, French, German) becomes effective the next time the program is started.

A.10. Program parameters

The global default values (calculation parameters, output parameters, pixel size, triangulation measures, interface language, etc.) are saved in the file BISTRA.prm in the application data folder (C:/Users/*username*/Appdata/Roaming/Physibel/BISTRA5). When the program BISTRA is started, the program parameters are loaded from the parameter file.

The program parameter default values can be changed from several input dialog boxes. When the button “Set As Default” in an input dialog box is clicked, the corresponding program parameters are saved in the program parameter file BISTRA.prm at exiting BISTRA.

CHAPTER B INPUT DATA

B.1. BISTRA input data file

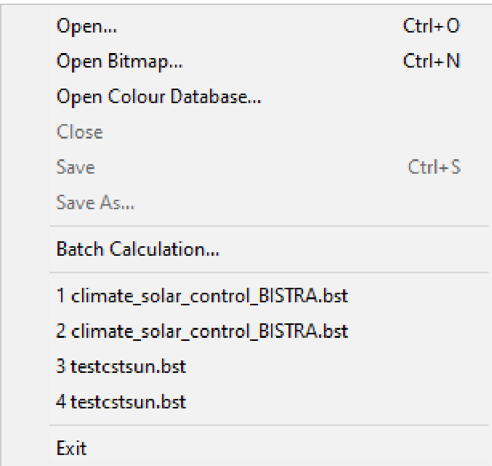
The input data are stored in a BISTRA data file with extension .bst (since BISTRA v2.0) and a Bitmap file with extension .bmp, both in the same directory.
The file syntax of a .bst file is based on the syntax of a BISCO file (extension .bsc), but extended for BISTRA specific features (dynamic material properties, functions, dynamic calculation parameters, report definition).
The BMP file is a 256-colours (uncompressed or run-length encoded compressed) Microsoft Windows Bitmap.
Because the BST file only stores the file name of the corresponding BMP file, both BST and BMP files must be in the same directory. It is a good practice to give both files the same file name.

BISTRA can read BST files and BSC files (using *File → Open...* and choosing the file type).
If a BST file should be read in BISCO, first rename its extension to .bsc, then open the BSC file in BISCO. But all BISTRA properties are lost after saving the (edited) BSC file in BISCO.

B.2. BISTRA start up

When BISTRA is launched, the parameter file BISTRA.prm is read (see A.10) to load global program settings.
Then the colour database ColourDatabase.bst is read (see F.2) to initialise material and surface boundary condition properties of the **Colours window**.
There is no visual feedback in the initial screen of BISTRA to indicate if BISTRA.prm and/or ColourDatabase.bst are not found and thus not read.

B.3. File commands



File → Open...
Opens an existing BST or BSC file by selecting it in the File Open dialog box. The thermal properties, triangulation mesh size, pixel size, calculation parameters and output settings from the selected file are read. The linked BMP file is loaded and displayed in the **Bitmap window**.
Thermal properties from a previous open document (of the current BISTRA session) for colours not present in the new loaded bitmap, remain loaded in memory.

File → Open Bitmap...
Creates a new BISTRA document by selecting an existing bitmap (BMP file).
The new document gets the same file name as the file name of the selected bitmap.
If no document has previously been opened, the default data from ColourDatabase.bst and BISTRA.prm (see B.2) are used, both of which can be customized (see F.2 and A.10).
As an alternative, a customized BST template file could be opened before opening the BMP file, as the thermal properties from the previous open document remain active in memory. Use the same colour palette, and the same colour numbers in the new bitmap to retrieve the existing thermal properties. Only the thermal properties for colours not occurring in the BST template file, must be defined.
The pixel size and triangulation meshes are set according to the user-defined values in *Settings → Default Measures....* (see A.9).

File → Open Colour Database...
The colour database contains predefined material and boundary condition properties (stored in the file ColourDatabase.bst in the application data folder, see F.2), which is loaded at every BISTRA start-up (see B.2). It is advisable to add frequently used materials and boundary conditions to the colour database.
These predefined colours of the colour database are then available for new colours in any document.

File → Close
Closes the active document (after a prompt to save it), but the thermal properties, pixel size and calculation parameters remain present in memory, for further use in the next opened document (*File → Open Bitmap...* or *File → Open...*).

File → Save
Saves the current document (BMP file and BST or BSC file). The file names are displayed in the BISTRA application title bar (BST file) and in the **Bitmap window** title bar (BMP file). The files are only written when they were modified, which is indicated by an asterisk after the respective file names.

File → Save As...
Allows to save the open document as new files (BMP file and BST or BSC file). The file paths of the new BMP and BST or BSC files can be entered in two successive File Save dialog boxes (first for the BMP file, then for the BST or BSC file). Use the same data file folder for both BMP and BST or BSC files (because the BST or BSC file does not save the directory of the BMP file, but only the file name).

File → Batch Calculation...: run multiple simulation files (BST) successively, see section C.10.

File → Exit
Quits the current session of BISTRA.
Global program parameters are saved into the parameter file BISTRA.prm.

B.4. BISTRA program layout and input windows

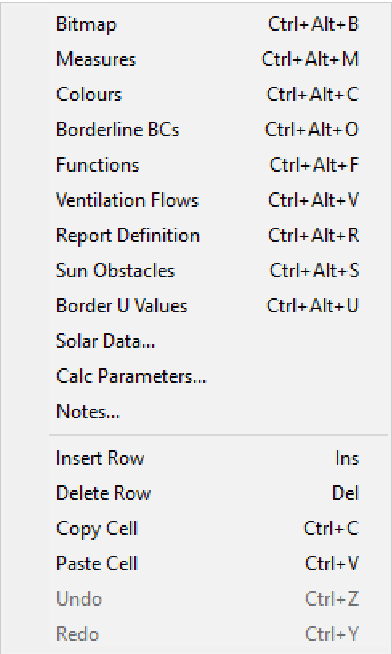
The input in BISTRA is organised in several windows. When a BISTRA document is opened (e.g. with *File → Open Bitmap...* or *File → Open...*), the following windows are opened:

- **Bitmap window** (top left) with an image of the BMP file.
  The BMP file name is displayed in the title bar.
- **Measures window** (top right) with measurements per colour present in the BMP file.

- **Colours window** (bottom) with thermal properties per colour present in the BMP file.

The name of the current document (BST file name) is displayed in the BISTRA application title bar.

The Edit submenu (or corresponding buttons in the toolbar) allows to open and activate an input window. The active input window has a blue title bar.

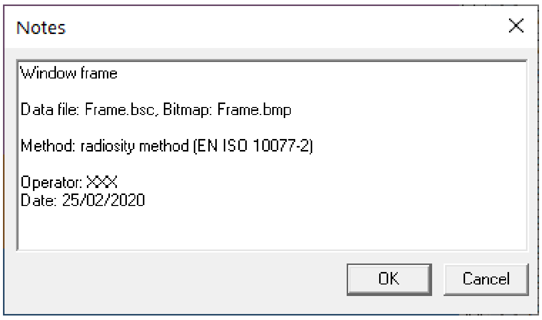


Other input windows are:

- **Borderline BCs window** with borderline boundary conditions.
- **Functions window** with functions.
- **Ventilation Flows window** with ventilation flow paths.
- **Report Definition window** with selection of reported outputs.
- **Sun Obstacles window** with definition of obstacles around the model.
- **Border U Values window** with U-values of wall sections at the bitmap borders.

B.5. Document notes

In the Notes dialog box (via *Edit → Notes...*) some comments can be written for the current document, e.g. project description, operator, date. These notes are saved in the BST file.



B.6. Bitmap window

The **Bitmap window** is automatically loaded when opening a document.

The title bar shows the corresponding BMP file name. An asterisk after the file name indicates that the bitmap is modified (after a bitmap edit operation) and should be saved.

The **Bitmap window** shows a view of the bitmap image.
When the **Bitmap window** is made active (e.g. by clicking on its title bar), the coordinates of the mouse point in the bitmap are shown in the status bar (at the left bottom of the BISTRA application).

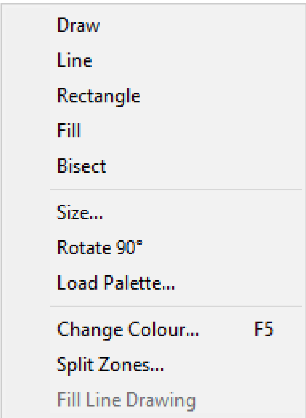
The following coordinates are displayed:

- Pixel coordinates (x_p,y_p).
  The pixel coordinate x_p is measured from the left bitmap border.
  The pixel coordinate y_p is measured from the top bitmap border.
  The pixel coordinates always have integer values.
- Colour number of the current bitmap pixel.
- Scaled coordinates (x_s,y_s).
  The coordinates are scaled using the pixel size, as defined in the **Measures window**.
  The scaled coordinate x_s is the distance from the left bitmap border.
  The scaled coordinate y_s is the distance from the top bitmap border.
  The scaled coordinates have of a resolution of 0.0001 m.

When the <Shift> key is held down, relative coordinates are displayed in the status bar (after a mouse move).
Relative coordinates are measured against a new origin defined by the last clicked point.

If another input window is active, the **Bitmap window** highlights the current item with dotted lines.

B.7. Bitmap editing functions



The active drawing colour is defined by the row of the current cell in the **Colours window**.

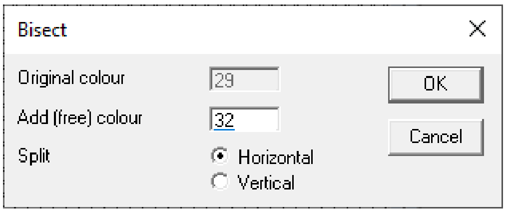
Bitmap → Draw : enter “draw mode”.
In draw mode pixels and lines can be drawn using the active drawing colour.
Drawing a pixel: set the mouse point on the pixel and click the left mouse button.
Drawing a line: hold down the <Shift> key, move the mouse (now the status bar shows the relative coordinates from the last painted pixel) to the end pixel of the line and click the left mouse button. A line is drawn from the last clicked pixel to the new clicked pixel.

Bitmap → Line : enter “line mode”.
A line is drawn from the start point to the end point using click and drag with the left mouse button.

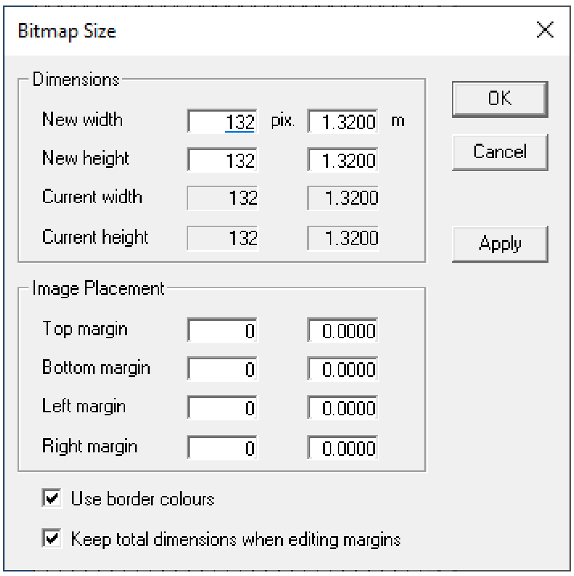
Bitmap → Rectangle : enter “rectangle mode”.
A rectangle is filled using click and drag with the left mouse button.

Bitmap → Fill : enter “fill mode”.
When the left mouse button is clicked, the colour zone around the pixel under the mouse point is filled. The flood fill stops at the border with any other colour.

Bitmap → Bisect : enter “bisect mode”.
When the left mouse button is clicked, the circumscribed rectangle of the colour zone around the pixel under the mouse point is bisected.
The colour number of the newly created zone and the direction of the split are defined by the user.



Bitmap → Size...
Allows to expand or shrink the bitmap at the borders.
In the Bitmap Size dialog box, enter the new width and height (in pixels or in metres).
Then adjust the image placement by entering the top, bottom, left and right margins.
These margins can be positive or negative.
New margins are adjusted at the opposite side if the check box “Keep total dimensions when editing margins” is marked; otherwise the total dimension is adjusted.
Press the command button “Apply” to update the other values after editing. Using the <tab> key has the same result.
When the bitmap is extended at a border (top, bottom, left and/or right), the pixels at that border are copied if the check box “Use border colours” is marked. Otherwise colour number 1 is used for the new border margin.

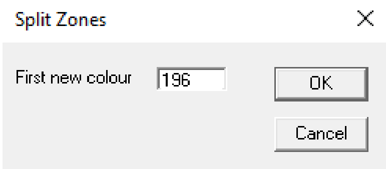


Bitmap → Rotate 90°
Rotates the entire bitmap over 90° in clockwise orientation.

Bitmap → Load Palette...
Import the colour palette of another BMP file (to select in the File Open dialog box).
All colour numbers of the original bitmap get new colour values from the imported colour palette (see A.1.1).

Bitmap → Change Colour...
Assigns a new colour number to the active colour (selected in the **Colours window** or **Measures window**).

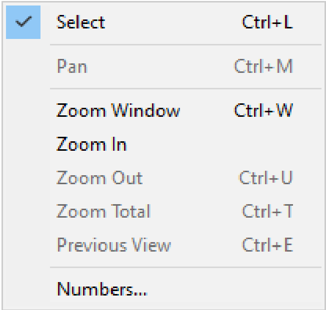
Bitmap → Split Zones...
The function Split Zones works differently in BISTRA than in BISCO (e.g. detection of grooves and interconnections is not possible).
The function allows to split a multi-zone colour into a set of single-zone colours with different colour numbers. First select the multi-zone colour (using *Zoom → Select* and clicking upon the colour in the bitmap).
The function *Bitmap → Split Zones...* is enabled from the **Colours window** or the **Measures window** if the selected colour contains more than one zone and enough free colours are available.
The function is useful for colours of type BC_FRE_S, BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT, which require single-zone colours to be valid.
When the function is called, a Split Zones dialog box is opened to prompt for the first new colour number. The function then takes all successive colour numbers of the colours not yet present in the bitmap. The original colour number can also be reused.



Bitmap → Fill Line Drawing (enabled if exactly two colours are present in the bitmap)
Splits a 2-colours bitmap (formatted as 256-colours BMP file), consisting of a foreground colour (line drawing) and a background colour, into a multi-coloured image. The original lines are removed by thinning.
In a first step all zones surrounded by lines are filled with free colours (different from the line colour of the line drawing). It is important that the lines in the line drawing are closed, because a flood fill technique is used. In a second step the original lines (with foreground colour) are removed by thinning.
This function is useful when the available DXF has only 1 layer containing all different materials (e.g. output from *Sketchup → Export → 2D Graphic*). From such a DXF file a 2-colours bitmap can be generated by BiscoDxf.

B.8. Zoom commands

Zoom submenu



Zoom in/out via the mouse wheel

The commands *Zoom → Zoom In* and *Zoom → Zoom Out* can also be carried out using mouse wheel scrolling (when the **Bitmap window** is active).
Rotating forward (away from the user) zooms in with the mouse point as zoom centre.
Rotating back (toward the user) zooms out.

Zoom → Select

Enters "select mode". A following click with the left mouse button on the bitmap selects the colour under the mouse point as current colour in the **Colours window** and **Measures window**.
Colour selection can also be obtained by a right mouse button click from "pan mode".

Zoom → Pan

Enters "pan mode" (only possible for a zoomed view). A following arrow key stroke (left, right, up, down) or mouse drag using the left mouse button recentres the view.

Zoom → Zoom Window

Enters "zoom window mode". Then a zoom rectangle can be drawn on the bitmap with click and drag, that defines the next zoom view. The zoom operation can be cancelled by pressing <Esc> before releasing the left mouse button.

Zoom → Zoom In

Enters "zoom in mode". A following click using the left mouse button on the bitmap defines the centre point of the next zoomed view. The zoom factor is 50 %.
Zooming in can also be obtained by rotating forward using the mouse wheel.

Zoom → Zoom Out

Zooms out using a zoom factor of 200 %, or calls *Zoom → Zoom Total* if the image becomes too small.
Zooming out can also be obtained by a right mouse button click from "zoom window mode" or "zoom in mode", or by rotating back using the mouse wheel.

Zoom → Zoom Total

Shows total bitmap (the original view).

Zoom → Previous View

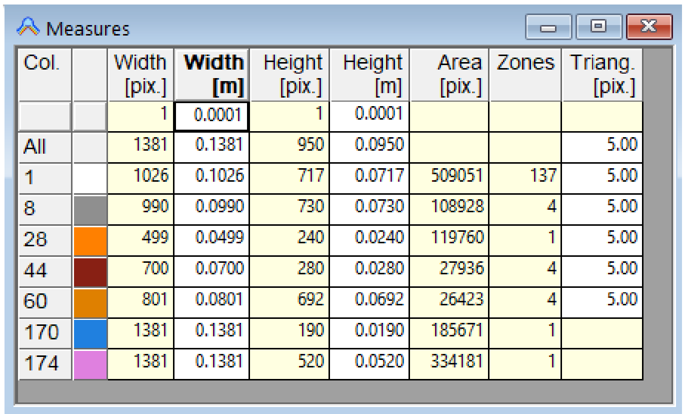
Shows the previous zoom view. (More than one previous view cannot be recalled.)

Zoom → Numbers...

Opens a dialog box with the pixel coordinates of the current zoom view. By editing the coordinates the zoom view can be changed. A zoom view can be restored later (i.e. reset to the same zoom factor and position) via these zoom numbers.

B.9. Measures window

The **Measures window** is the input window for the pixel size and triangulation mesh sizes per colour. The triangulation mesh sizes are used in generating the automatic triangulation grid as part of a thermal system calculation.
The current colour (defined by the row of the current cell) is highlighted in the **Bitmap window** by dotted contour lines.



Measures

Col.		Width [pix.]	Width [m]	Height [pix.]	Height [m]	Area [pix.]	Zones	Triang. [pix.]
		1	0.0001	1	0.0001			
All		1381	0.1381	950	0.0950			5.00
1		1026	0.1026	717	0.0717	509051	137	5.00
8		990	0.0990	730	0.0730	108928	4	5.00
28		499	0.0499	240	0.0240	119760	1	5.00
44		700	0.0700	280	0.0280	27936	4	5.00
60		801	0.0801	692	0.0692	26423	4	5.00
170		1381	0.1381	190	0.0190	185671	1	
174		1381	0.1381	520	0.0520	334181	1	

Dimensions

The first line of the **Measures window** shows the size of 1 pixel (width = height) in the bitmap. The default value can be set in *Settings → Default Measures....*
The second line shows the width and height of the total bitmap.
The following lines list the width and height of the surrounding rectangle for each colour (defined by colour index in the colour palette) in the bitmap, and the area (= number of pixels in the bitmap having this colour).
The measures are shown both in pixels (not editable) and in metres (editable).
When any width or height is changed, all other widths and heights are modified proportionally.

Colour zones

The number of zones per colour is displayed in the column "Zones".
A colour zone is a connected pixel area of the same colour in the bitmap. Each colour in the bitmap can occur in one or more zones. The different zones of the same colour are separated from one another by other colours.
Colours of type BC_FRE_S, BC_FREE, BC_SKY, BC_NOSKY and TRANSMAT must consist of only one zone. Use the function *Bitmap → Split Zones...* to split multi-zone colours.

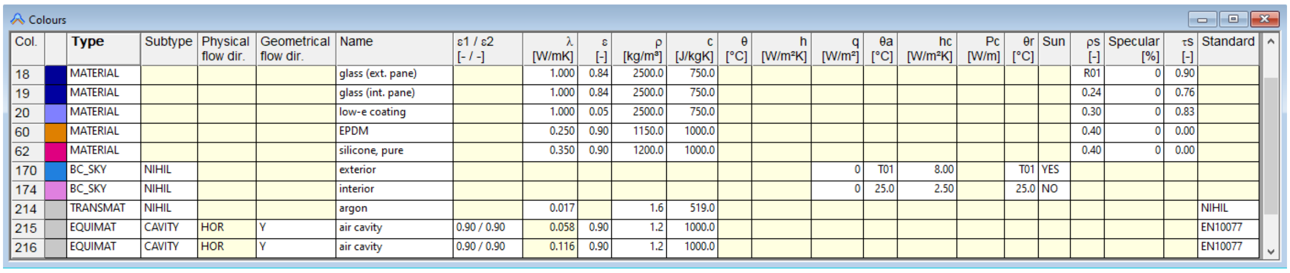
Triangulation mesh sizes

Per colour a triangulation mesh size can be edited.
Only the triangulation mesh sizes of material colours (type MATERIAL, EQUIMAT or TRANSMAT) are enabled and used in a triangulation mesh generation.
Editing the triangulation mesh size on the second line (for the total bitmap) modifies the triangulation mesh sizes of all colours. The default value can be set in *Settings → Default Measures....*
The purpose of different mesh sizes is to influence the calculation accuracy and speed.

B.10. Colours window

The **Colours window** is the input window for thermal properties of materials and boundary conditions. Each row refers to the properties of one colour.

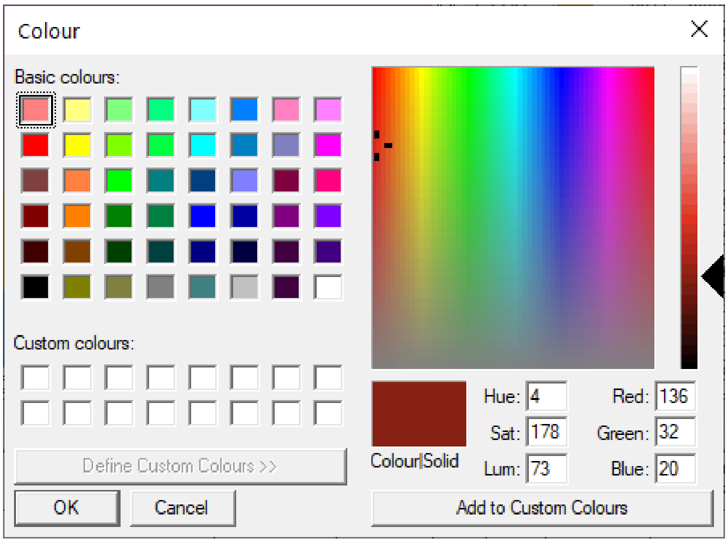
The selected colour (defined by the row of the selected cell) is highlighted in the **Bitmap window** by dotted contour lines.



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
18		MATERIAL				glass (ext. pane)		1.000	0.84	2500.0	750.0									R01	0	0.90	
19		MATERIAL				glass (int. pane)		1.000	0.84	2500.0	750.0									0.24	0	0.76	
20		MATERIAL				low-e coating		1.000	0.05	2500.0	750.0									0.30	0	0.83	
60		MATERIAL				EPDM		0.250	0.90	1150.0	1000.0									0.40	0	0.00	
62		MATERIAL				silicone, pure		0.350	0.90	1200.0	1000.0									0.40	0	0.00	
170		BC_SKY	NIHIL			exterior								0	T01	8.00		T01	YES				
174		BC_SKY	NIHIL			interior								0	25.0	2.50		25.0	NO				
214		TRANSMAT	NIHIL			argon		0.017		1.6	519.0												NIHIL
215		EQUIMAT	CAVITY	HOR	Y	air cavity	0.90 / 0.90	0.058	0.90	1.2	1000.0												EN10077
216		EQUIMAT	CAVITY	HOR	Y	air cavity	0.90 / 0.90	0.116	0.90	1.2	1000.0												EN10077

<u>Colour number</u> (1st column)
Index (between 0 and 255) in the colour palette of the bitmap.

<u>Colour value</u> (2nd column)
Select a cell and press Enter (or double click) to edit the colour value.
If a colour value is changed, then the colour palette of the bitmap is modified, which requires to save the modified BMP file.
The colour value is edited in a Colour dialog box.



<u>Type</u> (3rd column)
Toggle value having one of the following values (press Enter to switch), which defines the meaning of the colour:

- **MATERIAL**: material defined by thermal conductivity.
- **EQUIMAT**: equivalent material defined by a single equivalent thermal conductivity (e.g. air cavity). The equivalent conductivity is typically calculated from standard rules (C.1).
- **BC_SIMPL**: simplified boundary condition (with known temperature and global surface heat transfer coefficient for combined convection and radiation).
- **BC_FRE_S**: enclosure with unknown (free-floating) internal temperature, possible additional internal heat power, simplified surface heat transfer defined by a global surface heat transfer coefficient and possible additional surface heat flux.
  The unknown environmental temperature is calculated from the heat balance equation: Σ (convective heat transfer from environment to surface) = injected convective heat power.

With the RADCON module (which supposes separate convection and radiation based on view factors, see Chapter H) also:

- **BC_FREE**: surface boundary condition modelled as enclosure with unknown (free-floating) air temperature, radiation between the surfaces (using the infrared emissivities of the adjacent materials) and convective heat transfer coefficient.
- **BC_SKY**: surface boundary condition modelled as an environment with defined air and radiation temperature (the sky) and convective heat transfer coefficient.
- **BC_NOSKY**: surface boundary condition modelled as an environment with defined air temperature, no radiation to the environment (no sky) and convective heat transfer coefficient.
- **TRANSMAT**: transparent material defined by thermal conductivity, and radiation between the surfaces (using the infrared emissivities of the adjacent materials).

<u>Standard</u> (last column)
Standard used for the automatic calculation of λ_{eq} or h_c (cf. section C.1).
- NIHIL: no automatic calculation of thermal properties.
- EN10077: standard EN ISO 10077-2.
- EN6946: standard EN ISO 6946.
- EN673: standard EN 673.

Within each standard different subtypes can be chosen.

<u>Subtype</u> (4th column)
Subtype toggle value to define automatic calculation of equivalent thermal conductivity (type EQUIMAT and TRANSMAT) or convective heat transfer coefficient (BC_FREE, BC_SKY and BC_NOSKY). The accessible subtypes are dependent on the actual type (3rd column) and standard (last column).
For type <u>EQUIMAT</u>:
- NIHIL: user defined thermal conductivity (no automatic calculation).
- CAVITY: calculated equivalent thermal conductivity for unventilated air cavity (EN10077 or EN6946).
- CAVITY_E: calculated equivalent thermal conductivity for slightly ventilated air cavity (EN10077).
- LAYER: calculated equivalent thermal conductivity for unventilated gas layer (EN6946 or EN673).

For type <u>BC_SIMPL</u>:
- NIHIL: user defined global heat surface coefficient.
- HI_NORML: normal internal heat transfer (EN10077).
- HI_REDUC: reduced internal heat transfer (EN10077).
- HI: internal heat transfer (EN6946).
- HE: external heat transfer (EN10077 or EN6946).
- HI_CAV_E: slightly ventilated air cavity at the internal surface (EN10077 – radiosity method).
- HE_CAV_E: slightly ventilated air cavity at the external surface (EN10077 – radiosity method).

For type <u>BC_FREE</u>:
- NIHIL: user defined convective heat transfer coefficient (no automatic calculation).
- CAVITY: calculated convective heat transfer coefficient for unventilated air cavity (EN6946).
- LAYER: calculated convective heat transfer coefficient for unventilated gas layer (EN6946 or EN673).
- CONVEC: calculated convective heat transfer coefficient for large air space.

For type <u>BC_SKY</u> or <u>BC_NOSKY</u>:
- NIHIL: user defined convective heat transfer coefficient (no automatic calculation).
- CONVEC: calculated convective heat transfer coefficient for natural convection.

For type TRANSMAT:

- NIHIL: user defined thermal conductivity (no automatic calculation).
- CAVITY: calculated equivalent thermal conductivity for unventilated air cavity (EN10077 or EN6946).
- LAYER: calculated equivalent thermal conductivity for unventilated gas layer (EN6946 or EN673).

For more details on the corresponding calculation procedures see C.1.

Physical heat flow direction (5th column)
Heat flow direction with reference to the physical reality:

- HOR: horizontal heat flow.
- UP: upward heat flow.
- DOWN: downward heat flow.
- ANY: user-defined heat flow direction (by defining the inclination angle of the construction element and assuming a heat flow perpendicular to the construction element)

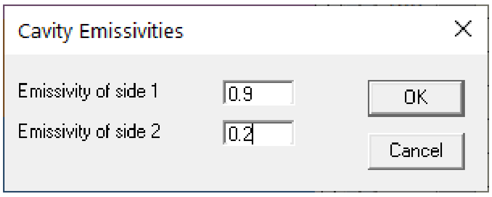
Geometric heat flow direction (6th column)
Heat flow direction with reference to the X and Y directions of the screen:

- X: heat flow parallel to the X axis of the screen.
- Y: heat flow parallel to the Y axis of the screen.
- DIR: heat flow following the local temperature gradient.

Name (7th column)
Name of material or boundary condition.

Thermal properties (next columns):

- ε1 / ε2 [- / -]: infrared emissivities (values between 0.001 and 1) at warm and cold sides of cavity (type EQUIMAT).
  Editing opens a dialog box for definition of the values.

  If any emissivity differs from 0.9 (the default value), the corresponding grid cell in the **Colours window** is highlighted in blue.
- λ [W/(m.K)]: thermal conductivity of material (MATERIAL), equivalent material (EQUIMAT) or transparent material (TRANSMAT).
- ε [-]: infrared emissivity (value between 0 and 1) of material surfaces (MATERIAL, EQUIMAT) adjacent to boundary condition or cavity with radiative heat transfer.
- ρ [kg/m^3]: density of material (MATERIAL), equivalent material (EQUIMAT), transparent material (TRANSMAT) or enclosure (BC_FREE and BC_FRE_S).
- c [J/(kg.K)]: specific heat of material (MATERIAL), equivalent material (EQUIMAT), transparent material (TRANSMAT) or enclosure (BC_FREE and BC_FRE_S).
- θ [°C]: temperature of simplified boundary condition (BC_SIMPL).
- h [W/(m^2.K)]: global surface heat transfer coefficient (BC_SIMPL, BC_FRE_S).
- q [W/m^2]: heat flux dissipated onto adjacent material surfaces (BC_SIMPL, BC_FRE_S, BC_FREE, BC_SKY, BC_NOSKY).
- θa [°C]: air temperature (BC_SKY, BC_NOSKY).
- hc [W/(m^2.K)]: convective heat transfer coefficient (BC_FREE, BC_SKY, BC_NOSKY).

- Pc [W]: convective power dissipated in the environment (BC_FRE_S, BC_FREE).
- θr [°C]: radiation temperature (BC_SKY).

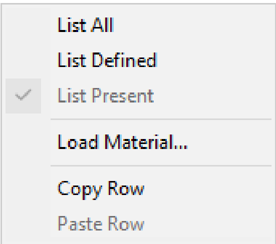
<u>Solar data</u> (four columns with header Sun, ρs, Specular and τs):

– Sun: sun active status (YES or NO) to define a solar zone, for a colour of type BC_SIMPL or BC_SKY.
– ρs [-]: solar reflection factor (for a colour of type MATERIAL), a constant value (between 0 and 1), or a function reference (R##) when the solar reflection factor is a function of the angle of incidence (see also section B.12.2). See C.8.1 for a detailed explanation of the definition of ρs.
– Specular [%]: specular part of the direct solar radiation reflection (for a colour of type MATERIAL), a constant value (between 0% and 100%). The other part is diffuse reflection.
– τs [-]: solar transmission factor (for a colour of type MATERIAL), a number between 0 and 1 representing the resulting transmission factor – after reflection - of the MATERIAL layer and all transparent material layers (MATERIAL or EQUIMAT) behind it until another zone or an opaque material (τs equals 0) is reached. See C.8.1 for a detailed explanation of the definition of τs.

The properties λ, c, θ, h, q, θa, hc, Pc, θr and ρs can each either have a constant value (as in BISCO) or refer to a function (defined in the **Functions window**) via the function reference name: L## (for λ), C## (for c), T## (for θ, θa, θr), H## (for h, hc), I## (for q), P## (for Pc), R## (for ρs).

B.11. Colour functions

The colour functions are available through the **Colours submenu**.

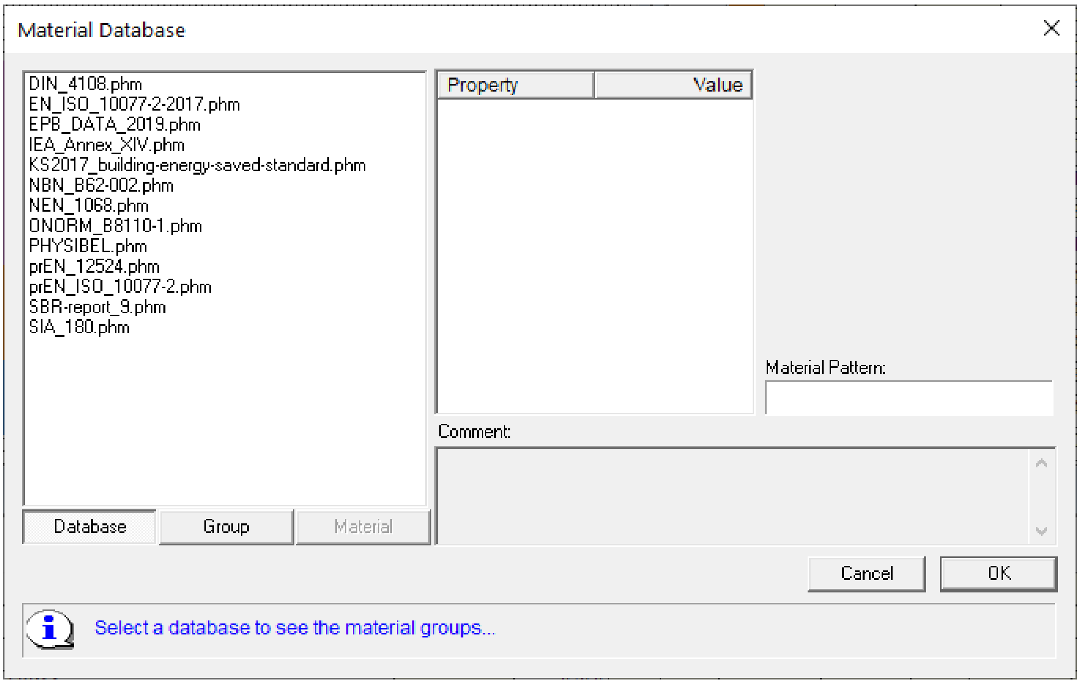


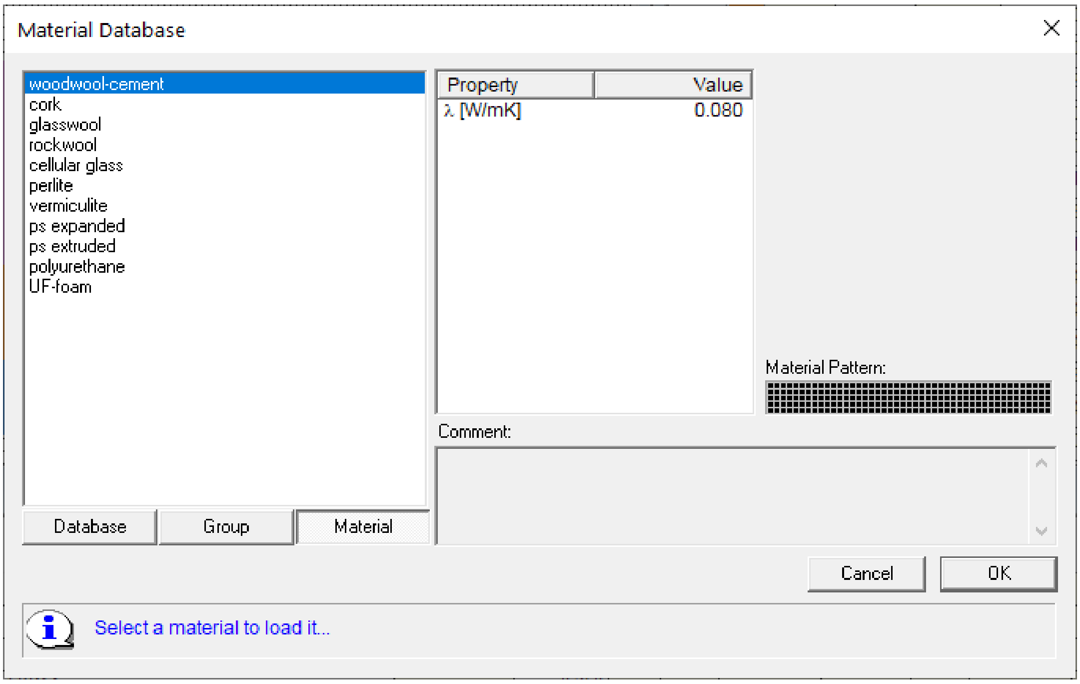
<u>*Colours → List All*</u>
List all 256 colours of the colour palette of the bitmap.
The properties of colours not present in the bitmap are greyed.

<u>*Colours → List Defined*</u>
List all colours present in the bitmap and colours having defined thermal properties.
Defined thermal properties of colours not present in the bitmap are greyed, and originate from the colour database or previous loaded BST files.

<u>*Colours → List Present*</u> (default option when opening a BISTRA document)
List only the colours present in the bitmap.

<u>*Colours → Load Material...*</u>
Load predefined material properties.
From the Material Database dialog box choose a database file (file with extension .phm from the directory ...\Physibel\Materials, see A.6), a material group and then a material.
The database files (with extension .phm) can be edited using the program MatEdit.exe, also in the directory ...\Physibel\Materials.



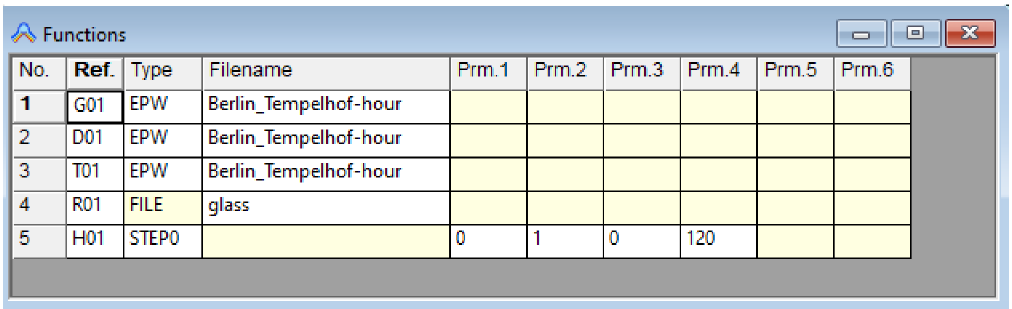


Colours → Copy Row and *Colours → Paste Row*
Copy all properties from one colour to another colour.

B.12. Functions window

For the variable boundary conditions and material properties BISTRA refers to functions: either an internal function (parameters defined in the **Functions window**), or an external function (data read from a file).

All functions that are used in a BISTRA data file, are defined in the **Functions window**, opened with the command *Edit → Functions*.
The picture below shows an example of **Functions window**.



No.	Ref.	Type	Filename	Prm.1	Prm.2	Prm.3	Prm.4	Prm.5	Prm.6
1	G01	EPW	Berlin_Tempelhof-hour						
2	D01	EPW	Berlin_Tempelhof-hour						
3	T01	EPW	Berlin_Tempelhof-hour						
4	R01	FILE	glass						
5	H01	STEP0		0	1	0	120		

Each function is uniquely defined by a function reference name:

Reference	Description	Units	Date file formats
T01 up to T99	Temperature function	[°C]	*.fte, *.epw, *.csv
H01 up to H99	Surface heat transfer coefficient function	[W/(m^2.K)]	*.fht
P01 up to P99	Power function	[W]	*.ffh
I01 up to I99	Imposed flux function (I01 is used in the Solar Data dialog box)	[W/m^2]	*.fir
G01 up to G99	Horizontal global solar radiation function (only G01 is used in the Solar Data dialog box)	[W/m^2]	*.fsg, *.epw, *.csv
D01 up to D99	Horizontal diffuse solar radiation function (only D01 is used in the Solar Data dialog box)	[W/m^2]	*.fsd, *.epw, *.csv
V01 up to V99	ventilation function	[m^3/s]	*.fvr
M01 up to M99	thermal conductivity function (time dependent)	[W/(m.K)]	*.fco
L01 up to L99	thermal conductivity function (temperature dependent)	[W/(m.K)]	*.fla
C01 up to C99	specific heat function (temperature dependent)	[J/(kg.K)]	*.fce
R01 up to R99	solar reflection factor function (angular dependent)	[-]	*.frf

Function reference names can be used in:
the **Colours window** (columns with header λ, c, θ, h, q, θa, hc, Pc, θr, ρs),
the **Borderline BCs window** (columns with header θ and q),
the **Ventilation Flows window** (column with head "Flow").

Temperature functions (L## and C##) and solar reflection factor functions (R##) can only have type FILE (see B.12.2).

All function values are used in BISTRA as average values over the simulation time step, where the simulation time is understood as the middle of the simulation time step (see C.8.2).

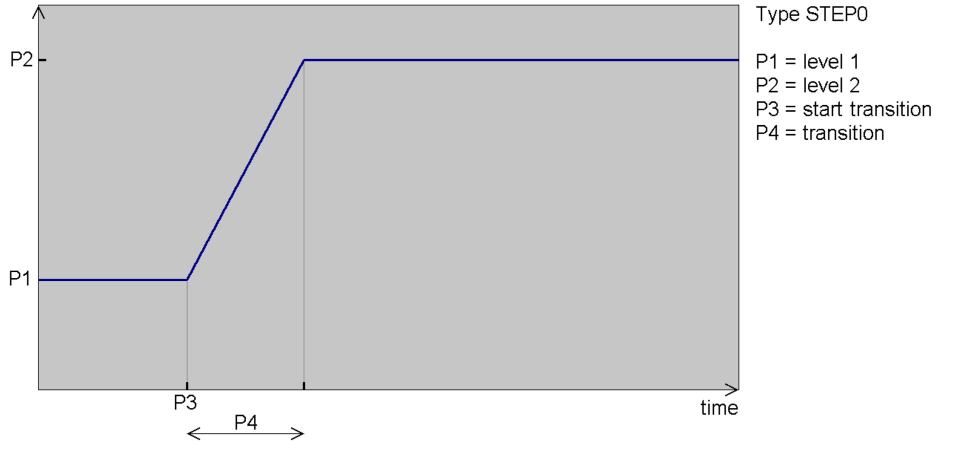
A new function can be inserted via *Edit → Insert Row.*
The current function can be deleted via *Edit → Delete Row.*

B.12.1. Internal time functions (types STEP0, STEP1, STEP2, SINE, and SINPOS)

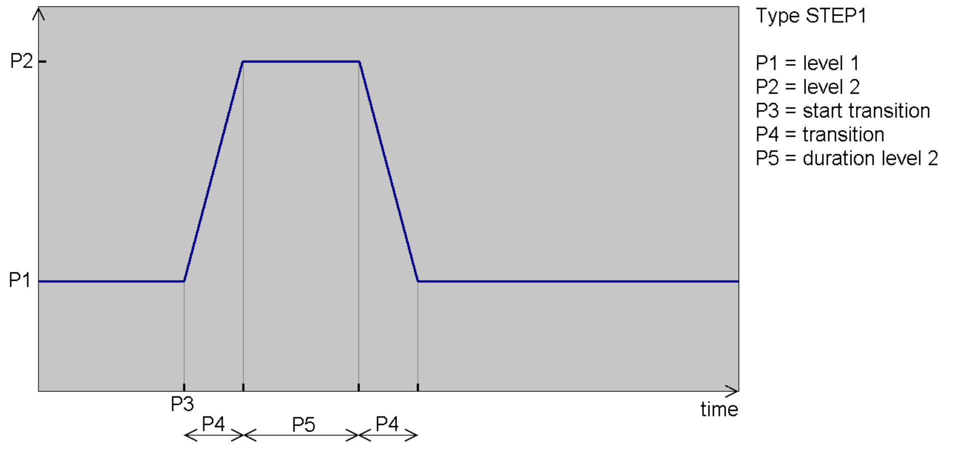
An internal time function is a built-in program function, defined by one or more parameters. BISTRA contains 5 built-in function templates.

The meaning of each parameter per function type is explained in the status bar (cf. figures below).
All time parameters must be entered in minutes (e.g. 1 day = 24 h x 60 min/h = 1440 min).

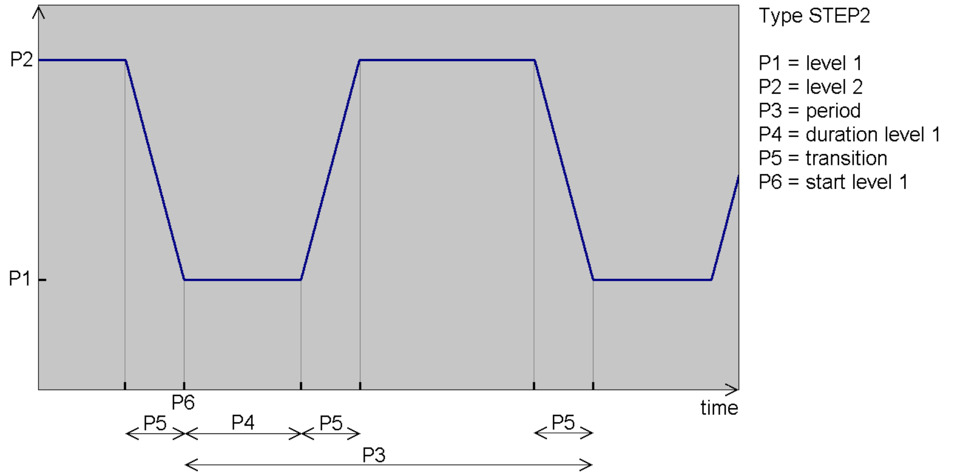
- STEP0 for a step function defined by 4 parameters (P1, P2, P3, P4)



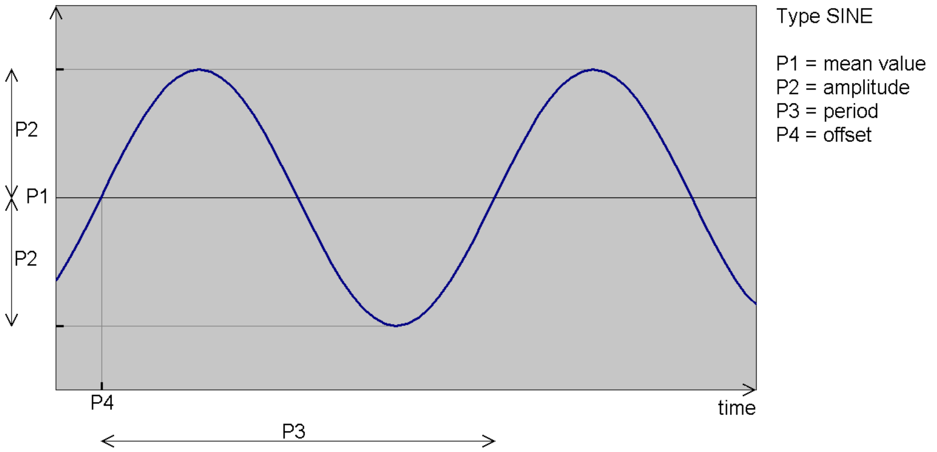
- STEP1 for a step function defined by 5 parameters (P1, P2, P3, P4, P5)



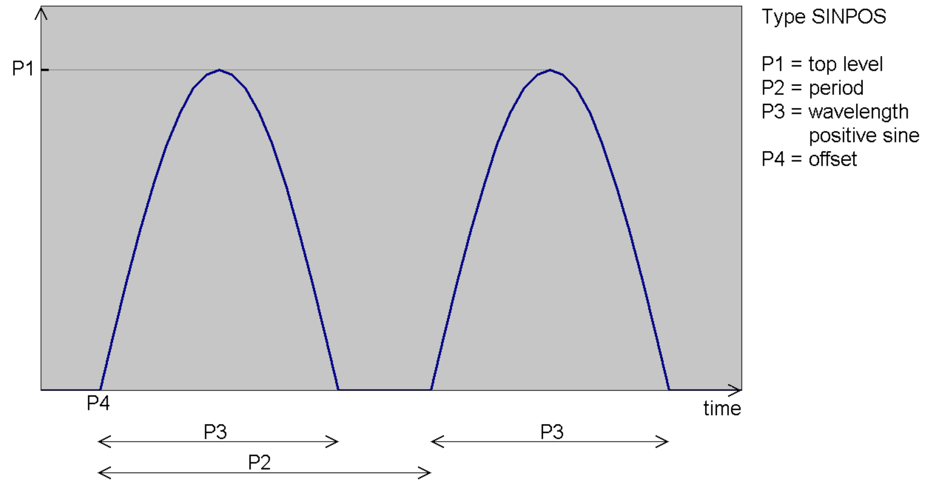
- STEP2 for a step function defined by 6 parameters (P1, P2, P3, P4, P5, P6)



- SINE for a sine function, defined by 4 parameters (P1, P2, P3, P4)



- SINPOS for a positive sine function, defined by 4 parameters (P1, P2, P3, P4)



B.12.2. External functions (type FILE)

An <u>external time function</u> is defined in a separate data file, with extension:

- .fte (temperature function)
- .fht (surface heat transfer coefficient function)
- .ffh (power function)
- .fir (imposed flux function)
- .fsg (horizontal global solar radiation function)
- .fsd (horizontal diffuse solar radiation function)
- .fvr (ventilation function)
- .fco (time dependent thermal conductivity function).

The program FUNCEDIT (cf. Chapter G) allows to edit these files.

External data as a source for an external time function can either be formatted as a linear function, or as a step function (see G.3).
In case of a *linear function format*, function values at simulation times in between external data timestamps are obtained by simple linear interpolation between the external data timestamps.

In case of a *step function format*, the values in the external data file are interpreted as the average value during the data interval preceding the external data timestamp and are thus assumed constant and equal to the value at the data interval's end timestamp for any simulation times in between external data timestamps[1]. An exception is made for solar radiation functions (G## and D##), in which case external data formatted as a step function are converted to instantaneous values at simulation times using a mathematical algorithm (see C.8.2)[2]. For this algorithm to work, the simulation start time and time step have to be defined in such a way that the simulation hits the hours precisely (see C.2.1).

Some material properties (thermal conductivity, specific heat, solar reflection factor) may be dependent on another property (temperature, angle of incidence).
These temperature functions (thermal conductivity, specific heat) or angular functions (solar reflection factor) are defined in separate data files, with extension:
- .fla (temperature dependent thermal conductivity function)
- .fce (temperature dependent specific heat function)
- .frf (angular dependent solar reflection factor function).

These function data files are text files consisting of two or more text lines:

```
x0   y0
x1   y1
x2   y2
…
xn   yn
```

with x0 ≤ x1 ≤ x2 ≤ … ≤ xn.
Each text line consists of two float numbers, the abscissa (i.e. a temperature value or an angle of incidence) and the ordinate (i.e. the corresponding thermal conductivity, specific heat value or solar reflection factor) of a characteristic point of the function. The function is linearly interpolated between the characteristic points. If $x < x0$, then $y = y0$. If $x > xn$, then $y = yn$.
The user can define these functions with a text editor (e.g. Windows Notepad).

When the function filename field is double clicked (or when Enter is pressed), a file path can be chosen in the Open dialog box. If the external files are stored in the same directory (or a subdirectory of this directory) as the BISTRA data file, the file paths are relative (so that copying of the .bst file together with the function files to another directory has the desired result that the new .bst file refers to the function files in the same new data directory). If the external files are not stored in the same directory as the BISTRA data file, the absolute file paths are saved in the .bst file.

B.12.3. Weather data files (types EPW and TMY3)

A weather data file is a data file containing observations of weather variables such as temperature, relative humidity, solar radiation, wind speed, etc. for a specific location. Two different data file formats can be imported into BISTRA: EPW or *EnergyPlus Weather* (extension .epw), and TMY3 or *Typical Meteorological Year* (extension .csv).

[1] Note that in older versions of BISTRA (v4.2 and before), step function formatted external data were interpreted differently, namely as the average value during the data interval *following* the external data timestamp and thus assumed constant and equal to the value at the data interval's *begin* timestamp for any simulation times in between external data timestamps.
[2] This algorithm was not included in older versions BISTRA (v4.2 and before).

The weather data files can only be used as functions in BISTRA if they (i) contain data for a complete year, (ii) are defined in local time (not solar time), (iii) do not contain lines with more than 512 characters, and (iv) start at hour 1 after midnight, January 1st.[3]
Weather data files can be used as source for the functions:

- Temperature (T##): the dry-bulb temperature of the weather file is read and interpreted as instantaneous values occurring at the timestamps denoted in the weather data file.
- Global horizontal radiation (G##): the total horizontal radiation is read and interpreted as the total amount of radiation (Wh/m²) received in the interval preceding each timestamp.
- Horizontal diffuse radiation (D##): the diffuse horizontal radiation is read and interpreted as the total amount of diffuse radiation (Wh/m²) received in the interval preceding each timestamp.

The temperature values from the weather data file are linearly interpolated between the instantaneous values occurring at the data file timestamps[4]. The radiation values from the weather data file are converted to instantaneous values at simulation times using a mathematical algorithm (see C.8.2). For this algorithm to work, the simulation start time and time step have to be defined in such a way that the simulation hits the hours precisely (see C.2.1).

If function G01 for global horizontal radiation is a weather data file, the geographical location is automatically read and used in the solar processor (see B.15.1).

When the function filename field is double clicked (or when Enter is pressed), a file path can be chosen in the Open dialog box.
If the weather data files are stored in the same directory (or a subdirectory of this directory) as the BISTRA data file, the file paths are relative (so that copying of the .bst file together with the weather data files to another directory has the desired result that the new .bst file refers to the weather data files in the same new data directory). If the weather data files are not stored in the same directory as the BISTRA data file, the absolute file paths are saved in the .bst file.

B.13. Function Graph window

The **Function Graph window** shows a graph of the current function in the **Functions window**.
The **Function Graph window** is automatically opened when the **Functions window** is activated, and automatically closed when another window is activated (e.g. **Measures window** or **Colours window**).

Zoom functions (via the Zoom submenu) allow to view function details.

The quantities defined by the X axis (time, temperature, angle of incidence) and Y axis (temperature, surface heat transfer coefficient, flux, power, lambda, specific heat, solar reflection factor) are determined by the current function in the **Functions window**.
The origin of the X axis of a time function (i.e. time = 0) corresponds to the calculation start time, as defined in the Calculation Parameters dialog box.

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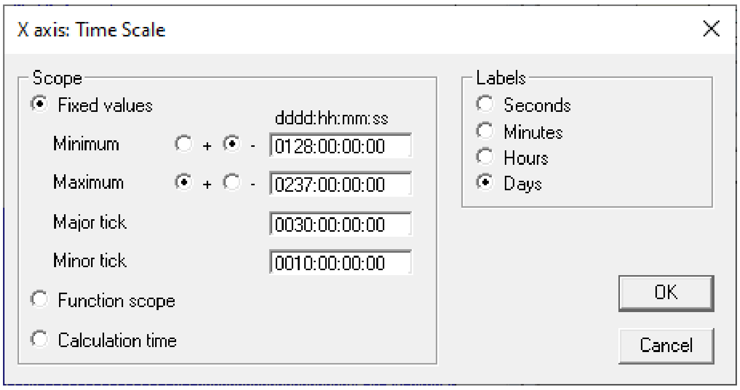
[3] In case the simulation start time is hour 0 (midnight), January 1st, the values from the weather data file for hour 1 are copied for hour 0.
[4] Note that in the .epw file format valid values for the 'hour' field run from 1 to 24 (hour 1 is 00:01 to 01:00 in local time) and values for the 'minute' field run from 1 to 60. This means that e.g. the combination of hour 2 and minute 60 indicates a time stamp of 02:00 in local time. If the 'minute' field is undefined in the .epw file (typically with value 0), it is interpreted as having value 60.

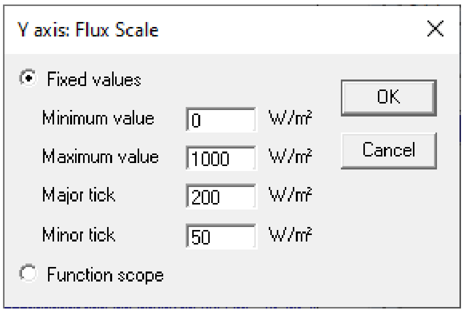
In case of solar radiation functions (G## and D##) using an external data file with data formatted as a step function (B.12.2) or a weather file (B.12.3) the source data are visualised in the **Function Graph window**, not the converted function values used in the simulation (see C.8.2).

B.14. Function commands

The X and Y axis tick marks and labels from the graph shown in the **Function Graph window** can be redefined via the commands *Functions → X Scale...* and *Functions → Y Scale...*.



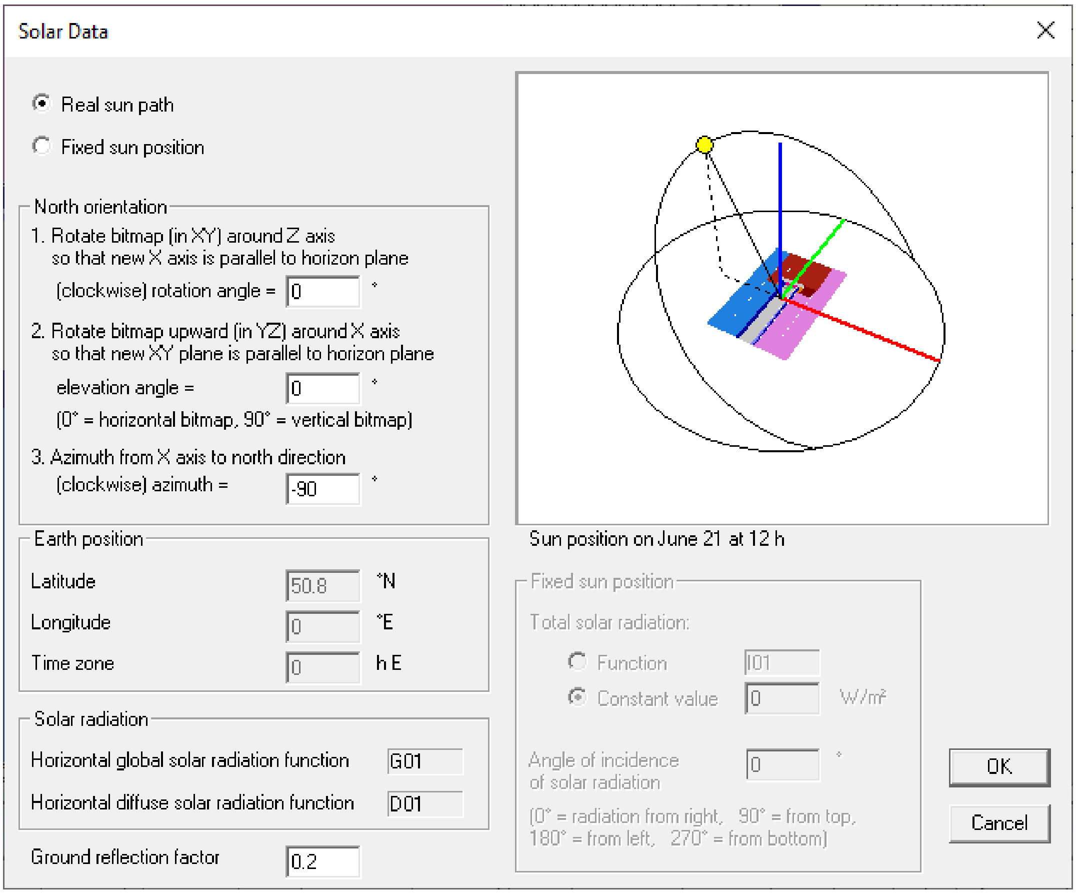
The scope of the time scale on the X axis can be chosen between fixed values, function scope (corresponding to the definition of the function) and calculation time (corresponding to the calculation duration as defined in the Calculation Parameters dialog box).
When fixed values are chosen, the minimum and maximum value (with plus or minus sign), and the major and minor tick distances can be set. Also the label unit can be chosen (seconds, minutes, hours or days).



B.15. Solar data

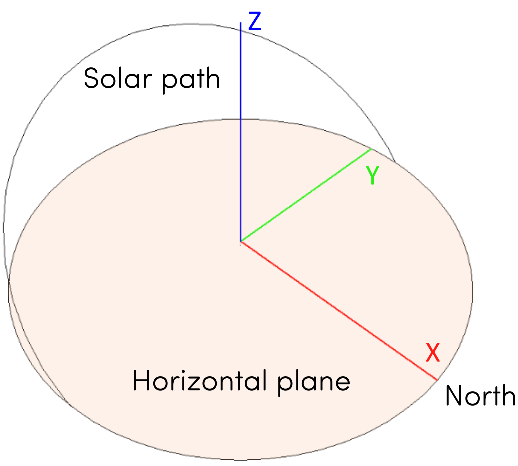
The solar processor requires the definition of parameters in the Solar Data dialog box (*Edit → Solar Data...*).

First, a choice can be made between a Real sun path or a simplified calculation with a Fixed sun position.



B.15.1. Real sun path

North orientation: The bitmap must be positioned into the horizontal coordinate system. 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 X_bY_b into 3D horizontal coordinate system XYZ) is defined by three rotation angles. 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.



- The first rotation brings the X_b axis in a horizontal position.
  This rotation happens within the bitmap X_bY_b plane (i.e. a rotation around the Z_b axis, perpendicular to the bitmap).

After the rotation the original system $X_bY_bZ_b$ becomes the new system X'Y'Z' (with $Z' = Z_b$). The rotation angle is chosen so that after rotation the new X' axis is set in the horizontal plane XY.
The rotation angle is clockwise oriented (i.e. the angle which moves Y_b to X_b is +90°).
For a horizontal or vertical bitmap this first rotation is not required (angle = 0°, because the X_b axis is already in a horizontal position), but for a slanted bitmap (e.g. cross section of a slanted roof) it may be required.

- The second rotation brings the Y' axis too in a horizontal position (while X' remains horizontal).
  This rotation turns the bitmap (located in the X'Y' plane = X_bY_b plane) around the X' axis (i.e. within the Y'Z' plane).
  After the second rotation the system X'Y'Z' is transformed to the new system X"Y"Z" (with X" = X').
  The rotation angle is counterclockwise oriented (i.e. the angle which moves Y' to Z' is +90°).
  This rotation angle is equal to the angle between the normal (Z_b axis) on the bitmap X_bY_b plane and the zenith (Z-axis), i.e. the elevation angle.
  For a bitmap representing a horizontal section view the second rotation angle equals 0°.
  For a bitmap representing a vertical section view the second rotation angle equals 90°.
- The third rotation let the X" axis point to the north (while the X"Y" plane remains horizontal).
  This rotation around the Z" axis turns the system X"Y"Z" into the final horizontal system XYZ (with Z = Z"). The rotation angle is clockwise oriented (i.e. the angle which moves Y" to X" is +90°).

The position of the bitmap in the 3D horizontal coordinate system XYZ after these rotations is shown in the dialog box as a visual aid for defining the rotation angles.

Geographical location ("earth position"): latitude (°N), longitude (°E) and time zone (h E).
The input fields are disabled when these parameters are present in the weather data file containing the global solar radiation data, as defined in the **Functions window** (G01). The coordinates are then loaded from the solar radiation weather data file.
Solar radiation functions: the function reference names of the horizontal global and diffuse solar radiation functions are always G01 and D01. These solar radiation functions must be defined in the **Functions window**.
Ground reflection factor: reflection factor of (horizontal) ground surface around the object model. The reflected solar radiation is projected on the external object surfaces using an isotropic diffuse model.
The input value must be between 0 and 1. A typical value is 0.2. For very reflective grounds a higher value can be used (e.g. snow: 0.8).

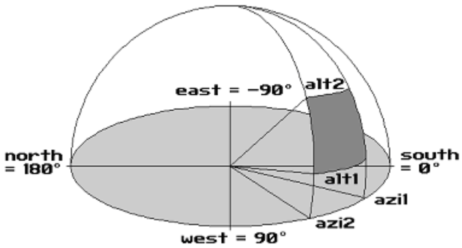
B.15.2. Fixed sun position

An alternative to a Real sun path is to impose a fixed sun position for a simplified calculation. In this case, the user can choose between a function or a constant value for the total solar radiation. The total solar radiation is treated as direct radiation in the calculation (see C.8.2).
In case a function is selected, the function reference name I01 is always used and should be defined in the **Functions window**. This function I01 contains time dependent data for the total solar radiation.

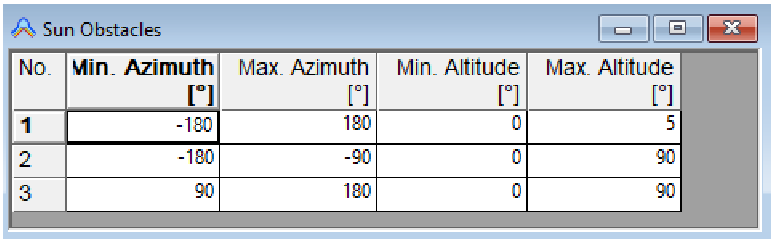
This direct radiation originates from a user-defined angle around the bitmap. An angle of 90° for example means the solar radiation comes from the top border of the bitmap, in a direction perpendicular to that bitmap border.

B.16. Sun obstacles window

Sun obstacles around the 3D object obtained by extrusion of the bitmap are defined in the **Sun Obstacles window**, opened with *Edit → Sun Obstacles*. Each sun obstacle is a spherical rectangle defined by azimuth and altitude coordinates within which the sun is invisible. If the solar zone does not surround the complete object defined in the bitmap, the explicit definition of sun obstacles is necessary to prevent that the sun hits the object from unwanted angles.
The azimuth and altitude coordinates are defined in the coordinate system XYZ (see B.15).
Each sun obstacle is defined by four parameters: minimum and maximum azimuth (clockwise angle between –180° and 180°, 0° = south, 90° = west), and minimum and maximum altitude (between 0° at the horizon and 90° at the zenith).



By default one sun obstacle (defined by a zone up to 5° high above the horizon in all directions around) is present for each new BISTRA file (cf. figure below).


Sun Obstacles

No.	Min. Azimuth [°]	Max. Azimuth [°]	Min. Altitude [°]	Max. Altitude [°]
1	-180	180	0	5
2	-180	-90	0	90
3	90	180	0	90

A new sun obstacle is added using *Edit → Insert Row.*
A sun obstacle is deleted using *Edit → Delete Row.*

Note that the Sun Obstacles window is disabled in case a fixed sun position is defined in the Solar Data dialog box (see B.15), as sun obstacles are not taken into account in that case.

B.17. Border U Values window

The **Border U Values window** allows to derive 1D U-values at the bitmap's borders, which are shown for information.

The **Border U Values window** automatically calculates the U-values at the bitmap borders based on 1D heat transfer through material layers of type MATERIAL, EQUIMAT or TRANSMAT, or cavity layers of type BC_FREE between two different boundary conditions of type BC_SIMPL (or BC_FRE_S) or BC_SKY along the outermost pixel strip at the bitmap borders.
For MATERIAL and EQUIMAT layers, the lambda value as shown in the **Colours window** is used in the U-value calculation.
For TRANSMAT and BC_FREE layers, the U-value shown is calculated assuming linear radiation using the black linear radiation coefficient h_{rb} as defined in the Calculation Parameters dialog box (C.2.4).

For BC_SKY boundary conditions, the U-value shown is calculated assuming a constant radiation surface heat transfer coefficient h_r of 5.2 W/m²K.
The field is blank if the U-value calculation fails.

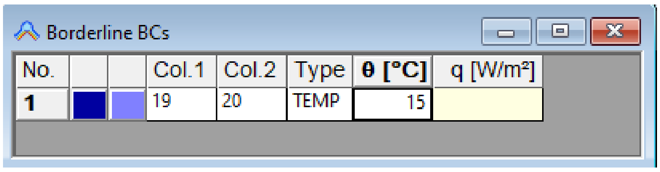
B.18. Borderline boundary conditions window

In the borderline between two different colours (identified by their colour numbers) user-defined temperatures or heat fluxes (as constant values or functions of time) can be imposed.
The borderline boundary conditions are defined in the **Borderline BCs window**, opened with *Edit → Borderline BCs*.

A new borderline boundary condition is added using *Edit → Insert Row*.
A borderline boundary condition is deleted using *Edit → Delete Row*.

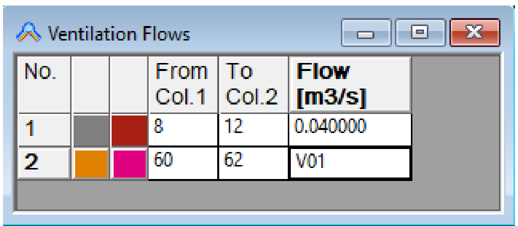
For each borderline boundary condition, enter:

- Colour numbers of two adjacent colours.
  Invalid colour numbers (not present or not adjacent in the bitmap) cannot be entered.
- Type: "TEMP" (fixed temperature) or "FLUX" (fixed heat flux).
- Temperature θ (if type = TEMP), either a constant value or a function reference (defined in the **Functions window**): T##, with ## a number from 01 to 99.
- Heat flux q (if type = FLUX), either a constant value or a function reference (defined in the **Functions window**): I##, with ## a number from 01 to 99.



B.19. Ventilation flows window

Ventilation flow paths can be defined in the **Ventilation Flows window**, opened with *Edit → Ventilation Flows*. Add new ventilation flows with the command *Edit → Insert After*.



For each ventilation flow definition line a ventilation source and ventilation destination must be entered. Both are identified by colour numbers to the corresponding boundary conditions.
The ventilation source (in the column with header "From Col. 1") can be any type of boundary condition (BC_SIMPL, BC_FRE_S, BC_FREE, BC_SKY or BC_NOSKY). The ventilation destination (in the column with header "To Col. 2") must be a boundary condition of type BC_FRE_S or BC_FREE (with unknown air temperature influenced by the incoming ventilation flow). Ventilation flows with destination a zone with fixed air temperature can not be entered, because they have no effect on the system.
The ventilation flow (last column) is a constant value or a reference to a ventilation function (V##) as defined in the **Functions window**.
The user should take care that all defined ventilation flows refer to a realistic ventilation scheme. A ventilation path can originate from an outside environment, pass through some internal zones

and leave to another outside environment. But a ventilation path can also pass through a closed circuit of only internal zones.

All air cavities of type BC_FRE_S and BC_FREE that occur as ventilation source or ventilation destination in the **Ventilation Flows window** are automatically unlinked without the need of explicit definition as explained in section C.6.

The following error messages may occur when doing a calculation:
- "Syntax error in ventilation flow N":
  The ventilation flow in the **Ventilation Flows window** at line N contains a syntax error. Either the ventilation source is not a boundary condition (i.e. a colour of type BC_SIMPL, BC_FRE_S, BC_FREE, BC_SKY or BC_NOSKY), or the ventilation destination is not a boundary condition of type BC_FRE_S or BC_FREE, or the specific heat (c) and/or the density (ρ) of the ventilation source and destination are not equal (see B.10).
- "Error in ventilation system":
  The combination of all ventilation flows as defined in the **Ventilation Flows window** does not correspond to a physically correct ventilation system. This error occurs when the ventilation system has no unique solution (undetermined system).

B.20. Report Definition window

The contents of a report in the **Text Output window** (see E.4) after a calculation has been executed, is determined by the report definition and the report frequency (cf. section B.21).
The input of the report definition is done in the **Report Definition window**, opened with *Edit → Report Definition*.
The report definition consists of several report items, one per line in the **Report Definition window**. A new report item is added via *Edit → Insert Row*.
During the generation of a report in the **Text Output window**, a report line is written per report step (which equals the calculation time step or a multiple of it, as defined by the report frequency).
The report line consists of the actual values of the report items (separated by tabs) at the current time step.

Report Definition

No.	Object	Object No.	Type	Width	Decimals
1	DATE TIME		[dddd:hh:mm:ss]	13	
2	SUN		AZIMUTH	8	2
3	SUN		ALTITUDE	8	2
4	2 COLOURS	19 / 20	θmax	8	2
5	COLOUR	21	Qsol	8	2
6	COLOUR	18	Qsol	8	2
7	COLOUR	18	θmin	8	2
8	COLOUR	20	Etot	8	2
9	COLOUR	18	Etot	8	2
10	COLOUR	18	Edif	8	2
11	COLOUR	170	hc	8	2
12	COLOUR	12	Qsol	8	2
13	BORDER BC	1	θ	8	2

A report item is defined by the following elements (corresponding to the different columns):
- Object: a toggle with values TIME, DATE TIME, COLOUR, 2 COLOURS, BORDER BC, SUN.
- Object No., which meaning is dependent on the selected object:

- TIME: not applicable.
- DATE TIME: not applicable.
- COLOUR: colour number (cf. first column in **Colours window**).
- 2 COLOURS: 2 colour numbers (cf. first column in **Colours window**).
- BORDER BC: borderline boundary condition number (cf. first column in **Borderline BCs window**).
- SUN: not applicable.

- Type, a toggle with values dependent on the selected object:

Object	Type	Meaning
TIME	[s]	time in seconds of the current time step
DATE TIME	[dddd:hh:mm:ss]	time in days, hours, minutes and seconds of the current time step
COLOUR	θ_{min}	minimum temperature [°C] (for colour of type MATERIAL or EQUIMAT)
	θ_{max}	maximum temperature [°C] (for colour of type MATERIAL or EQUIMAT)
	$\Delta\theta_{max}$	maximum temperature difference (θ_{max} - θ_{min}) [°C] (for colour of type MATERIAL or EQUIMAT)
	θ_{mean}	mean temperature ((θ_{min} + θ_{max})/2) [°C] (for colour of type MATERIAL or EQUIMAT)
	Q_{in}	heat flow per unit length into object [W/m] (for colour of type BC_SIMPL, BC_FRE_S, BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT)
	Q_{out}	heat flow per unit length out of object [W/m] (for colour of type BC_SIMPL, BC_FRE_S, BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT)
	λ	(Equivalent) thermal conductivity [W/(m.K)] (for colour of type MATERIAL, EQUIMAT or TRANSMAT)
	θ	boundary condition temperature [°C] (for colour of type BC_SIMPL or BC_FRE_S)
	h	total surface heat transfer coefficient [W/(m^2.K)] (for colour of type BC_SIMPL or BC_FRE_S)
	q	heat flux into boundary condition [W/m^2] (for colour of type BC_SIMPL, BC_FRE_S, BC_FREE, BC_SKY or BC_NOSKY)
	θ_a	air temperature [°C] (for colour of type BC_FREE, BC_SKY or BC_NOSKY)
	h_c	convective heat transfer coefficient [W/(m^2.K)] (for colour of type BC_FREE, BC_SKY or BC_NOSKY)
	P_c	convective power into boundary condition [W/m] (for colour of type BC_FREE or BC_FRE_S)
	θ_r	radiation temperature [°C] (for colour of type BC_SKY)
	Q_{sol}	absorbed solar heat flow per unit length [W/m] in all interface(s) with *zone(s)* of the colour (See C.8.3) and in the contact surface behind transparent materials for opaque colours (see C.8.6) (for colour of type MATERIAL or EQUIMAT) A *zone* in this context is either a solar zone (BC_SIMPL or BC_SKY) or an internal zone with detailed radiation calculation (BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT).

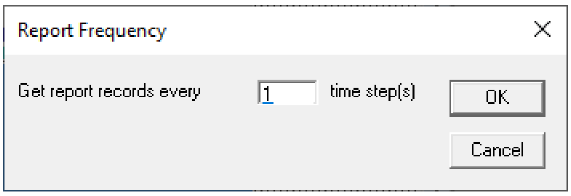
	q_{sol}	absorbed solar flux [W/m^2] in all interface(s) with *zone(s)* of the colour (See C.8.3) and in the contact surface behind transparent materials for opaque colours (see C.8.6) (for colour of type MATERIAL or EQUIMAT) A *zone* in this context is either a solar zone (BC_SIMPL or BC_SKY) or an internal zone with detailed radiation calculation (BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT).
	E_{tot}	Total solar irradiance in interface with solar zone [W/m^2]
	E_{dir}	Direct solar irradiance in interface with solar zone [W/m^2]
	E_{dif}	Diffuse solar irradiance in interface with solar zone [W/m^2]
	E_{gr}	Ground reflected solar irradiance in interface with solar zone [W/m^2]
2 COLOURS	θ_{min}	minimum temperature [°C] occurring in set of 2 colours
	θ_{max}	maximum temperature [°C] occurring in set of 2 colours
	$\Delta\theta_{max}$	maximum temperature difference (θ_{max} – θ_{min}) [°C] occurring in set of 2 colours
	θ_{mean}	mean temperature ((θ_{min} + θ_{max})/2) [°C] of set of 2 colours
BORDER BC	θ	temperature [°C]
	q	heat flux [W/m^2]
SUN	AZIMUTH	sun azimuth [°] (0:south, 90:west, -90:east)
	ALTITUDE	sun altitude [°] (0:horizon, 90:zenith)

- Width: (maximum) number of characters for formatting the output values in the output report
- Decimals: number of digits after the decimal point, to which the output values are rounded.

If a report item definition is logically impossible, no values are given in the report (-).

B.21. Report Frequency

A report line in the report output is written for every time step or every fixed number of time steps. This number is set, before the calculation is started, in the **Report Frequency dialog box**, opened with *Calc → Report Frequency...*.
When a calculation is started, the amount of memory is allocated to save the report records during the calculation. At the end of the calculation the report records are saved in a text file and a CSV file (with same name and file folder as input data file, and extensions .txt and .csv). This report file can be viewed in the text output.



B.22. Save Frequency

During a calculation, time step solutions (i.e. the calculated temperatures in all calculation nodes and the absorbed solar fluxes) at every fixed number of time steps can be saved to disk to use later in graphic output or text output (to view the solutions at those time steps).
The save frequency must be set, before the calculation is started, in the **Save Frequency dialog box**, opened with *Calc → Save Frequency...*.

The node temperature solutions are saved in .sol files with the same file name of the input data file appended with a 4-digit serial number. For example if the input data file is PilotexBistra.bst, then the solution files are PilotexBistra0000.sol, PilotexBistra0001.sol, PilotexBistra0002.sol etc. The absorbed solar fluxes are saved in .sfx files with the same file name of the input data file appended with a 4-digit serial number in the same way as the .sol files.

B.23. General editing commands

Copy – paste
Edit → Copy Cell: copies the value from the current input cell into the clipboard.
Edit → Paste Cell: copies the value from the clipboard into the current input cell.

Undo – redo
Edit → Undo
Undoes the last edit action (to cancel a mistake).
This command can be repeated to undo more edit actions.
Only the last 100 edit actions are stored for possible later recovery using *Edit → Redo*.
The undo command is impossible after saving a file (*File → Save* and *File → Save As...*), closing the current file (*File → Close*, also *File → Open Bitmap...*, *File → Open...*) or starting a calculation (*Calc → Calc System* and *File → Batch Calculation...*).
Edit → Redo
Restores the previous edit action that was made undone using *Edit → Undo*.
This command can be repeated to restore more edit actions that were made undone.

CHAPTER C SYSTEM CALCULATION

C.1. Automatic calculation of thermal properties

In the **Colours window** colour types and subtypes can be selected which contain an automatic calculation of thermal properties.
Whenever this automatic calculation (or definition) of thermal properties is according to an international standard, the relevant standard is denoted in the Standard column in the **Colours window**.
Some standards explain how to *determine* the thermal resistance of air/gas cavities and layers, but not how to *model* them (EN ISO 6946 and EN 673, namely[5]). In this case, modelling them as equivalent materials (EQUIMAT, TRANSMAT) or modelling them as an enclosure with a single convective air/gas node (BC_FREE) are both possible in BISCO.
Conversely, standard EN ISO 10077-2 explicitly states that air cavities should be modelled as an equivalent material, either including convection and radiation (EQUIMAT) or only including convection and modelling radiation explicitly (TRANSMAT).

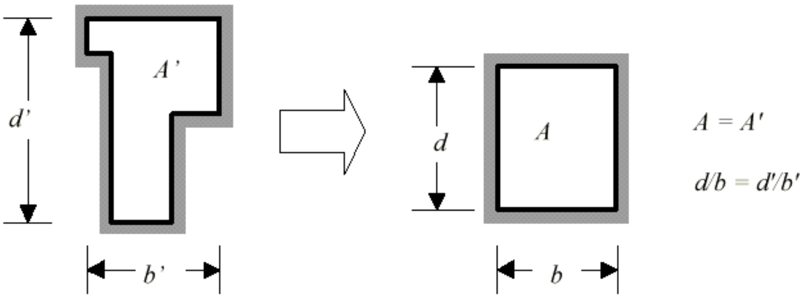
C.1.1. Colour type EQUIMAT

Colour modelled as *equivalent material* (with *single equivalent thermal conductivity* λ_{eq} for combined convective and radiation heat transfer)

Type	*Subtype*	*Meaning*	*Standard*
EQUIMAT	NIHIL	Thermal conductivity λ defined by user	
	CAVITY	Unventilated (internal) air cavity with given heat flow direction	EN10077 EN6946
	CAVITY_E	Ventilated (external) air cavity with given heat flow direction	EN10077
	LAYER	Unventilated air/gas layer with given heat flow direction	EN6946 EN673

<u>Characteristic dimensions of an air cavity</u>
The characteristic dimensions for a rectangular air cavity are its *depth* (parallel to the heat flow direction) and *width* (perpendicular to the heat flow direction).
A non-rectangular air cavity is transformed into a rectangular air cavity, using the same ratio of depth to width for the surrounding rectangle of the non-rectangular air cavity and the new rectangular air cavity (both oriented along the heat flow direction):

[5] Note that standard EN ISO 10211 states that air/gas cavities and layers should be considered as homogeneous materials with an equivalent thermal conductivity based on the thermal resistance determined by EN ISO 6946 or EN 673, i.e. type EQUIMAT.



The characteristic dimensions d and b (of the rectangular air cavity) are further used in the formulas below.

<u>Equivalent thermal conductivity of unventilated air cavity</u> (subtype CAVITY)
$\lambda_{eq} = (h_c + h_r) \cdot d$

- h_c = convective heat transfer coefficient (from warm surface to cold surface)
  if b < 0.005 m (EN ISO 10077-2), then
  $h_c = \frac{C_1}{d}$
  if b ≥ 0.005 m (EN ISO 10077-2) or for any b (EN ISO 6946), then
  $h_c = max\left\{\frac{C_1}{d}, C_2 \cdot (\Delta\theta_{ss})^{C_3}\right\}$
  $\Delta\theta_{ss}$ = maximum surface temperature difference in air cavity ($\Delta\theta_{ss}$ ≥ 5°C for EN ISO 6946)
  or $\Delta\theta_{ss} = \Delta\theta_{ss,default}$ (see C.2.5)

Standard	*Heat flow direction*	*C_1*	*C_2*	*C_3*	$\Delta\theta_{ss,default}$
EN ISO 10077-2	horizontal	0.025	0.73	0.333333	10°C
EN ISO 6946	horizontal	0.025	0.73	0.333333	5°C
	upward	0.025	1.14	0.333333	5°C
	downward	0.025	$0.09 \cdot d^{-0.44}$	0.187	5°C

- h_r = radiative heat transfer coefficient
  EN ISO 10077-2: $h_r = 4 \cdot 5.67 \cdot 10^{-8} \cdot (\theta_m + 273.16)^3 \cdot E \cdot F$
  EN ISO 6946: $h_r = 4 \cdot 5.67 \cdot 10^{-8} \cdot (\theta_m + 273.16)^3 / \left(\frac{1}{E} + \frac{1}{F} - 1\right)$
  $E = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$
  $F = \left(1 + \sqrt{1 + \left(\frac{d}{b}\right)^2} - \frac{d}{b}\right) / 2$
  $\theta_m = \frac{\theta_{s,min} + \theta_{s,max}}{2}$
  $\theta_{s,min}$ = minimum surface temperature in air cavity [°C]
  $\theta_{s,max}$ = maximum surface temperature in air cavity [°C]
  or θ_m = 10°C (default mean temperature, see C.2.5)
  ε_1, ε_2 = emissivities at warm and cold sides of air cavity (default values: $\varepsilon_1 = \varepsilon_2 = 0.9$)

<u>Equivalent thermal conductivity of slightly ventilated air cavity</u> (subtype CAVITY_E, standard EN10077)
An air cavity is considered to be slightly ventilated when there is an open connection to an exterior or interior boundary condition with a slit between 2 and 10 mm, and $d \geq b$.

λ_{eq} $= 2 \cdot (\lambda_{eq}$ of unventilated air cavity).

Equivalent thermal conductivity of air/gas layer (subtype LAYER)

- Standard EN ISO 6946: in the formula above for subtype CAVITY, set *d/b* = 0 for h_r.
- Standard EN 673:

  $\lambda_{eq} = (h_c + h_r) \cdot d$

  - h_c = convective heat transfer coefficient

    $h_c = Nu \frac{\lambda}{d}$

    With:

    $Nu = \max(1, A \cdot (Gr \cdot Pr)^n)$ or $Nu = 0$ in case of vacuum

    $Gr = \frac{9.81 d^3 \Delta\theta_{ss} \rho^2}{T_m \mu^2}$

    $Pr = \frac{\mu c}{\lambda}$

    $\Delta\theta_{ss}$ = maximum surface temperature difference in layer

    or $\Delta\theta_{ss}$ = 15°C (see C.2.5)

    $T_m = \frac{\theta_{s,min} + \theta_{s,max}}{2} + 273.16$

    $\theta_{s,min}$ = minimum surface temperature in layer [°C]

    $\theta_{s,max}$ = maximum surface temperature in layer [°C]

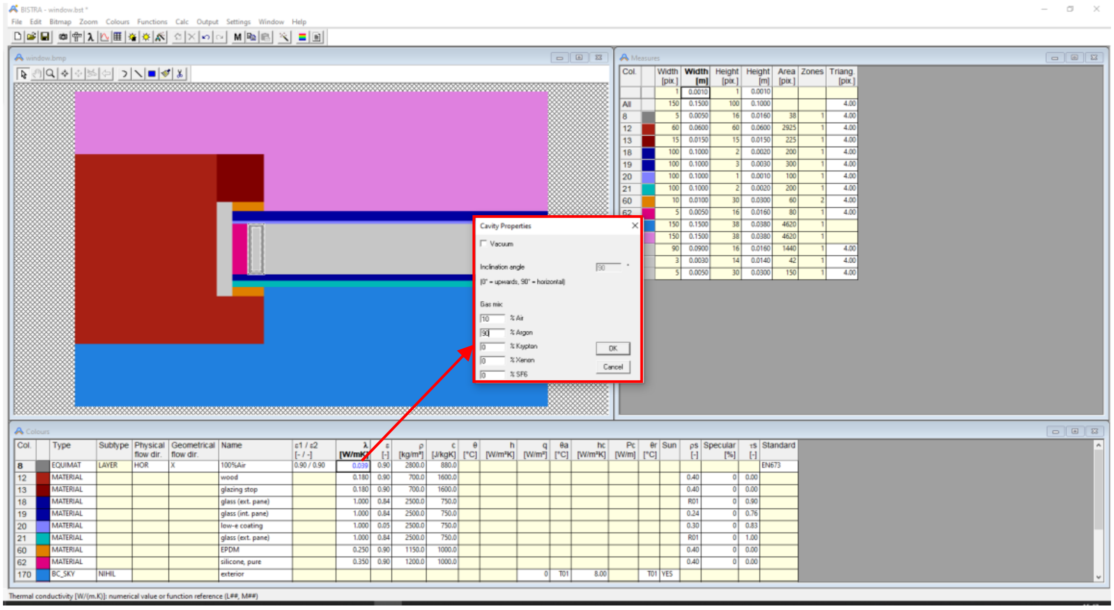
    or θ_m = 10°C (default mean temperature, see C.2.5)

Heat flow direction	*Inclination angle*	A	n
Downward	>90°	0	N.A.
Horizontal	90°	0.035	0.38
	45°	0.10	0.31
Upward	0°	0.16	0.28

(Values for h_c are interpolated for intermediate heat flow directions)

Gas	ρ	μ	λ	c
Air	1.232	$1.761 \cdot 10^{-5}$	$2.496 \cdot 10^{-2}$	$1.008 \cdot 10^{3}$
Argon	1.699	$2.164 \cdot 10^{-5}$	$1.684 \cdot 10^{-2}$	$0.519 \cdot 10^{3}$
SF_6	6.360	$1.459 \cdot 10^{-5}$	$1.275 \cdot 10^{-2}$	$0.614 \cdot 10^{3}$
Xenon	5.689	$2.226 \cdot 10^{-5}$	$0.529 \cdot 10^{-2}$	$0.161 \cdot 10^{3}$
Krypton	3.560	$2.400 \cdot 10^{-5}$	$0.900 \cdot 10^{-2}$	$0.245 \cdot 10^{3}$

(In case of a gas mix, the gas properties are proportioned in the ratio of the user-defined volume fractions)



- h_r = radiative heat transfer coefficient
  $h_r = 4 \cdot 5.67 \cdot 10^{-8} \cdot (\theta_m + 273.16)^3 \cdot E$
  $E = \dfrac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$
  $\varepsilon_1, \varepsilon_2$ = emissivities at warm and cold sides of layer (default values: ε_1 = ε_2 = 0.9)

<u>Adiabatic boundaries</u>
An adiabatic boundary (i.e. a boundary through which there is no heat transfer) can be considered as a symmetry axis (with symmetric heat flow pattern).
When there is an adiabatic boundary at one side of the width direction, the equivalent width *b* is automatically doubled for subtype CAVITY.
When there are adiabatic boundaries at both sides of the width direction, the equivalent width *b* is automatically considered to be infinite for subtype CAVITY (so *d/b* = 0, as for subtype LAYER).
If the air cavity touches a bitmap border, then the calculation parameter “Bitmap border is axis of symmetry” decides whether it is an adiabatic boundary (see C.2.5).

C.1.2. Colour type BC_SIMPL or BC_FRE_S

Purpose: simplified surface boundary condition (using a global surface heat transfer coefficient). For BC_SIMPL, the environment temperature is defined by the user. For BC_FRE_S, the environment temperature is unknown (free-floating).

Type	*Standard*	*Subtype*	*Physical heat flow*	*Meaning*
BC_SIMPL	NIHIL	NIHIL		Global surface heat transfer coefficient h and temperature θ defined by user
		HI		Global surface heat transfer coefficient h and temperature θ at interior surface defined by user
	EN10077	HI_NORML	horizontal	Normal h at interior surface: $h = 7.7\ W/(m^2.K)$, $\theta_i = 20°C$
		HI_REDUC	horizontal	Reduced h at interior surface: $h = 5\ W/(m^2.K)$, $\theta_i = 20°C$
		HE		h at exterior surface: $h = 25\ W/(m^2.K)$, $\theta_e = 0°C$
		HI_CAV_E	horizontal	Slightly ventilated air cavity: $h = 3.33\ W/(m^2.K)$, $\theta_i = 20°C$
		HE_CAV_E	horizontal	Slightly ventilated air cavity: $h = 3.33\ W/(m^2.K)$, $\theta_e = 0°C$
	EN6946	HI	horizontal	h at interior surface: $h = 7.7\ W/(m^2.K)$
			upward	h at interior surface: $h = 10\ W/(m^2.K)$
			downward	h at interior surface: $h = 5.9\ W/(m^2.K)$
		HE		h at exterior surface: $h = 25\ W/(m^2.K)$

C.1.3. Colour type BC_FREE

(This type requires the RADCON module, see Chapter H)

Purpose: enclosure with unknown (free-floating) air temperature (single thermal node) to be calculated from convective heat balance, and radiation based on view factors.

Type	*Subtype*	*Meaning*	*Standard*
BC_FREE	NIHIL	Thermal conductivity λ defined by user	NIHIL
	CONVEC	Large air space, without preferential heat flow direction*	NIHIL
	CAVITY	Unventilated (internal) air cavity with given heat flow direction	EN6946
	LAYER	Unventilated air layer with given heat flow direction	EN6946 EN673

*typically larger than 0.3m

CAVITY and LAYER:
The CAVITY and LAYER subtypes are to be used when a global heat flow direction is assumed (surface-to-surface heat transfer with an air temperature in between temperature of 'hot' and 'cold' surface temperatures, e.g. typically used for a cavity in a façade).
The characteristic dimensions of the air cavity, *d* (= depth, parallel to heat flow) and *b* (= width), are calculated as for colour type EQUIMAT (see C.1.1).
The convective surface heat transfer coefficient h_c is calculated as for colour type EQUIMAT (see C.1.1). The values calculated according to the different standards in C.1.1 are defined however as surface-to-surface. Since the convective surface heat transfer coefficient h_c for BC_FREE is surface-to-air, the values calculated in C.1.1 are doubled.
h_c = convective surface heat transfer coefficient (surface-to-air)
$h_c = 2 \cdot (h_{c,EQUIMAT})$

CONVEC:
The subtype CONVEC must be used when no global heat flow direction can be assumed in the enclosure (surface-to-air heat transfer with an air temperature higher or lower than surface temperatures, e.g. typically used for a room).
h_c= convective surface heat transfer coefficient (surface to air)
$h_c = 2 \cdot C_2 \cdot (\Delta\theta_{sa})^{C_3}$
$\Delta\theta_{sa}$= greatest difference between air temperature and surface temperature
$\Delta\theta_{sa} = \max\left(|\theta_a - \theta_{s,min}|, |\theta_a - \theta_{s,max}|\right)$
θ_a = air temperature
$\theta_{s,min}$ = minimum surface temperature in contact with given boundary condition colour
$\theta_{s,max}$ = maximum surface temperature in contact with given boundary condition colour
or $\Delta\theta_{sa}$= calculation parameter "Default temperature difference for h_c calculation (subtype CONVEC)" (see C.2.5)

Heat flow direction	*C_2*	*C_3*
horizontal	0.73	0.333333
upward	1.14	0.333333
downward	0.09	0.187

C.1.4. Colour type BC_SKY or BC_NOSKY

(This type requires the RADCON module, see Chapter H)

Purpose: environment with known air temperature and either user defined radiation temperature (BC_SKY) and radiation based on view factors or no radiation exchange (BC_NOSKY).

Type	*Subtype*	*Meaning*
BC_SKY or BC_NOSKY	NIHIL	Convective surface heat transfer coefficient h_c defined by user
	CONVEC	Natural convection surface-air (calculation of h_c: cf. above BC_FREE - CONVEC, see C.1.3)

C.1.5. Colour type TRANSMAT

(This type requires the RADCON module, see Chapter H)

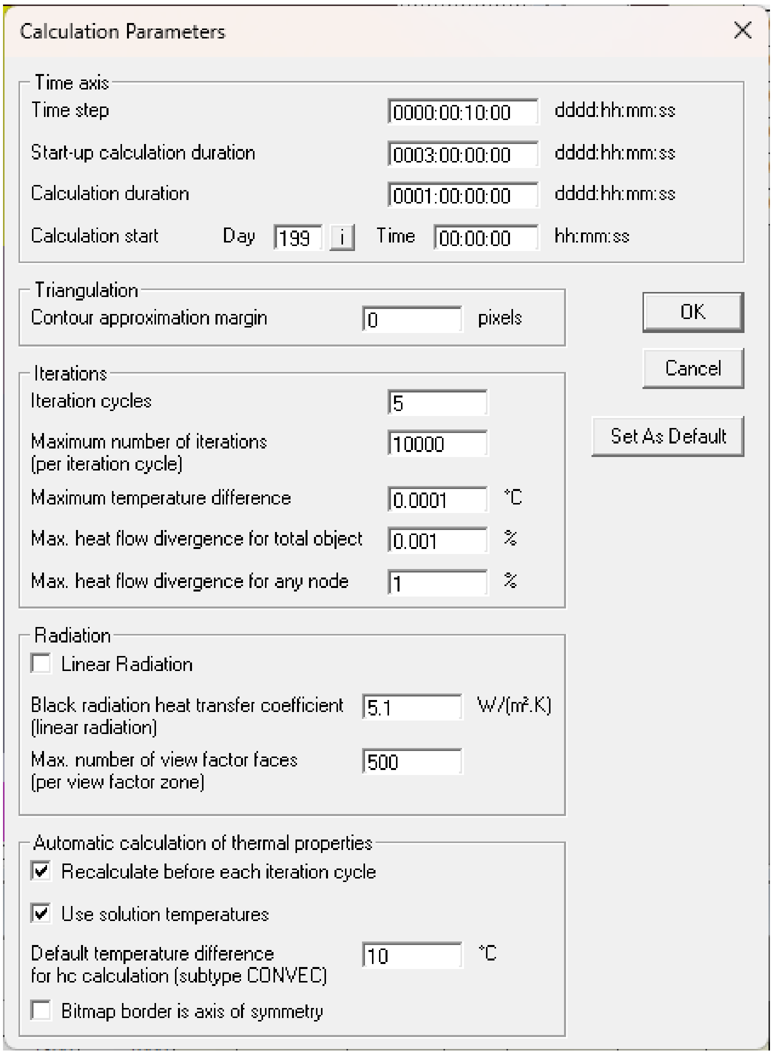
Purpose: air cavity modelled as *transparent material* (radiation based on view factors, cf. radiosity method (EN ISO 10077-2), and *equivalent thermal conductivity* λ_{eq} for convective heat transfer)

Type	*Subtype*	*Meaning*	*Standard*
TRANSMAT	NIHIL	Thermal conductivity λ defined by user	
	CAVITY	Unventilated air cavity with given heat flow direction or along temperature gradient* (calculation of λ_{eq}: cf. above EQUIMAT, CAVITY with h_r = 0, because radiation is calculated using view factors)	EN10077 EN6946
	LAYER	Unventilated air layer with given heat flow direction (calculation of λ_{eq}: cf. above EQUIMAT, LAYER with h_r = 0, because radiation is calculated using view factors)	EN6946 EN673

*Geometrical flow direction: DIR

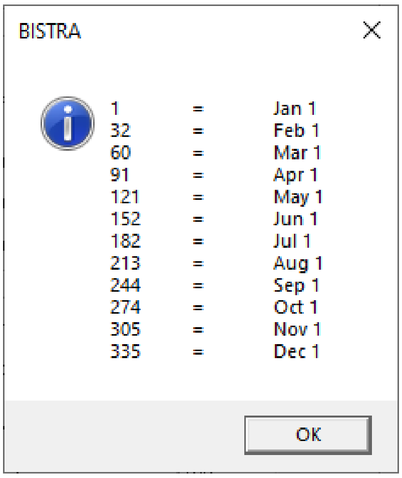
C.2. Calculation parameters

A system calculation (*Calc → Calc System*) is controlled by calculation parameters.
The menu command *Edit → Calc Parameters...* opens a dialog box in which the calculation parameters can be edited. The parameters not relevant to the current BISTRA document are disabled (greyed in the dialog box).



C.2.1. Time

- <u>Time step</u>: this is the time distance between two successive dynamic system calculations (time format: days, hours, minutes and seconds separated by colons).
- <u>Start-up calculation duration</u>: this is the time duration before the actual start of the calculation (where reporting starts) with the purpose to get good dynamic start values. The boundary condition values of time-dependent functions are taken before the time origin of those functions, so that the actual calculation (at the end of the start-up calculation duration) starts at time 0. Internal functions which are not periodic (i.e. functions of type STEP0 and STEP1), get the function value at time 0 during the entire start-up calculation duration. Periodic functions are extended for negative time values with the same periodic function course. For external functions the "previous function" is taken, as defined in the function editor FUNCEDIT (cf. Chapter F).
- <u>Calculation duration</u>: duration of the dynamic calculation during which time step results and report items can be saved (e.g. to produce a graphic animation).
- <u>Calculation start</u>: definition of the day number (between 1 and 365) and exact time of day to indicate the moment in the year where the calculation starts. This is important when the used (external) function is related to a calendar date: e.g. a test reference year, with hourly climatic data of a typical year in a given location. The start date of the external function or weather data file may be different from the start date of the calculation. The button "i" near the input field gives, when pressed, the day numbers for the first day of each month for information.



In case of solar radiation functions (G## and D##) using an external data file with data formatted as a step function (B.12.2) or a weather file (B.12.3), the time step and calculation start have to be defined in such a way that the simulation hits the hours precisely. If this condition is not met, an error message is shown when starting the calculation.

C.2.2. Triangulation

<u>Contour approximation margin</u>
Defines the maximum allowed distance between the original bitmap colour contours and the approximated contours used in the triangulation.
Normally the margin is set to 0 (e.g. for bitmaps converted from CAD drawings).
For bitmaps from scanned images, with some scan noise, apply a small margin ≤ 1.

C.2.3. Iterations

<u>Iteration cycles</u>
An iteration cycle is part of a system calculation (cf. section C.3), and involves building and solving a linear system of equations. A non-linear system is solved by stepwise linearisation. Each step using new linearised coefficients corresponds to an iteration cycle. This is needed for automatic refinement of calculated thermal properties (equivalent thermal conductivities and convective heat transfer coefficients) or non-linear infrared radiation. Before each new iteration cycle the linearised thermal resistances are recalculated based on the last available solution (i.e. from the previous iteration cycle).
The given number of iteration cycles is only applied for the first time step (i.e. solution of the initial steady-state system, cf. section C.4). If the initial temperature differences are rather high, the number of iteration cycles should also be high (to get reliable start values of temperature dependent thermal properties). For the next time steps there is always only one single iteration cycle (independent of the given number of iteration cycles in the Calculation Parameters dialog box).

<u>Iteration stopping criteria</u>
The linear system of each iteration cycle is solved using an iterative method.
The iteration process is stopped when the *maximum number of iterations* (given as calculation parameter; by default 10000) is reached, or more likely when all three following conditions are fulfilled:

- *Temperature difference condition*
  For every system node the absolute value of the difference between the temperatures

obtained in the current and previous iteration step must be smaller than the parameter *maximum temperature difference* (by default 0.0001°C).

- *Energy heat balance for the total object*
  The residual heat flow into or outside the object compared to the total heat flow passing through the object must be less than the parameter *maximum heat flow divergence for total object* (by default 0.001 %).
- *Worst energy heat balance for all control volumes*
  For all system nodes the residual heat flow into or outside the control volume compared to total heat flow passing through the control volume must be less than the parameter *maximum heat flow divergence for any node* (by default 1 %).

Definition of heat flow divergences: see section C.9.

C.2.4. Radiation

(see Chapter H for more on view factor based radiation heat transfer)

Linear radiation

The linear radiation between two black surfaces is:

$q_r = F_{ij} \cdot h_{rb} \cdot (\theta_i - \theta_j)$

q_r = radiation heat flux [W/m^2]

F_{ij} = view factor from surface i to surface j (= fraction of radiation leaving surface i that is intercepted by surface j)

h_{rb} = black radiation heat transfer coefficient [W/(m^2.K)]

θ_i = temperature of surface i [°C]

θ_j = temperature of surface j [°C]

The linear radiation between grey surfaces, having an emissivity (as defined in the **Colours window**), is derived from the radiation between the black surfaces by adding supplementary resistances between the grey and black surface nodes (cf. section H.2).

The *black radiation heat transfer coefficient* is a calculation parameter. The default value is 5.1 W/(m^2.K) (as in EN 673).

Non-linear radiation

When non-linear radiation is wanted, the coefficient h_{rb} is locally adjusted in function of the surface temperatures, before each new iteration cycle. The surface temperatures are known from the previous iteration cycle, or else from the previous existing solution file (when a calculation is restarted). For the first iteration cycle when no solution file is present, the calculation parameter "black radiation heat transfer coefficient" is used.

The non-linear radiation model is physically more precise than the linear model (cf. section H.2).

Calculation of view factors

The view factors calculation between elementary surfaces is affected by the parameter *Maximum number of view factor faces (per view factor zone)*: radiative triangle sides are clustered into larger view factors if the number of triangle sides in a view factor zone exceeds this parameter. In general, the *view factor triangulation* may be less fine than the *system triangulation* without loss of accuracy. The default value is 500.

C.2.5. Automatic calculation of thermal properties

(See section C.1 for an overview of all automatically calculated thermal properties)

- *Recalculate before each iteration cycle*: the automatically calculated thermal properties (equivalent thermal conductivities and convective heat transfer coefficients) are recalculated before each iteration cycle (see C.2.3).

- *Use solution temperatures*: the automatically calculated thermal properties are updated using the last available solution temperatures. If this option is unchecked, default temperature values (mean temperature inside cavity/layer of 10°C, and fixed temperature difference as imposed by the relevant standard (see C.1.1, C.1.3 and C.1.5) or as defined by the calculation parameter *Default temperature difference for hc calculation (subtype CONVEC)* for colours not according to a standard (no value in 'Standard' column, see B.10).
- *Bitmap border is axis of symmetry*: the bitmap border acts as adiabatic boundary condition (without absorption and only diffuse reflection, which affects the radiative heat transfer via the view factors for cavities adjacent to the bitmap border).

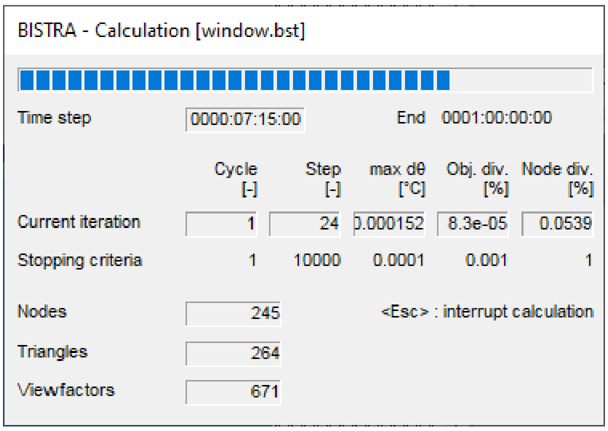
During the input (i.e. editing in the **Bitmap window**, **Measures window** or **Colours window**) the automatically calculated thermal properties λ_{eq} en h_c always assume default temperature values (mean temperature of 10°C, and fixed temperature difference as imposed by the relevant standard (see C.1.1, C.1.3 and C.1.5) or as defined by the calculation parameter "Default temperature difference for h_c calculation (subtype CONVEC)" for colours not according to a standard (no value in 'Standard' column, see B.10).

Contrary to BISCO, the user-defined geometric heat flow direction (X or Y, see B.10) is never updated according to the calculated mean temperature gradient in BISTRA.
The geometrical heat flow direction "DIR" follows the local temperature gradient and requires that both calculation parameter options "Recalculate before each iteration cycle" and "Use solution temperatures" are checked.

The updated automatically calculated thermal properties (λ_{eq}, h_c) at every iteration cycle (based on the last available solution temperatures) are not refreshed in the **Colours window** (as opposed to BISCO). The changed values can only be viewed in a report output (cf. sections B.20 and E.4).

C.3. System calculation

After the input of data is finished, a calculation can be started with the command *Calc → Calc System.* First the automatic triangulation and calculation of view factors (if required) are executed (as in BISCO), then the dynamic system calculation is started. During the system calculation a monitor is shown containing the current time step, the iteration parameters (as in BISCO) for the current time step, the number of system nodes, triangles and view factors.



If a start-up calculation is requested, first the start-up time steps are shown (from time 0000:00:00:00 up to the total start-up duration). Neither reporting nor solution saving is done during the start-up duration. After finishing the start-up calculation, the normal calculation duration begins. The time steps of the normal calculation duration are shown again starting from time 0000:00:00:00. During the normal calculation, reporting and solution saving are possible.

At the end of the calculation a report file is written, when at least 1 report item is defined in the **Report Definition window** (cf. sections B.20 and B.21). The content is the same as in the Report output (cf. section E.4). The report file has the same file name as the data file, and has the extension .txt.

A calculation can be interrupted at any time by pressing the <Esc> key. If the "Save step solutions to disk" option is enabled in the Save Frequency dialog box (cf. section B.22), the solution files up to the last calculated time step can be viewed in the **Graphics Output window** and **Text Output window**. If a report definition is given (cf. section B.20), the report records up to the last calculated time step can be viewed in the **Text Output window**.

If a calculation is restarted after it has been interrupted, the calculation restarts from the very beginning without reuse of the already calculated time step solutions.
It is possible to start from a predefined solution file StartBistra.sol (cf. next section), to get an initial temperature distribution.

C.4. Calculation principles

For the first time step (of the start-up calculation duration if requested, else of the normal calculation duration) a steady-state system (as in BISCO) based on the boundary condition function values evaluated at the initial time is set up and solved. Multiple iteration cycles (as defined as calculation parameter) are used to get good initial temperature dependent properties. If the initial temperature differences of the steady-state system are high, the number of iteration cycles should also be high (so that the temperature dependent thermal properties converge to stable values).

If a start solution (defined as .sol file) should be adopted at the first time step (of the start-up calculation duration if requested, else of the normal calculation duration), this solution should be renamed to the fixed file name StartBistra.sol in the directory of the .bst input data file.
The start solution is only used if this solution is compatible with the current triangulation (i.e. same number of nodes, same number of triangles, same number of boundary condition edges).
Delete the file StartBistra.sol after the calculation, otherwise it will be reused as start solution (if compatible with the triangulation) in all following calculations.

For the next time steps the boundary condition function values are updated and the material volume capacity is taken into account. The Cranck-Nicolson finite difference method is used to formulate the energy balance for all control volumes around material nodes. For all other nodes without capacity (e.g. black surface nodes, radiation and convection nodes of a boundary condition) the energy balance at the current time step is formulated.
Only 1 iteration cycle per next time step is considered, even if the calculation parameter "number of iteration cycles" has a higher value. This supposes fluent boundary condition changes (no abrupt discontinuities) during the calculation period.

When the thermal conductivity and/or specific heat of some materials are defined as temperature dependent functions, those properties are adapted before each new iteration cycle (of the steady-state system for the first time step) and each next iteration step based on the obtained temperatures in the previous iteration cycle or previous time step.

Automatically calculated thermal properties are recalculated (if required by the corresponding setting in the Calculation Parameters dialog box, see C.2.5) before each iteration cycle or time step, and can be reported in the output report (see variables of type λ_{eq} and h_c in the report definition; cf. section B.20), but the initial values in the **Colours window** are not updated (as opposed to what happens in BISCO, where the recalculated values are refreshed in the **Colours window**).

C.5. Automatic triangulation

Before starting the triangulation, the BISTRA data are saved to a BST file.
The result of the triangulation is written to a TRI file in the same directory of the BST file.
The resolution of the coordinates of the triangulation vertices is 16 times finer than the pixel resolution of the bitmap.
When a TRI file with the same file name as the BST file name already exists, the user is asked to keep this TRI file (and skip the triangulation, which is valid when the geometry is not modified) or to redo the triangulation (and overwrite the existing TRI file).

The following parameters are used for the triangulation:

- The contour approximation margin (calculation parameter).
- The triangulation mesh sizes (per material colour, defined in the **Measures window**).

The triangulation consists of the following steps:

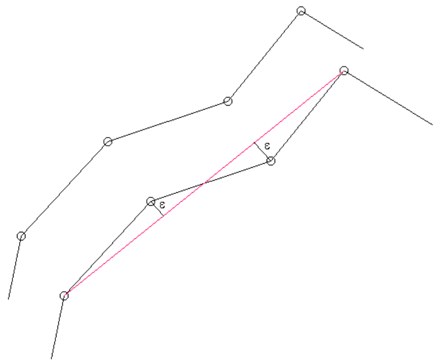
- Contouring.
- Straightening contours.
- Calculation of inner nodes.
- Creation of the triangulation mesh.

C.5.1. Contouring

Contouring is the process of finding the borderlines between the colour zones in the bitmap, and connecting them into polygons. Only the contours of the colours assigned to materials (type MATERIAL, EQUIMAT and TRANSMAT) are created.
Step lines in the bitmap are converted into slanting lines. The contouring is done in a reversible way, so that rasterising the contours would yield the original bitmap.

C.5.2. Straightening contours

The purpose of straightening is to reduce the number of contour edges by skipping redundant vertices, so that the new contours lay within the contour approximation margin ε (defined as calculation parameter; cf. section C.2.2) with respect to the original contours.



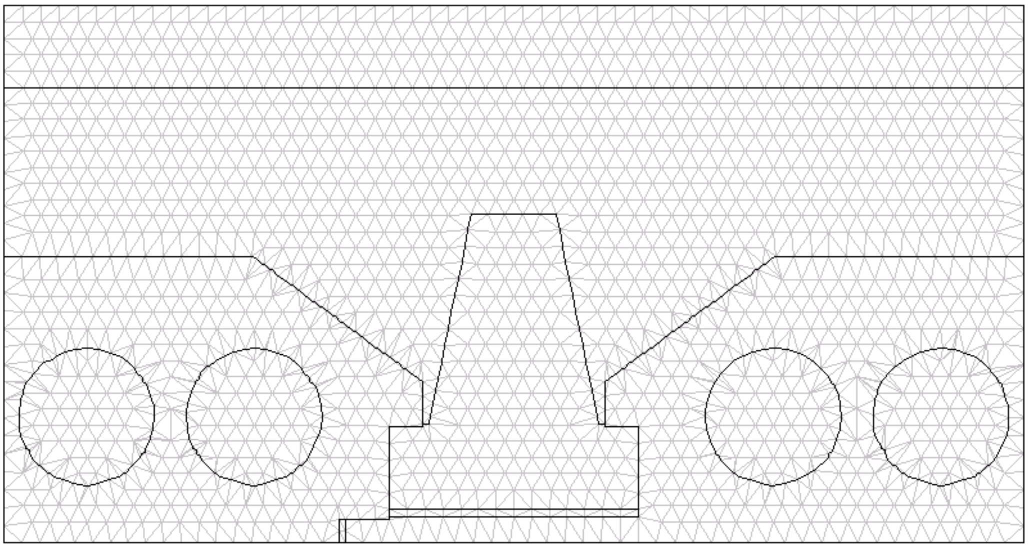
Sometimes straightening can cause problems, when self-intersecting contour edges are created.
That is why the contour approximation margin ε should not be chosen too large.
For bitmaps derived from CAD drawings, straightening normally should not be applied ($\varepsilon = 0$).
For bitmaps of scanned images, where scan noise may be present, apply a small margin: $\varepsilon \leq 1$.

C.5.3. Calculation of inner nodes

Inner nodes are positioned within each material upon a hexagonal grid (in order to obtain equilateral triangles).
Each contour line longer than the triangulation mesh size (for the two colours at both sides of the contour line) is split into shorter segments by inserting new nodes on the contour line.

C.5.4. Creation of the triangulation mesh

The contour nodes and inner nodes are used to form triangles so that the smallest triangle angle occurring is maximal. This principle (Delaunay triangulation) assures the best possible triangulation mesh for finite element analysis. A good triangulation mesh allows to generate a well-conditioned system, which guarantees a fast and stable solution.



C.6. Unlinking air temperatures in cavities of type BC_FRE_S or BC_FREE

A cavity or layer (filled with air or any other fluid) can be modelled using several (adjacent) blocks having different colours. These colours can have different thermal properties (e.g. surface heat transfer coefficient), but must have the same type (i.e. all BC_FRE_S or all BC_FREE). Otherwise the calculation is immediately stopped, with the error message "BC (colour ...) touches other BC of different type".

The default implementation is to assume that all these adjacent colours making up the cavity or layer are linked.

- If the cavity is modelled with colours all of type BC_FRE_S, then this means that all colours get the same (unknown) environmental temperature, which is calculated solving the system. Possible convective heat powers for the individual colours in the same air cavity (column Pc in the **Colours window**) are cumulated and allocated to the central convection node (having the single environmental temperature).
- If the cavity is modelled with colours all of type BC_FREE (only possible with the RADCON module), then the radiative heat transfer is calculated taking together all these colours forming one zone in which all view factors are calculated. The convective heat transfer is calculated with reference to one central convection node (having an unknown air temperature).

This default behaviour can be changed. An air cavity can contain more than 1 convection node by using several colours in that cavity and unlinking those colours. For each unlinked colour and for the remaining block of not unlinked colours in the same air cavity a separate convection temperature will be calculated using separate convective heat balances (based on the surface temperatures and convective heat transfer coefficients of the adjacent material surfaces, and on the injected convective heat power). The radiative heat balance (in case of BC_FREE cavity) remains unchanged, i.e. considering the global air cavity in which all view factors are determined.

A colour can be manually unlinked by adding per colour (that you want to unlink) a text line at the end of the BISTRA data file (with extension .bst) using a text editor (e.g. Windows Notepad). The syntax of this line is:

unlk=c

where c = colour number (0..255) for unlinked colour.

When considering ventilation flows through different air zones (cf. section B.19 and C.7), the air temperatures of these zones are automatically made unlinked.

C.7. Processing ventilation flows

When ventilation flows are present in the input data, the system matrix is not symmetrical anymore, and therefore each iteration cycle is split in two successive subtasks:

- First the solution of a small subsystem of only convection nodes into which ventilation flows are injected. The number of these ventilation nodes is always less than or equal to the number of colours of type BC_FRE_S or BC_FREE (so ≤ 256). The surface temperatures that affect the convection nodes are considered as fixed boundary condition values (as obtained by the solution of the second subtask).
  The ventilation subsystem has an unsymmetrical system matrix, but has a limited number of unknowns (i.e. the temperatures of the ventilation nodes, always ≤ 256), and is solved using a direct solution method.
- Secondly the solution of the ventilation replaced system, i.e. the whole system in which the calculated temperatures of the ventilation nodes are considered as fixed boundary conditions. This system has a symmetrical system matrix, and can be solved using an optimised iterative method.
  The calculated surface temperatures adjacent to ventilation zones are taken as fixed boundary condition values in the next ventilation subsystem to solve.

In the very first iteration cycle (i.e. of the first time step) no initial values of the surface temperatures are known (as required by the first subtask). The complete system is then solved without any ventilation flows to get start values for the surface temperatures for the first subtask of the next iteration cycle.

When ventilation flows are present, a variable number of iteration cycles is executed per iteration step independent of the given maximum number of iteration cycles as defined in the Calculation Parameters dialog box. The number of iteration cycles per iteration step is automatically stopped when all temperature differences between the calculated temperatures in the ventilation nodes of the current and previous iteration cycle are smaller than the given maximum temperature difference in the Calculation Parameters dialog box (a typical value is 0.0001°C, see C.2.3). However it may be possible (dependent on the input data) that there will be no convergence. In this case the iteration cycles are also stopped when any temperature difference of a ventilation node between the current and previous iteration cycle is greater than 1000000°C. The program resets all node temperatures of the whole system to 0°C, and the user is prompted to inspect and alter the input data.

C.8. Solar radiation processing

The solar processor is activated when:

1. A solar zone is present: i.e. a colour of type BC_SIMPL or BC_SKY with sun flag set (defined in **Colours window**, column "Sun", toggle value set to YES).
2. Solar radiation data are present: both a function G01 and a function D01 must be defined in the **Functions window** (B.12) in case of a real sun path (B.15.1); and a function I01 must be defined in the **Functions window** (B.12) in case of a fixed sun position with variable radiation (see B.15.2).
   G01 refers to a function for the global solar radiation (in W/m^2) on a horizontal surface.
   D01 refers to a function for the diffuse solar radiation (in W/m^2) on a horizontal surface.
   I01 refers to a function for the total solar radiation (in W/m^2) in a user-defined direction.

Input parameters with respect to the solar processor:

- The solar data as defined in the Solar Data dialog box (see B.15)
- Per material: solar reflection factor, specular part of the direct solar radiation reflection, and solar transmission factor (see C.8.1).
  These material properties are defined in the last three columns of the **Colours window** (see B.10).
  A solar reflection factor function is referenced by R##, with ## = 01 to 99, and refers to the **Functions window** (see B.12.2).
- Calculation start day and time (*Edit → Calc Parameters...*, cf. section C.2.1). A calculation may be preceded by a pre-calculation period (to get dynamic start values of the node temperatures).
- Sun obstacles: shadow zones of other objects around the input bitmap, defined by spherical angular coordinates in the horizontal coordinate system (*Edit → Sun Obstacles*, cf. section B.16).

At every time step the solar load, calculated in 3D, on the 2D object model is calculated (see C.8.2 for external surfaces, C.8.5 for internal surfaces, and C.8.6 for opaque surfaces behind transparent materials). The solar load is expressed as a calculated node power (in W/m) per system node. These node powers are used as supplementary boundary conditions of the thermal system besides the other boundary conditions (e.g. the external temperature).

C.8.1. Definition of solar properties ρs and τs for MATERIAL

For each colour of type MATERIAL, the solar reflection factor (ρs) and the solar transmission factor (τs) need to be defined in the **Colours window** (see B.10).

For incident direct solar radiation the actual value of ρs may be dependent on the angle of incidence, if defined by a solar reflection factor function referenced by R## (see B.12.2).

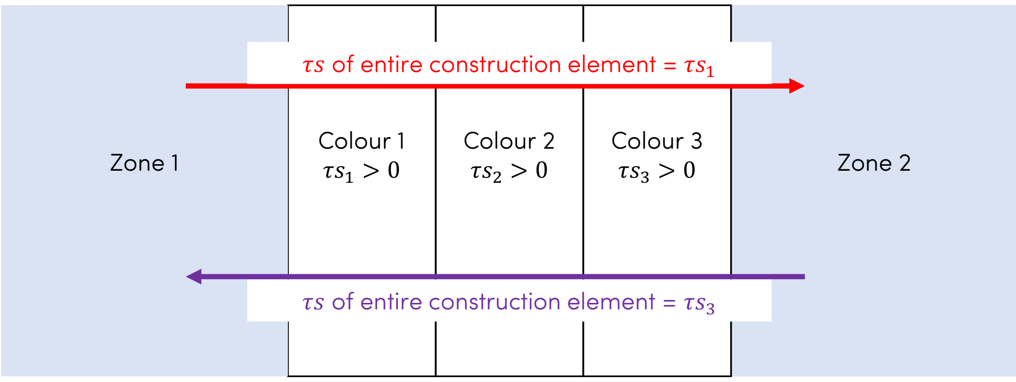
There are two important calculation aspects to consider when quantifying these solar properties as inputs for a colour of type MATERIAL:

1. The solar reflection factor (ρs) and solar transmission factor (τs) are applied at the contact of a surface with a zone.
   A *zone* in this context is either a solar zone (BC_SIMPL or BC_SKY) or an internal zone with detailed radiation calculation (BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT).

If a colour of type MATERIAL in contact to the source zone from which the radiation enters has a solar transmission factor τs equal to 0, it is an *opaque material* (see C.8.5).

A *transparent construction element* in BISTRA consists of a single colour of type MATERIAL with τs > 0 or a system of adjacent transparent colour layers of type MATERIAL with τs > 0 or of type EQUIMAT (always assumed τs = 1).

Within a system of adjacent transparent colour layers from a zone up to the next zone, only ρs and τs at the outer surface of the first colour layer (in contact to the source zone from which the radiation enters) are considered. τs can thus be understood as a property of the entire system of adjacent material layers and not just the material layer in contact to the source zone, it is good practice to give all adjacent enclosed material layers the same τs value in the **Colours window**.



A system of adjacent transparent material layers can alternatively be placed between a source zone from which the radiation enters and an opaque material (τs = 0). This is discussed in C.8.6.

2. The solar transmission factor τs in BISTRA is applied *after* subtraction of the solar reflection (which can be dependent on the angle of incidence of solar radiation).

   Typically, the solar reflection, transmission and absorption are defined relative to the total incoming radiation, so
   $\rho + \tau + \alpha = 1$
   Or for normal incidence (angle of incidence 0°):
   $\rho_0 + \tau_0 + \alpha_0 = 1$

   However, for the input value of τs in BISTRA, after subtraction of reflection ρs, applies:
   $\tau s + \alpha s = 1$.

   The input value of τs in BISTRA can be calculated from the typical solar properties at normal incidence (angle of incidence 0°) ρ_0 and τ_0:
   $\tau_0 = (1 - \rho_0) \cdot \tau s$ or $\boxed{\tau s = \frac{\tau_0}{1-\rho_0}}$

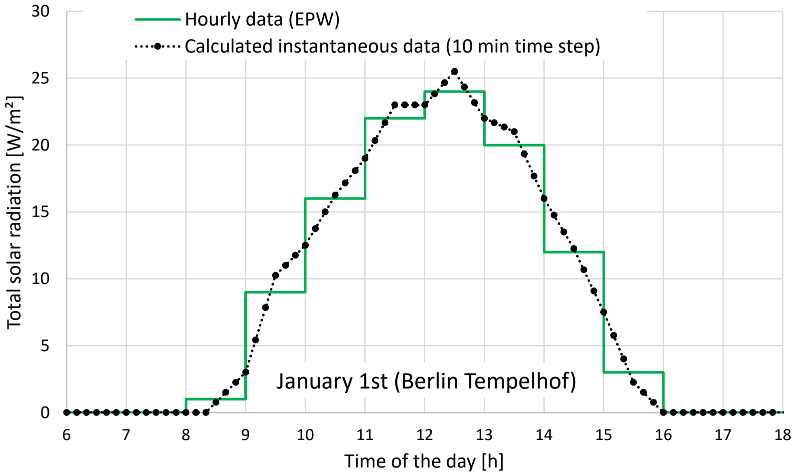
C.8.2. Irradiance: solar load to external surfaces

An *external surface* is a surface of an object (with colour type MATERIAL) in direct contact with a *solar zone* (colour type BC_SIMPL or BC_SKY, and sun flag set in column "Sun" in the **Colours window**).

The position of the sun is calculated at the current simulation time (day of year, clock time) and the geographical location (latitude, longitude, time zone) [6]. Daylight savings time is not taken into account. The position of the sun is located by two angular measures: azimuth (horizontal clockwise angle between the sun position and south) and altitude (angle between the sun position and the horizon). The azimuth of the sun at a fixed clock time may differ for different days of the year due to the irregular movement of the sun (defined by the equation of time): e.g. the azimuth at 12 a.m. solar mean time for every day fluctuates around 0° (= south direction).

For the current time step the actual global solar radiation and diffuse solar radiation (in W/m^2) on a horizontal surface are derived from the corresponding external data files (see B.12.2) or weather data files (see B.12.3). Typically these weather data files contain hourly values. Values at simulation times are derived through simple linear interpolation in case of an external data file with linear function format (see B.12.2).

In case of an external data file with step function format (see B.12.2) or a weather data file (see B.12.3), the values in the external data file are converted to instantaneous values at simulation times using a mathematical algorithm[7]. This algorithm takes the empirically calculated times of sunrise and sunset into account and produces instantaneous solar radiation values for any defined time step. The resulting solar radiation profiles ensure that the total solar radiation received matches the information in the data file, and have 'realistic' (though obviously estimated) shapes without discontinuities.



All produced instantaneous solar radiation values at simulation times are used in BISTRA as average values over the simulation time step, where the simulation time is understood as the middle of the simulation time step (since the solar angles are calculated at each simulation time).

For each external surface the angular position against the north direction is computed: orientation (compass direction) and tilt (height above horizon). From the global and diffuse solar radiation on a horizontal surface, the direct and diffuse solar irradiance on the area around each node of the external surface is calculated.

The direct solar irradiance is derived from the direct solar radiation on a horizontal surface and the position of the sun. If the sun is not hidden by any sun obstacle (as defined in the **Sun Obstacles window**), a test ray from the surface node towards the sun is inspected on possible intersections with other (non-transparent) object surfaces (present in the bitmap). When there are

[6] Roy G. et al., A note on solar declination and the equation of time, Architectural Science Review, Vol. 32, p. 43-51 (1989)
[7] McDowell T. et al., A new method for determining sub-hourly solar radiation from hourly data, Proceedings of the 2018 Building Performance Analysis Conference and Simbuild, p. 518-252 (2018)

no intersections, the node is sunlit. Otherwise the node is shaded and the direct solar irradiance on the area around the node is cancelled.

The estimation of the diffuse solar irradiance on the area around the node of the external surface is more complex.

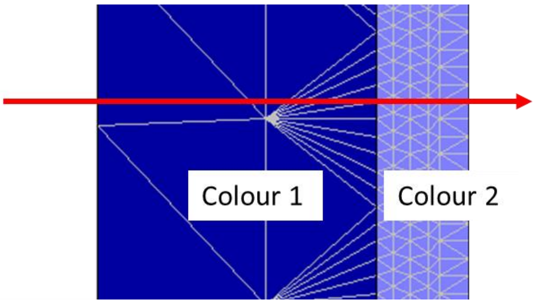
- First the sky visibility from the elementary area around the node is used as reduction factor of the diffuse radiation. The sky visibility is calculated using 100 test rays from the node with random direction on the hemisphere above horizon. For all directions at the front side of the surface, the sky visibility is estimated as the fraction of the test rays not shaded by any sun obstacle or other (non-transparent) object in the bitmap. This is a good estimation of the view factor to the open sky from the elementary area around the node.
- Secondly the diffuse radiation depends on the tilt of the surface.
  In an isotropic diffuse model the diffuse radiation on a sloped surface is proportional to the square of the cosine of half the tilt angle. E.g. the diffuse radiation on a vertical surface is half the diffuse radiation on a horizontal surface (i.e. the surface only sees half of the sky dome).
  BISTRA uses the more correct anisotropic diffuse model developed by Muneer[8], which also distinguishes between shaded and sunlit surfaces and between overcast and non-overcast conditions of the sunlit surfaces. The required parameters can be derived from sun position, slope, orientation, day of year, sunlit status, sky visibility, global and diffuse solar radiation data on a horizontal surface.
- Finally radiation reflected from the ground in front of the surface, must be added. This radiation is assumed isotropic, and is a function of the global solar radiation on a horizontal surface, the tilt of the surface, and the ground reflection factor, which is an input parameter in the Solar Data dialog box (normal value = 0.2). The ground reflected radiation on a vertical surface is half the ground reflected radiation on a horizontal downward surface.

If the solar zone is of type BC_SIMPL, then the reflected (direct or diffuse) solar radiation from an external surface is further ignored. If the solar zone is of type BC_SKY, this reflected solar radiation is further processed (see C.8.4).

C.8.3. Absorption of solar radiation

For an opaque external surface (with solar transmission factor equal to 0, see C.8.1), the radiation that is not reflected is absorbed. The absorbed solar radiation is converted to node powers in the surface nodes.
For a transparent external surface (with solar transmission factor greater than 0, see C.8.1), some part of the solar radiation is transmitted to internal zones (see C.8.5) or to an opaque surface behind the transparent construction (see C.8.6). The remainder of the solar radiation is absorbed. The absorbed solar radiation is equally distributed as additional node powers over all nodes (limited to 10000) nearest to the normal of the external surface up to the opposite contact surface with an internal zone or opaque surface. The triangulation size should thus not be too small, because transmitted solar radiation can only pass through a limited number of 10000 of adjacent material triangles from surface to surface. Note also that if the transparent construction element consists of a number of adjacent transparent colour layers (see C.8.1), a different triangulation mesh size of the colour layers (as defined in the **Measures window**, see B.9) will result in unevenly distributed absorbed solar radiation over the thickness of the transparent construction element, as each node receives the same amount.

[8] Muneer T., Algorithms for estimating hourly solar irradiation on slopes, Building Serv. Eng. Res. Technol. 10(2), p. 81-83 (1989)



The report outputs Qsol and qsol or absorbed solar heat flow and flux (see B.20) are always given for the colour for which the relevant solar property τs is defined (see C.8.1). In case of a transparent construction element consisting of a number of adjacent transparent colour layers, only the colours in contact to the source zone from which the radiation enters thus will have non-zero Qsol and qsol outputs, even though the absorbed radiation is distributed over the entire thickness of the transparent construction element consisting of a number of adjacent transparent colour layers for the thermal solution.

C.8.4. Processing of reflection

Reflection is only processed in zones with detailed radiation calculation (BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT), so not in solar zones of type BC_SIMPL.

For direct radiation, if the reflection factor ρs of the surface is angle dependent (cf. definition of the material colour in the **Colours window**, see B.10), then this factor is determined through interpolation between the values in the solar reflection function file for the actual angle of incidence (angle between direct solar radiation and surface normal).
The reflection factor for diffuse radiation is the weighted mean value of the reflection factors for all possible angles of incidence.

If the specular part of the direct solar radiation reflection of the surface is greater than 0% (cf. definition of the material colour in the **Colours window**, see B.10), then this specular reflection of a direct solar radiation ray that hits the object surface is propagated following the mirroring direction (with angle of reflection equal to angle of incidence, and in the same plane of incident ray and object surface normal) up to the next object material surface, where the same process is repeated. If the specular reflection ray hits no object, this radiation is lost. Once a reflected direct solar radiation ray is smaller than 0.001 W, it is further ignored (as a stop criterium of the ray tracing method). Alternatively, after a maximum of 1000 tracing iterations of a ray, the ray tracing is stopped.

Diffusely reflected radiation originates from either incoming diffuse radiation or incoming direct radiation if the specular part of the direct solar radiation reflection of the surface is smaller than 100% (cf. definition of the material colour in the **Colours window**, see B.10). This reflected radiation is ideal diffuse (following Lambert's cosine law) and is again reflected, transmitted and absorbed. The final contributions of additional absorption on all surfaces are calculated using the radiosity method.
The radiosity of each elementary surface equals the amount of energy that is given off. The energy incident on the surface (which we consider as unknown of the system) equals the sum of all reflected and transmitted energy from other surfaces, multiplied by the view factors from those surfaces to the first surface. The reflected energy from another surface equals the energy incident on that surface (which is an unknown of the system) multiplied by the (diffuse) reflection factor plus the known reflected energy (at the initial state of the radiosity system). The transmitted

energy equals the energy incident on the opposite side of that wall (which is an unknown of the system) multiplied by the transmission factor at that side. The transmission factor must first be corrected for the reflection at that side (because the transmission factor in BISTRA is defined after deduction of reflection, see C.8.1). Finally this leads to a set of linear equations.
The radiosity method implies that every time step a supplementary linear system of equations must be formulated and solved. This system is global for all zones (based on view factors), because these zones may be linked with one another via transparent walls.

C.8.5. Transmission to internal zone: solar load to internal surfaces

If the transmitted solar radiation reaches a boundary condition of type BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT, then the corresponding zone is called an *internal zone*, through which the solar radiation is further propagated[9]. The material surfaces bordering an internal zone are *internal surfaces*. A zone of type BC_FREE has view factor based radiation and convection with a balanced unknown air temperature. This type is normally used for rooms or larger air cavities.
A zone of type TRANSMAT has view factor based radiation and conduction using a given thermal conductivity (of still air or another gas). This type is normally used for smaller cavities, e.g. the cavity of a double glazing.

The transmitted direct solar radiation in a node of an internal surface is projected along the direction of direct sun light (without refraction) upon the closest internal surface (of the same internal zone opposite to the emitter internal surface), forming the solar spot. When the projected power would cause a flux (i.e. power divided by area) that is greater than the solar radiation on an external surface with the same orientation, then this power excess is spread over adjacent boundary edges.
Part of the incident direct solar radiation on an internal surface is reflected, using the reflection factor of the surface material colour (see C.8.1). This reflection factor may be dependent on the angle of incidence (when the reflection factor is defined by a reflection factor function). The reflected radiation is treated as described in section C.8.4.
The remainder of the incident direct solar radiation on the internal surface is transmitted and absorbed. The transmitted and absorbed direct radiation are treated in the same way as transmitted and absorbed direct solar radiation on an external surface (cf. section C.8.2 and C.8.3).

The transmitted diffuse solar radiation is projected upon the other boundary edges (of the same internal zone) proportional to the view factors from the emitter surface to the receiver surfaces.
Part of the incident diffuse solar radiation on an internal surface is reflected, using the reflection factor for diffuse radiation. The reflected diffuse radiation is treated as described in section C.8.4.
The remainder of the incident diffuse solar radiation on an internal surface is transmitted and absorbed analogously to transmitted and absorbed diffuse solar radiation on an external surface (cf. section C.8.2 and C.8.3).

C.8.6. Solar load to opaque surfaces behind transparent materials

In previous versions of BISTRA (BISTRA v4 and before), in case a transparent construction element was placed in front of an opaque colour (τs = 0), the radiation transmitted through the transparent construction element was ignored. If the user wanted to account for absorption and reflection of radiation by the opaque surface behind a transparent construction element, a very thin layer representing a virtual zone needed to be drawn manually between the transparent

[9] Note that if the colour behind the transparent construction is of type BC_SIMPL, the transmitted solar radiation cannot be accounted for because BC_SIMPL is not a view factor zone. The amount of solar radiation that would be transmitted is thus disregarded in the thermal calculation.

construction element and the opaque surface. From BISTRA v5, this manual work-around is no longer necessary, as it is integrated in the calculation.

An infinitely thin gap (0 pixels thickness) is assumed in the calculation between a transparent construction element and an opaque material surface, with view factor between both opposite surfaces (which is the contact surface) equal to 1.
These infinitely thin gaps are treated as additional view factor zones (1 zone for each contact line in the triangulation of object nodes), thus similar to internal zones, as described in section C.8.5.
The direct and diffuse transmitted solar radiation that hits an opaque material behind a transparent material is added to the radiosity system for redistribution of diffuse radiation, based on diffuse reflection, absorption and transmission coefficients of the two opposite surfaces. The direct transmitted solar radiation is thus considered as additional diffuse transmitted solar radiation, so that it can be included in the radiosity system.
The absorbed radiation at the opaque material surface, resulting from the solution of the radiosity system, is then converted to system node powers on the opaque material surface.

C.9. Heat flow divergences

The quality of the solution is mainly determined by the heat flow divergence of the total object, called in short object divergence. It is defined as the sum of all heat flows (positive and negative) entering the object, divided by half the sum of the absolute values of all these heat flows:

$$OD = \frac{|\Phi_{in,o} - \Phi_{out,o}|}{0.5 \cdot (|\Phi_{in,o}| + |\Phi_{out,o}|)} \cdot 100$$

with	OD = object divergence	[%]
	$\Phi_{in,o}$ = total incoming heat flow for the object	[W]
	$\Phi_{out,o}$ = total outgoing heat flow for the object	[W]

By using the factor 0.5 in the denominator, the denominator can be interpreted as the heat flow "passing" the object.
The maximum possible object divergence is 200 %, i.e. when there are only incoming heat flows and no outgoing heat flows: $\Phi_{in,o}$ > 0 and $\Phi_{out,o}$ = 0 (or vice versa $\Phi_{in,o}$ = 0 and $\Phi_{out,o}$ > 0).
An object divergence tolerance (cf. calculation parameter "Maximum heat flow divergence for total object", see C.2.3) of 0.001 % is recommended as reliable stopping criterion. According to EN ISO 10211 the object divergence should be less than 0.1 %.

In BISTRA also a second heat flow divergence is used as stopping criterion: the maximum heat flow divergence for all nodes, called in short node divergence. It is defined in a similar way as the object divergence:

$$ND = max_n\left(\frac{|\Phi_{in,n} - \Phi_{out,n}|}{0.5 \cdot (|\Phi_{in,n}| + |\Phi_{out,n}|)} \cdot 100\right)$$

with	ND = node divergence	[%]
	$\Phi_{in,n}$ = total incoming heat flow for the control volume around node n	[W]
	$\Phi_{out,n}$ = total outgoing heat flow for the control volume around node n	[W]

In BISTRA the default node divergence tolerance is 1 % (cf. calculation parameter "Maximum heat flow divergence for any node").
Sometimes it happens that the node divergence does not decrease during the calculation. This is caused by an "unlucky" node, that is connected to its neighbouring nodes in an "unfavourable" way (due to obtuse triangles and/or strongly different thermal conductivities). Then a higher node divergence tolerance should be set.

Cancel the node divergence test by using a node divergence tolerance of 201 % (which is higher than the theoretical 200 %, to be safe for possible numerical rounding errors).

C.10. Batch calculation

The user can launch a batch calculation for several data files (with extension .bst) in the same folder. The calculations are executed one after the other without any intervention of the user.
To start a batch calculation call the command *File → Batch Calculation...*, select the data files in the Batch Calculation dialog box (hold down the <Ctrl> key to select more than one file) and press the Start button. It is not possible to select several data files located in different directories.

Per data file a report file is written to disk, containing the output report corresponding to the report definition of the data file (cf. sections B.20 and B.21). The report file has the same file name as the data file, and has the extension .txt.
When graphic output (i.e. snapshots at given time points and/or animation files of given time periods) is wanted afterwards, the data file should specify that step solutions must be saved to disk (cf. section B.22).

C.11. Command line program execution

BISTRA can be run from another application with a data file path (including directory and file extension .bst) as parameter.
Then no further user action is required. The program starts and ends automatically, and the output is a report file and/or a series of graphic snapshots (as in a batch calculation, cf. section C.9).
The switch "/Automation" is required to activate the batch calculation.

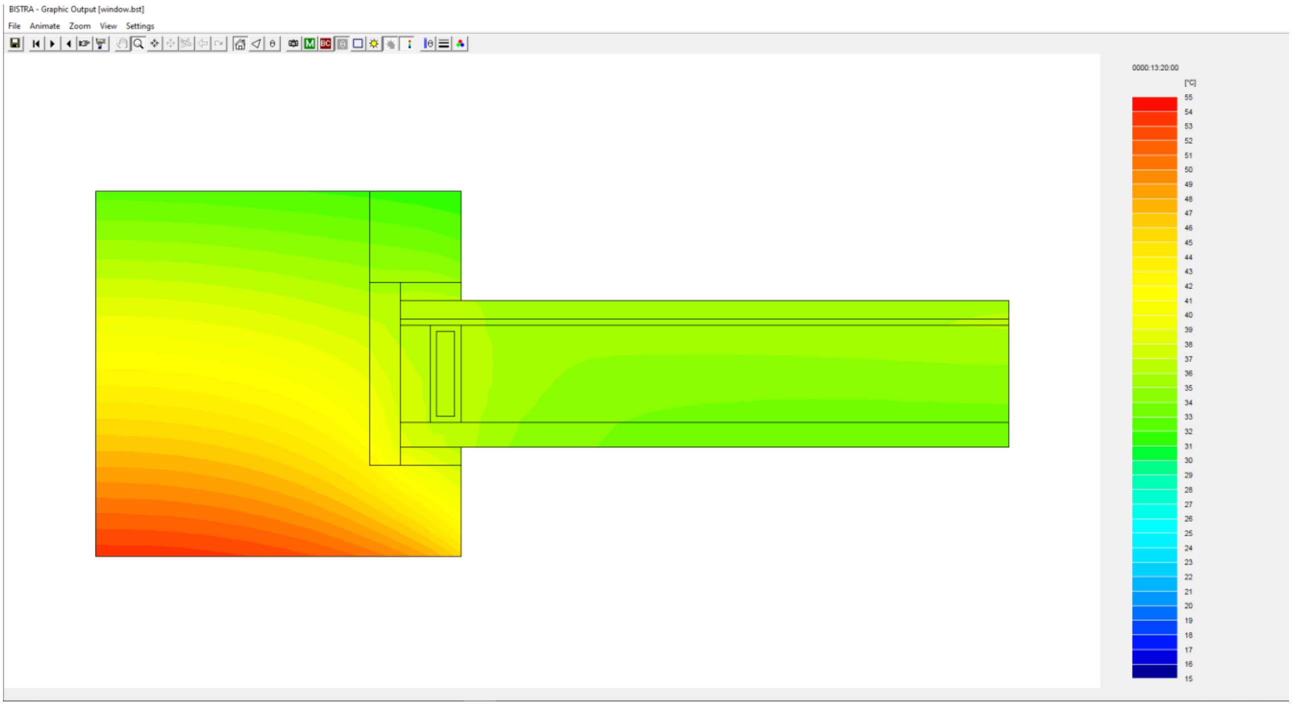
Example of command line launch:

Run → "c:\...\Physibel\BISTRA5\BISTRA.exe" "..\Documents\Physibel\BISTRA5\Demofiles\1 – SUMMER – THERMAL STRESS\flat_roof_solar.bst" /Automation

CHAPTER D GRAPHIC OUTPUT

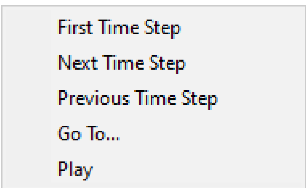
D.1. Graphic Output window

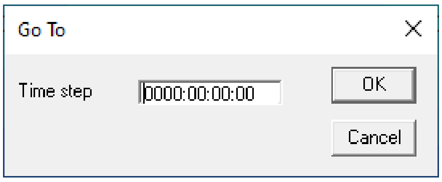
The **Graphic Output window** (which covers the complete BISTRA application window) is opened with the command *Output → Graphic Output*.
To return to the main BISTRA window, choose the command *File → Exit.*



D.2. Animate functions

The animate functions are available through the Animate submenu.





The next functions are only available when solution files (*.sol) of a calculation are present on disk (see section B.22):

First Time Step	Loads the first solution file (for the start of the calculation duration, after the precalculation duration).
Next Time Step	Loads the next solution file.
Previous Time Step	Loads the previous solution file.
Go To...	Loads the solution file of a time step (of the calculation duration) entered by the user.
Play	Shows successively all solution files starting from the current time step. The playing can be stopped by pressing the <Esc> key.

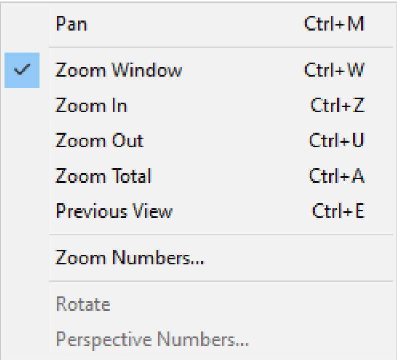
D.3. Save animation images

Menu command: *File → Save Animation Images...*
A sequence of all animation images (as a result of the command *Animate → Play*) can be saved on disk as separate .png files.

A Save As dialog box is opened to prompt for a file name.
The image size of saved bitmap and font size of legend text are defined via *Settings → Image Size....*

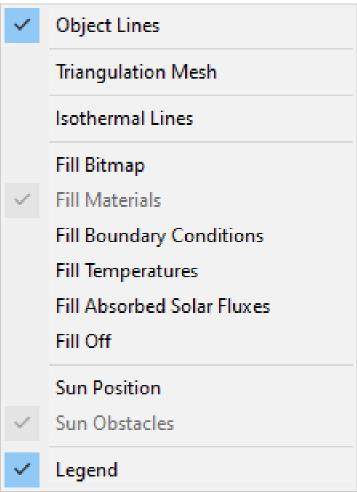
The solution files are loaded consecutively (started with the first solution at time 0000:00:00:00), shown in the **Graphics Output window** and saved. A 4 digit number (starting from 0000) is appended to the chosen file name to generate the different PNG files.
Saving animation images can be interrupted by pressing the <Esc> key.

D.4. Zoom commands



Compared to the main input menu (see B.8), 2 additional zoom commands are available (*Zoom → Rotate* and *Zoom → Perspective Numbers...*). These are only available when viewing the sun position (see D.7).

D.5. View submenu



- *View → Object Lines:* show contours of material colours.
- *View → Triangulation Mesh*: show triangles of triangulation.
- *View → Isothermal Lines:* show isothermal lines conform to the temperature range parameters (*Settings → Temperature Range...*).

Only possible when a calculation solution is available.

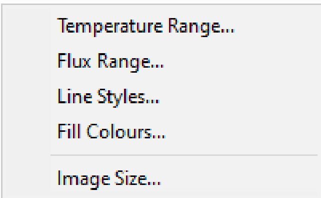
- *View → Fill Bitmap:* show original bitmap.
  If *View → Legend* is selected, labels with colour numbers are added.
- *View → Fill Materials:* fill object materials using the bitmap colours.
- *View → Fill Boundary Conditions:* fill boundary conditions using the bitmap colours.
- *View → Fill Temperatures:* fill object with temperature colours conform to the temperature range parameters (*Settings → Temperature Range…*).
  Only possible when a calculation solution is available.
- *View → Fill Absorbed Solar Fluxes:* show absorbed solar fluxes of MATERIAL type colours at contact surface with solar zone or internal zone with detailed radiation calculation (so absorbed solar flux at opaque surfaces behind transparent materials, see C.8.6, is not shown).
- *View → Fill Off:* switch off filling.

- *View → Sun Position:* see D.7
- *View → Sun Obstacles*: toggle for showing the sun obstacles (see B.16) in grey in the sun position view.

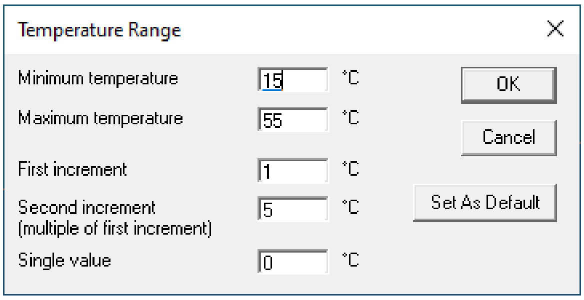
- *View → Legend:* show a legend bar at the right side of the figure (exception: show colour labels for *View → Fill Bitmap*).

Remark
For temperature dependent thermal conductivities the values that are shown in the legend (when the view option *View → Fill Materials* is chosen), are all taken at 10°C.

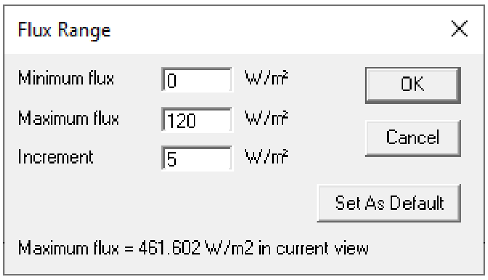
D.6. Settings



Settings → Temperature Range…
- Minimum temperature [°C] in graphic output.
- Maximum temperature [°C] in graphic output.
- First (or minor) increment [°C].
  Used for temperature filling (*View → Fill Temperatures*) and isothermal lines (*View → Isothermal Lines*).
- Second (or major) increment [°C] (must be a multiple of first increment).
  Only used with isothermal lines (*View → Isothermal Lines*).
- Single temperature value [°C] (e.g. dew point).
  Only used with isothermal lines (*View → Isothermal Lines*).

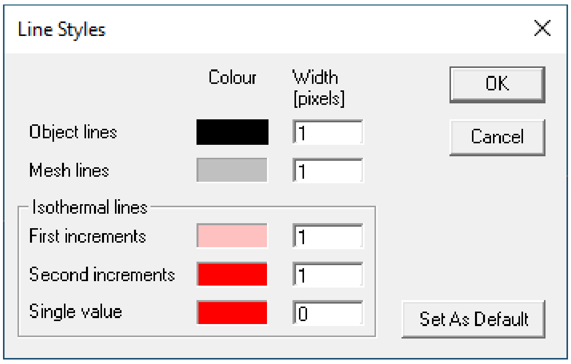


Settings → Flux Range...

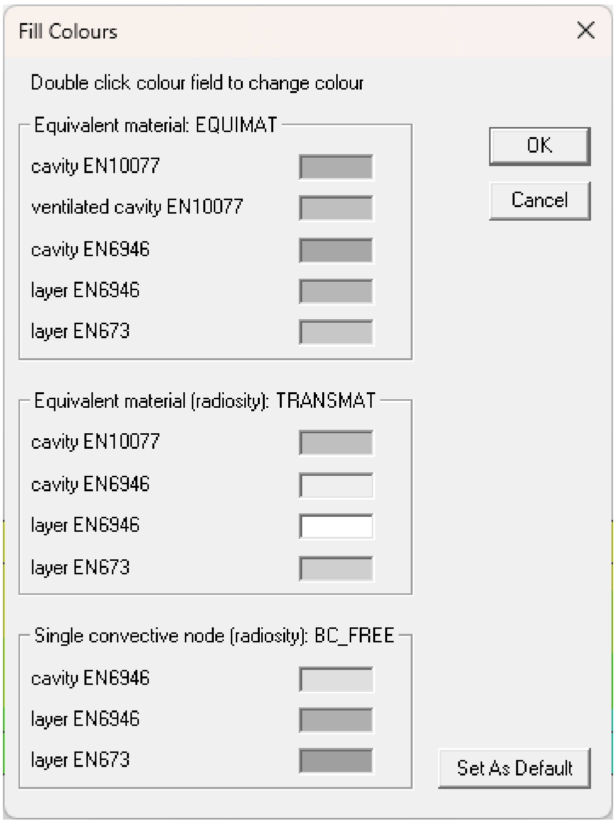


Settings → Line Styles...
A colour field can be edited by double clicking with the left mouse button, which opens a Colour dialog box in which the colour value (RGB components) can be defined.

The width of isothermal lines can be set to 0 pixels to hide them. This is useful when e.g. only the second isothermal lines are desired in the figure.

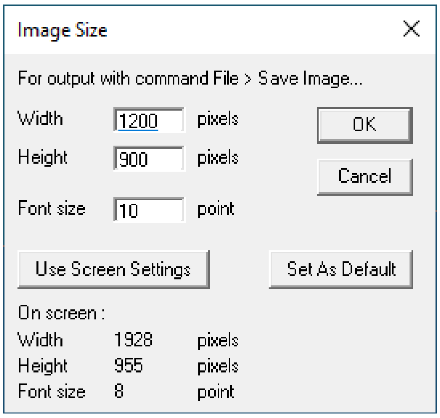


Settings → Fill Colours...



Colours with automatically calculated properties (see C.1) are clustered thematically in the **Graphic Output window** according to the categories of the Fill Colours dialog box, to avoid a potentially long list of colours of the same type (and subtype and standard) with small variations in the calculated thermal property. The fill colour of the clusters can be edited by double clicking on it with the left mouse button, which opens a Colour dialog box in which the colour can be defined.

Settings → Image Size...
Set bitmap size for saving PNG files (*File → Save Image...* and *File → Save Animation Images...*).



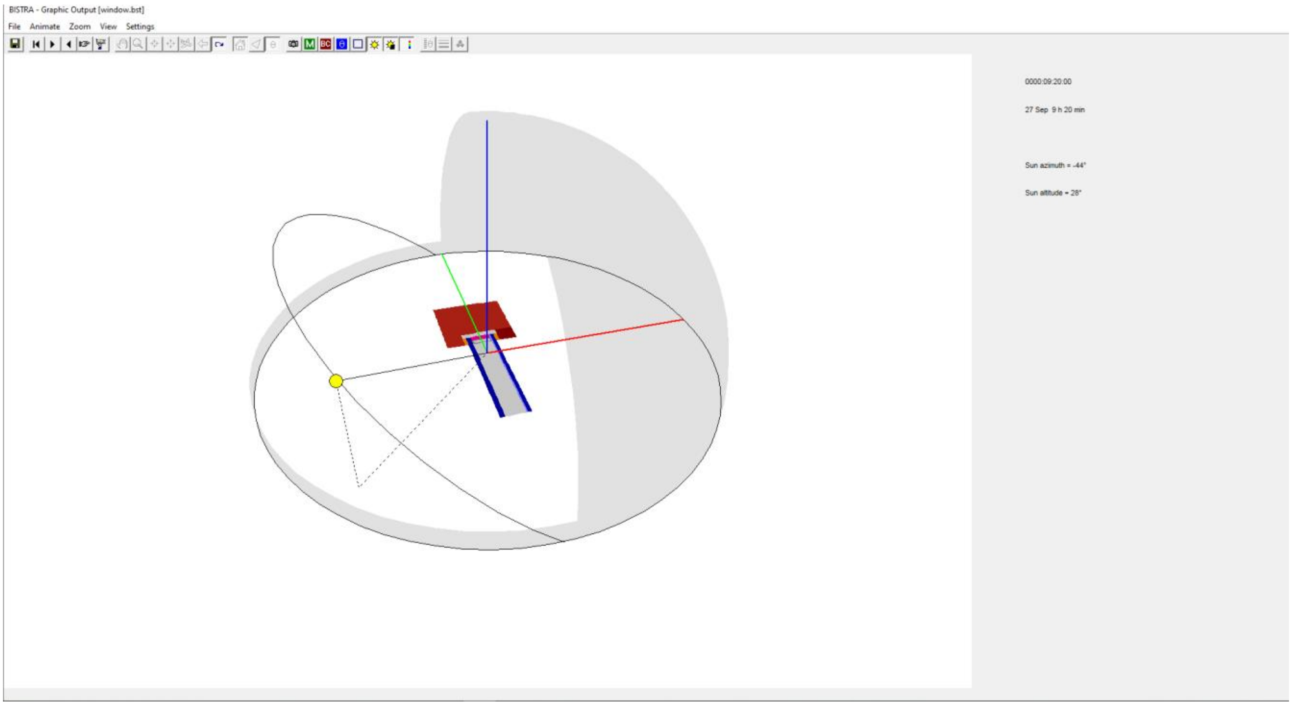
The font size refers to text characters in the legend or labels.

D.7. Sun position

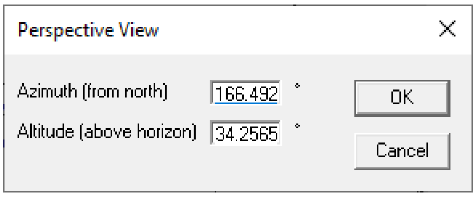
The sun position (azimuth and altitude) in the horizontal coordinate system (in which the plane XY coincides with the horizon, the X axis points to the north, the Y axis points to the west, and the Z axis points to the zenith) at any time can be viewed with *View → Sun Position*.

The parameters that define the position of the sun are:
- North orientation (*Edit → Solar Data...*).
- Geographic position (*Edit → Solar Data...*).
- Day of year at start of calculation (*Edit → Calculation Parameters...*).
- Time setting (*Animate → Go To...*).
  The start of calculation corresponds with time 0000:00:00:00.

If the toggle *View → Sun Obstacles* is on, the sun obstacles as defined in the **Sun Obstacles window** (B.16) are shown in grey.



The 3D image can be rotated with *Zoom → Rotate* (Rotate mode is activated automatically by holding down the mouse wheel).
The perspective viewpoint (azimuth and altitude from the midpoint of the bitmap to the observer in the horizontal coordinate system) is entered with *Zoom → Perspective View...*.
All other zoom functions are suppressed while the option *View → Sun Position* is used.



Use the function *Animate → Play* to show the sun position changing with time.
The time step defined in the Calculation Parameters dialog box (*Edit → Calc Parameters...*) is used as animation time step.

CHAPTER E TEXT OUTPUT

E.1. Text Output window

The **Text Output window** (which covers the complete BISTRA application window) is opened with the command *Output → Text Output.*
To return to the main BISTRA window, press the <Esc> key or choose the command *File → Exit*.

Views
Three different contents can be viewed in the **Text Output window**:
- An overview of input data (shown with the command *View → Input Data*, see E.2).
- The calculation results of a specific time step (shown with the command *View → Time Step Results*, see E.3). This is only available for the time steps for which the solution is saved to disk (see B.22).
- A report for the items defined in the **Report Definition window** (cf. section B.20) (shown with the command *View → Report Output*, see E.4).

Saving
- The user can select some part in the **Text Output window**, and copy it into the clipboard (using *Edit → Copy*). The contents of the clipboard can then be pasted into any other program (e.g. Microsoft Word).
- The text in the current view can also be saved into a DOC file (Microsoft Word document) using the command *File → Save As...*.
- The command *File → Save to CSV Files* saves the following data to 3 separate CSV files for use in a spreadsheet program (e.g. Microsoft Excel):
    - the bitmap colour sizes (cfr. the data in the **Measures window**, see B.9);
    - the thermal properties (cfr. the data in the **Colours window**, see B.10) for the specified time step (see E.3) in case of automatically calculated themal properties (see C.1);
    - the calculation results in terms of temperatures and heat flows per colour for the specified time step (see E.3), if this solution is saved to disk (see B.22).

BISTRA - Text Output [window.bst]

File Edit View Settings

BISTRA Calculation Results

BISTRA data file: window.bst
Number of nodes = 641

Time step 0000:00:00:00

Col.	Type	Name	tmin [°C]	tmax [°C]	ta [°C]	flow in [W/m]	flow out [W/m]
8	MATERIAL	aluminium	19.50	19.56			
12	MATERIAL	wood	16.73	22.60			
13	MATERIAL	glazing stop	20.41	22.80			
18	MATERIAL	glass (ext. pane)	16.66	19.50			
19	MATERIAL	glass (int. pane)	19.64	23.50			
20	MATERIAL	low-e coating	19.56	23.47			
21	MATERIAL	glass (ext. pane)					
60	MATERIAL	EPDM	18.42	20.69			
62	MATERIAL	silicone, pure	19.32	19.81			
170	BC_SKY	exterior	16.66	19.10		0.00	2.71
174	BC_SKY	interior	20.02	23.50		2.71	0.00
214	TRANSMAT	argon	16.70	23.46		0.25	0.25
215	EQUIMAT	air cavity	19.50	19.56			
216	EQUIMAT	air cavity	18.51	20.81			

E.2. Input data

The input data is shown in the **Text Output window** using the command *View → Input Data.*

BISTRA - Input Data

BISTRA data file: climate_solar_control_BISTRA.bst
Bitmap file: climate_solar_control_BISTRA.bmp
1 pixel = 0.01 m

MEASURES

Col.	Width [pixels]	Width [m]	Height [pixels]	Height [m]	Area [pixels]	Zones	Triang.Size [pixels]
2	112	1.1200	112	1.1200	144	4	10.00
28	100	1.0000	6	0.0600	600	1	10.00
29	6	0.0600	100	1.0000	600	1	10.00
30	100	1.0000	6	0.0600	600	1	10.00
31	6	0.0600	100	1.0000	600	1	10.00
170	132	1.3200	132	1.3200	4880	1	
174	100	1.0000	100	1.0000	10000	1	

FUNCTIONS
T01: FILE
G:\Weatherfiles\datafiles\Berlin_Tempelhof-hour.FTE
G01: EPW
G:\datafiles\Berlin_Tempelhof-hour.epw
D01: EPW
G:\datafiles\Berlin_Tempelhof-hour.epw

THERMAL PROPERTIES

Col.	Type	Subtype	Phys. flow	Geom. flow	Name	eps1 / eps2 [- / -]	lambda [W/mK]	eps [-]
2	MATERIAL						0.000	0.90
28	MATERIAL				North		1.000	0.90
29	MATERIAL				East		1.000	0.90
30	MATERIAL				South		1.000	0.90
31	TRANSMAT	CAVITY	HOR	DIR	West		0.094	
170	BC_SIMPL	NIHIL			exterior			
174	BC_SIMPL	NIHIL			interior			

Col.	rho [kg/m3]	c [J/kgK]	t [°C]	h [W/m²K]	q [W/m²]	ta [°C]	hc [W/m²K]	Pc [W/m]	tr [°C]	Sun	rs [-]	ts [-]	Standard
2	1.0	1.0									0.00	0.00	
28	1.0	1.0									0.00	0.00	
29	1.0	1.0									0.00	0.00	
30	1.0	1.0									0.00	0.00	
31	1.0	1.0											EN10077
170			T01	10.00	0					YES			NIHIL
174			0.0	10.00	0					NO			NIHIL

SOLAR DATA
North orientation

1. Rotation angle of XY around Z = 0°
2. Rotation angle of YZ around X = 0°
3. Azimuth from X to north = 270°
Latitude = 50.78° N
Longitude = 4.37° E
Time zone = 1 h E
Horizontal global solar radiation function = G01
Horizontal diffuse solar radiation function = D01
Ground reflection factor = 0.20

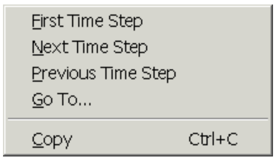
SUN OBSTACLES

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

CALCULATION PARAMETERS
Time step = 0000:00:15:00
Start-up calculation duration = 0000:00:00:00
Calculation duration = 0001:00:00:00
Start of calculation = 0000:12:30:00
Contour approximation margin (triangulation) = 0 pixels
Iteration cycles = 20
Nonlinear radiation
Automatic recalculation of thermal values
Use default temperatures in recalculation of thermal values
Default temperature difference across airspace = 10°C
Bitmap border is no axis of symmetry
Max. number of view factor faces per zone = 500
Black radiation heat transfer coeff. (linear radiation) = 5.25 W/m²K
Maximum number of iterations (per iteration cycle) = 10000
Maximum temperature difference = 0.0001°C
Heat flow divergence for total object = 0.001 %
Heat flow divergence for worst node = 1 %

E.3. Time step results

Calculation results for a specific time step are shown using the command *View → Time Step Results*. This is only available for the time steps for which the solution is saved to disk (see B.22). The time step can be set using one of the first four commands in the Edit submenu, which are analogous as in the Animate submenu in the **Graphic Output window** (cf. section D.2).



First Time Step — Loads the first solution file (for the start of the calculation duration, after the precalculation duration).
Next Time Step — Loads the next solution file.
Previous Time Step — Loads the previous solution file.
Go To... — Loads the solution file of a time step (of the calculation duration) entered by the user.

BISTRA Calculation Results

BISTRA data file: wooden_frame.bst
Number of nodes = 641

Time step 0000:00:00:00

Col.	Type	Name	tmin [°C]	tmax [°C]	ta [°C]	flow in [W/m]	flow out [W/m]
8	MATERIAL	aluminium	18.60	18.67			
12	MATERIAL	wood	15.38	22.20			
13	MATERIAL	glazing stop	19.66	22.44			
18	MATERIAL	glass (ext. pane)	15.30	18.60			
19	MATERIAL	glass (int. pane)	18.76	23.26			
20	MATERIAL	low-e coating	18.67	23.23			
60	MATERIAL	EPDM	17.35	19.98			
62	MATERIAL	silicone, pure	18.39	18.96			
170	BC_SKY	exterior	15.30	18.14		0.00	3.15
174	BC_SKY	interior	19.20	23.26		3.15	0.00
214	TRANSMAT	argon	15.35	23.21		0.29	0.29
215	EQUIMAT	air cavity	18.60	18.67			
216	EQUIMAT	air cavity	17.45	20.13			

E.4. Report output

For the items defined in the **Report Definition window** (cf. section B.20) a report can be output with records at a given frequency of time steps (cf. section B.21). The command *View → Report Output* shows the contents of the report written during the calculation. This report is automatically written to both a TXT file and CSV file in the BISTRA data file directory.

In the report, per report time step one line of values is written (no value ('-') is given for logically impossible report items). The report values are separated with tab characters in the TXT file. Each column in the table corresponds to a report item. The meaning of the columns is explained in the header.

```
BISTRA - Report Output

BISTRA data file: wooden_frame.bst

Column 1: Time [dddd:hh:mm:ss]
Column 2: Sun azimuth [°]
Column 3: Sun altitude [°]
Column 4: Colour 170 (exterior), air temperature [°C]
Column 5: Colour 18 (glass (ext. pane)), absorbed solar flux [W/m²]
Column 6: Colour 12 (wood), absorbed solar flux [W/m²]
Column 7: Colour 18 (glass (ext. pane)), minimum temperature [°C]
Column 8: Colour 18 (glass (ext. pane)), maximum temperature [°C]
Column 9: Colour 12 (wood), minimum temperature [°C]
Column 10: Colour 12 (wood), maximum temperature [°C]

0000:00:00:00     0.00   0.00   14.30   0.00   0.00   15.30   18.60   15.38   22.20
0000:00:10:00     0.00   0.00   14.18   0.00   0.00   15.26   18.60   15.33   22.20
0000:00:20:00     0.00   0.00   14.07   0.00   0.00   15.17   18.57   15.24   22.20
0000:00:30:00     0.00   0.00   13.95   0.00   0.00   15.08   18.53   15.15   22.20
0000:00:40:00     0.00   0.00   13.83   0.00   0.00   14.97   18.49   15.05   22.20
0000:00:50:00     0.00   0.00   13.72   0.00   0.00   14.87   18.44   14.96   22.20
0000:01:00:00     0.00   0.00   13.60   0.00   0.00   14.77   18.38   14.86   22.19
0000:01:10:00     0.00   0.00   13.48   0.00   0.00   14.66   18.32   14.76   22.18
0000:01:20:00     0.00   0.00   13.37   0.00   0.00   14.56   18.27   14.66   22.17
0000:01:30:00     0.00   0.00   13.25   0.00   0.00   14.45   18.20   14.56   22.15
0000:01:40:00     0.00   0.00   13.13   0.00   0.00   14.35   18.14   14.46   22.14
0000:01:50:00     0.00   0.00   13.02   0.00   0.00   14.24   18.08   14.35   22.12
0000:02:00:00     0.00   0.00   12.90   0.00   0.00   14.14   18.01   14.25   22.10
```

CHAPTER F BISTRA TEMPLATE FILES

F.1. General

BISTRA makes use of template files containing default information for a number of functions. These template files are each saved in the application data folder or personal folder (see A.6) of the user account on the computer where BISTRA is installed. The path to the application data folder is C:/Users/*username*/Appdata/Roaming/Physibel/BISTRA5 (AppData is a hidden folder by default in Windows).

The template files used by BISTRA are:

- ColourDatabase.bst (F.2)

The use of these template files in different BISTRA functions has been outlined throughout the manual. In the following sections, handling and customization of these template files is briefly discussed.

F.2. Colour database

The colour database file ColourDatabase.bst is saved in the application data folder (C:/Users/*username*/Appdata/Roaming/Physibel/BISTRA5). The colour database contains predefined material and boundary condition properties and is loaded at every BISTRA start-up (see B.2).

It is advisable to add frequently used materials and boundary conditions to the colour database. These predefined colours of the colour database are then available for new colours in any document.
The command *File → Open Colour Database...* allows to modify the 256 available predefined colours of the colour database. After editing the colour data, the file should be saved (*File → Save*) to adapt the colour database on disk.

Alternatively, if a user wants to save a custom file as colour database, this is possible by saving it with the name ColourDatabase.bst in the application data folder (*File → Save as...*) thus overwriting the default file. In the application data folder, the default colour database is present as ColourDatabase_PhysibelDefault.bst. This file can be saved as ColourDatabase.bst to restore the original colour database.

Since the colour database is a BST file, it needs to have an accompanying BMP file. For ColourDatabase.bst, the accompanying BMP file is Default.bmp (in the same location). This Default.bmp file is of no further significance, but must exist.

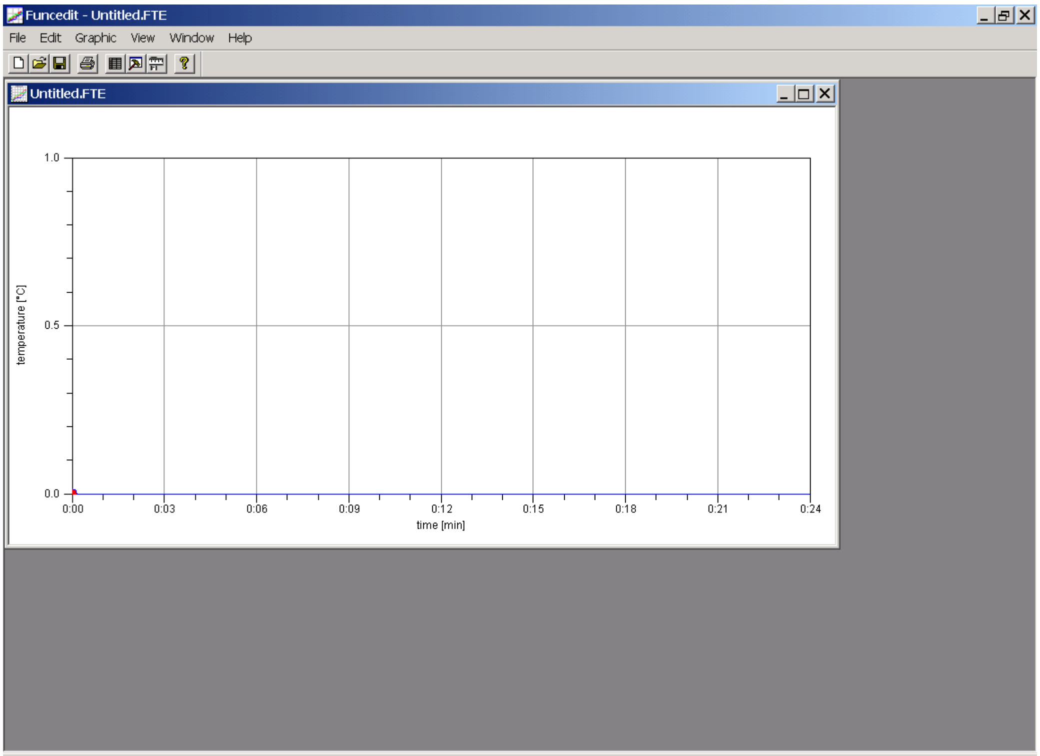
The ColourDatabase.bst file replaces the Bistra.bst file in older versions of BISTRA. Users who had been working with a customised Bistra.bst file, can thus easily transfer to the new system by opening Bistra.bst and saving it with the name ColourDatabase.bst in the application data folder. The bitmap file linked to Bistra.bst (Bistra.bmp) must then be saved as Default.bmp.
The legacy Bistra.bst file was also used to set the default bitmap pixel size and global triangulation size (see B.9). These properties can now be set via command *Settings → Default Measures...* (see A.9).

CHAPTER G PROGRAM FUNCEDIT

G.1. Introduction

The program FUNCEDIT is a utility program to edit and visualise external function files for use in non-steady state Physibel programs (BISTRA, VOLTRA), where they are used as dynamic boundary condition specifications (see B.12.2).

After starting FUNCEDIT or creating a new function using the command *File → New*, a null temperature function of length 24 hours (with hourly values of 0°C) is displayed.



An existing function file on disk is read using the command *File → Open...*. The function type can be chosen in the Open dialog box.

G.2. Function type

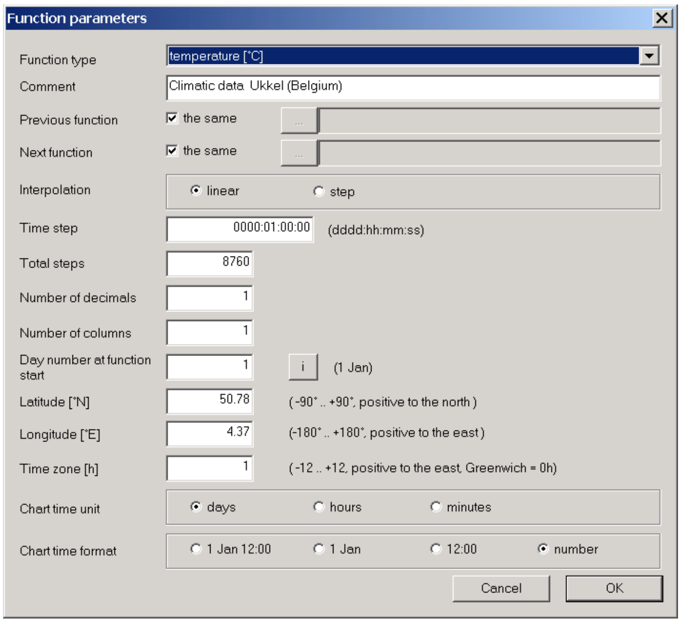
The following function types are available:

Function type	*Unit*	*ext.*	*Use in BISTRA*
temperature	[°C]	.fte	boundary condition temperature
horizontal global solar radiation	[W/m^2]	.fsg	boundary condition solar zone
horizontal diffuse solar radiation	[W/m^2]	.fsd	boundary condition solar zone
direct solar radiation	[W/m^2]	.fsb	not used
solar radiation	[W/m^2]	.fse	not used
infrared radiation	[W/m^2]	.fir	boundary condition heat flux
power	[W]	.ffh	boundary condition power
thermal conductivity	[W/(m.K)]	.fco	material property time-dependent thermal conductivity
surface heat transfer coefficient	[W/(m^2.K)]	.fht	boundary condition total surface heat transfer coefficient or convective heat transfer coefficient
ventilation rate	[/h]	.fvr	ventilation volume flow rate [m^3/s]

<u>Remark</u>
The ventilation rate in FUNCEDIT is shown with unit /h, which was used in the (now deprecated) Physibel program CAPSOL. However in BISTRA the same function type is used for ventilation volume flow rates, with unit m^3/s. So for BISTRA ventilation functions the unit specifier [/h] in FUNCEDIT should be read as [m^3/s].

G.3. Function parameters

General header information of a function file is edited via the command *Edit → Parameters....*

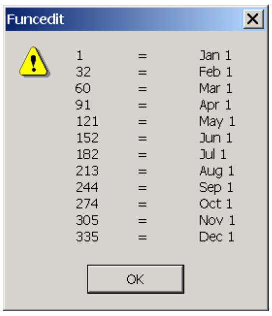


A dialog box is opened where the following parameters can be edited:

- <u>Function type</u>: see section G.2.
- <u>Comment</u>: text description of the function.
- <u>Previous function</u> and <u>next function</u>: file name of a function that precedes the current function (previous function) or comes next to the current function (next function). The previous and/or next function may be the same as the current function, in which case the

check box “the same” is marked.
If the time span of a BISTRA simulation is larger than the time span of the function definition, it is necessary to know which function comes next to the current one. In case a start-up calculation is used, a previous function is required. If the previous and the next function are checked as the same, then the current function corresponds to the definition of an infinite periodic function, with period the length of the current function.

- Interpolation: linear or step. Intermediate function values are either obtained by linear interpolation (linear function) or remain constant during the whole time step interval (step function).
- Time step [dddd:hh:mm:ss]: time interval between two successive function values in the function data window (see section G.4).
- Total steps: number of time steps required to span the total function length. This number is equal to the number of function values minus 1. The function length or duration equals the time step multiplied by the total number of steps.
- Number of decimals: number of digits after the decimal point, for all function values in the function data window (see section G.4) and in the function file.
- Number of columns: used in the function data window (see section G.4) and in the function file.
- Day number at function start [1..365]: day number in the year on which the function starts. The “i” button gives information about the start days of each month.



- Latitude [°N], longitude [°E] and time zone [h]: to position a function climate station on the globe.
- Chart time unit and chart time format: labelling information for the time axis in the function chart. This information is not stored in the function file.

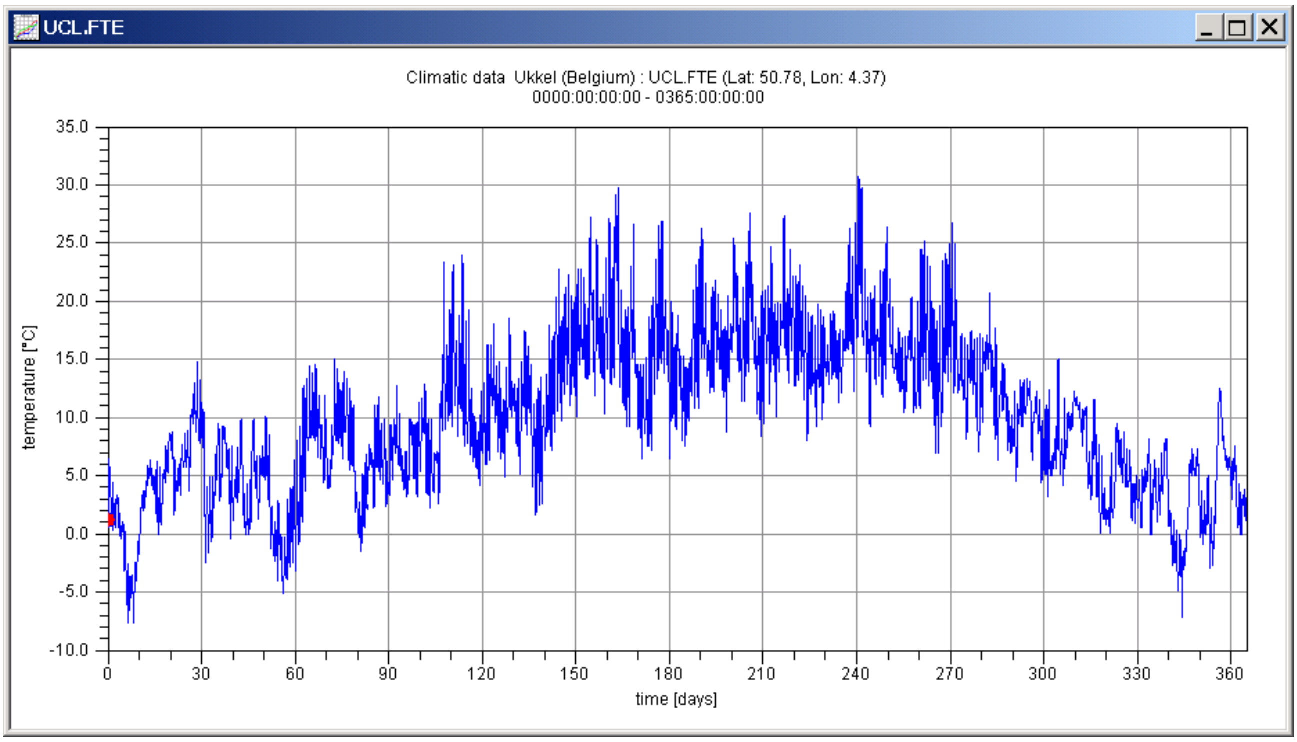
G.4. Function data

The function values at regular time step intervals can be edited in the function data window, opened with the command *Edit → Data*. The table format is controlled by the function parameters (see section G.3).

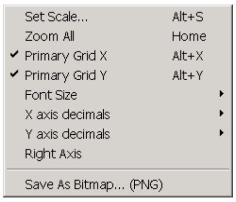
In the left (grey) column a time indication of the first value in the row is given. The table can be navigated by the mouse or by the arrow keys.
A new value can be inserted after the current one using the command *Edit → Insert After* or the Insert key. The “total steps” parameter in the function parameters dialog box is adapted accordingly.
A value can be deleted using the command *Edit → Delete Value* or the Delete key.
Individual table cells can be copied and pasted by using the commands *Edit → Copy* (or <Ctrl+C>) and *Edit → Paste* (or <Ctrl+V>).

G.5. Graphic parameters

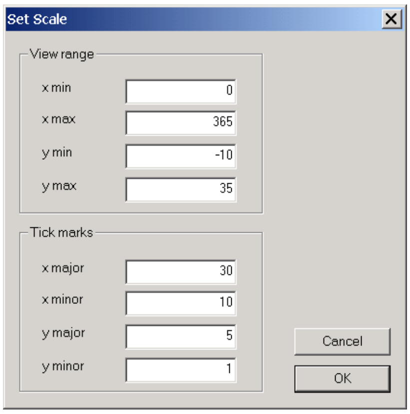
The window that is opened when a new function is created or an existing function file is read, contains a graphic representation of the numerical function data entered in the data window. The red point in the graph corresponds to the function value in the current cell of the data window.



The parameters about the graph can be edited in the Graphic submenu.



The command *Graphic* → *Set Scale...* opens a dialog box containing scale parameters. The view range for both axes and tick mark distances can be set.



When a rectangle is drawn in the graph with mouse dragging (holding down the left mouse button), a zoom rectangle is defined. The corresponding zoom view is drawn when the left mouse button is released. The initial total view (with view range as defined in the Set Scale dialog box) can be restored by using the command *Graphic → Zoom All* or pressing the Home key.

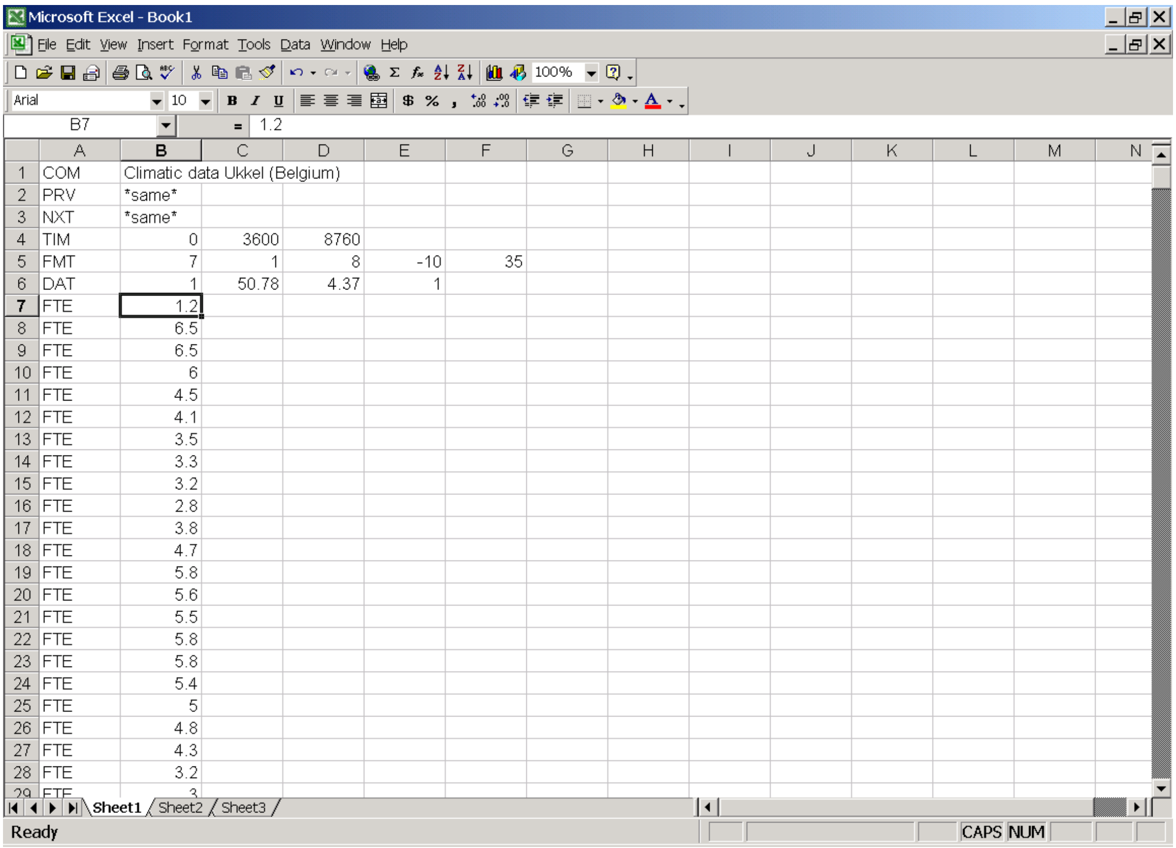
The commands *Graphic → Primary Grid X* and *Graphic → Primary Grid Y* enable to show grid lines through the primary tick marks on both axes X and Y.

The command *Graphic → Right Axis* allows to draw also a vertical axis with tick marks at the right side of the chart border.

The command *Graphic → Save As Bitmap (PNG)* opens a dialog box where you can enter the file name and size of the .png file, which will be saved in the same directory as where the function is stored.

G.6. Using a spreadsheet program to create functions

A function file can also be created using Microsoft Excel or another spreadsheet program. The spreadsheet contains 6 header rows (starting with the keywords COM, PRV, NXT, TIM, FMT and DAT) followed by data rows with function values. The syntax of the input data is given in the table below. Save the file (as text) in the function files directory, with the extension corresponding to the function type (cf. section G.2).
If an existing function file, created with FUNCEDIT, has to be modified using a spreadsheet program, it is recommended first to set the parameter "number of columns" in the Function Parameters dialog box equal to 1. Then there will be only 1 column with function values in the spreadsheet (as in the figure below).



	A	B	C	D	E	F
1	COM	Climatic data Ukkel (Belgium)				
2	PRV	"same"				
3	NXT	"same"				
4	TIM	0	3600	8760		
5	FMT	7	1	8	-10	35
6	DAT	1	50.78	4.37	1	
7	FTE	1.2				
8	FTE	6.5				
9	FTE	6.5				
10	FTE	6				
11	FTE	4.5				
12	FTE	4.1				
13	FTE	3.5				
14	FTE	3.3				
15	FTE	3.2				
16	FTE	2.8				
17	FTE	3.8				
18	FTE	4.7				
19	FTE	5.8				
20	FTE	5.6				
21	FTE	5.5				
22	FTE	5.8				
23	FTE	5.8				
24	FTE	5.4				
25	FTE	5				
26	FTE	4.8				
27	FTE	4.3				
28	FTE	3.2				
29	FTE	3				

row number	code	input data				
	column A	column B	column C	column D	column E	column F
1	COM	comment				
2	PRV	name of the previous function *				
3	NXT	name of the next function *				
4	TIM	interpolation: 0 = linear / 1 = step	time step (in seconds)	total number of steps		
5	FMT	total number of characters of the function values	number of digits after decimal point	number of columns of function values	minimum ordinate	maximum ordinate
6	DAT	date number at function start	latitude	longitude	time zone	
7 - ... - (7 + total steps)	function type**	function value	(function value)	(function value)	(function value)	(function value)

* The extension of the file name may be omitted; Omit this line to specify the same previous / next function (or use the name *same*).

** The function type as described in section G.2.

CHAPTER H RADCON MODULE

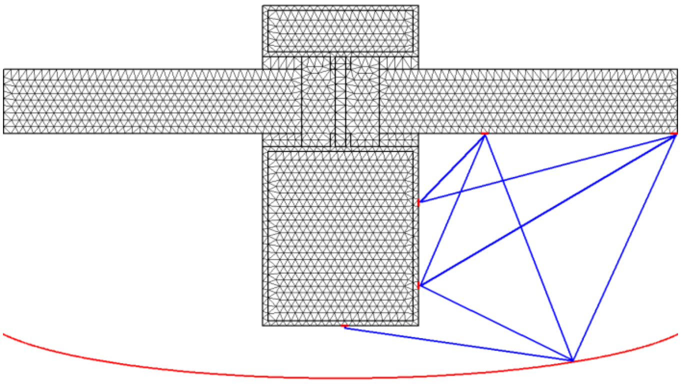
H.1. Purpose

The RADCON module is a program add-on feature to simulate more realistically the heat transfer between material surfaces and the adjacent environments.
The heat transfer has the following components:

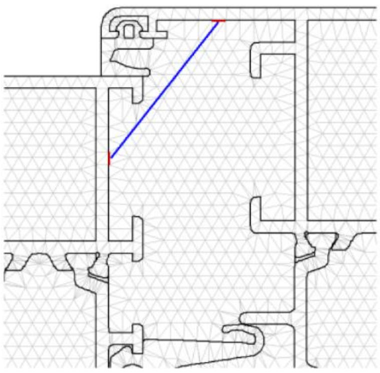
- Radiation: based on view factors and material surface emissivities.
- Convection: based on a (calculated) convective heat transfer coefficient applied to the contact surface between material and environment.
- Conduction: in a (transparent) material with given thermal conductivity.

The RADCON module offers a physically more correct alternative for:

- The global surface heat transfer coefficient.
- The equivalent thermal conductivity of an air cavity.



principle of view factor based radiation heat transfer using BC_SKY (at a surface)



principle of view factor based radiation heat transfer using TRANSMAT (in a cavity)

H.2. Implementation

The following colour types require the use of the RADCON module in BISTRA:

- TRANSMAT for a transparent material with known (or calculated) thermal conductivity (normally of still air or another gas) according to EN ISO 10077-2)
  Additionally to the gas conduction there is radiative heat transfer between the adjacent material surfaces (using their emissivities).
  If the transparent material is not fully surrounded by material surfaces, then the open side at the bitmap border is considered as an adiabatic surface, i.e. a radiation mirror with emissivity $\varepsilon = 0$.
  If there is convection within the cavity, the thermal conductivity for still gas should be multiplied by the Nusselt number.
- BC_FREE for an enclosure (normally fully surrounded by material surfaces, e.g. a cavity or a room) with unknown air temperature (free-floating air temperature), known surface heat flux (positive or negative), known (or calculated) convective heat transfer coefficient and known injected convective heat power (positive or negative).
  The unknown air temperature is calculated from the convective heat balance equation:
  Σ (convective heat transfer from environment to surface) = injected convective heat power.
  The radiation between the different surfaces bordering the environment are calculated based on view factors and surface emissivities.

When the environment is not completely surrounded by material surfaces, the open end (at the bitmap border) is considered to be a symmetry plane for heat transfer. The symmetry plane is simulated as a radiation mirror (with emissivity ε = 0).

- BC_SKY for an environment (normally not fully surrounded by material surfaces, i.e. open to the sky) with known air temperature, known radiation temperature, known surface heat flux (positive or negative) and known (or calculated) convective heat transfer coefficient.
  This implies there can be a resultant radiative heat flow and a resultant convective heat flow from the environment to the material surfaces.
- BC_NOSKY for an environment with known air temperature, known surface heat flux (positive or negative) and known (or calculated) convective heat transfer coefficient.
  There is no radiation exchange with the environment (i.e. no sky radiation). The surfaces bordering the environment exchange radiation based on view factors and surface emissivities.
  The known air temperature implies there can be a resultant convective heat flow from the environment to the material surfaces.

For use with RADCON the colour types MATERIAL and EQUIMAT also have a surface emissivity (defined in the **Colours window**), which is applied to the radiative heat transfer for the RADCON boundary conditions bordering the material.

Combined convective and radiative heat transfer (BC_SIMPL, BC_FRE_S)
The global (combined convective and radiative) heat flow is:
$Q = h \cdot (\theta_s - \theta_{bc}) \cdot A$
Q = global heat flow [W]
h = global heat transfer coefficient [W/(m^2.K)]
θ_s = surface temperature [°C]
θ_{bc} = environmental temperature [°C]
A = surface area [m^2]
In this formula the environmental temperature is not defined precisely. It can be the air temperature, the dry resultant temperature or an interpolated value. Depending on that choice, an appropriate value for the global heat transfer coefficient must be chosen.

Convective heat transfer (BC_FREE, BC_SKY, BC_NOSKY)
The convective heat flow is:
$Q_c = h_c \cdot (\theta_s - \theta_a) \cdot A$
Q_c = convective heat flow [W]
h_c = convective heat transfer coefficient [W/(m^2.K)]
θ_s = surface temperature [°C]
θ_a = air temperature [°C]
A = surface area [m^2]
The convective heat transfer coefficient h_c can be calculated based on the given subtype.

Black radiation (BC_FREE, BC_SKY, BC_NOSKY, TRANSMAT)
The radiative heat flow between two black surfaces is:
$Q_{ij} = A_i \cdot F_{ij} \cdot h_{rb} \cdot (\theta_{sbi} - \theta_{sbj})$
Q_{ij} = radiative heat flow between black surface i and black surface j [W]
A_i = area of surface i [m^2]
F_{ij} = view factor from surface i to surface j (between 0 and 1)
h_{rb} = black radiation heat transfer coefficient [W/(m^2.K)]
θ_{sbi} = black surface temperature of surface i [°C]
θ_{sbj} = black surface temperature of surface j [°C]

For linear radiation the black radiation heat transfer coefficient is constant, defined as a calculation parameter (default value 5.1 W/(m^2.K)). The value depends on the temperature range of the problem considered. Section H.3 contains a table with values of h_{rb}, depending on the mean temperature θ_m [°C] of the surfaces i and j and the temperature difference between the surfaces $\Delta\theta_{ij}$ [°C]. The table shows that the h_{rb}-value mainly depends on the mean surface temperature θ_m.
The default value 5.1 W/(m^2.K) is the h_{rb}-value at 10°C.

For non-linear radiation:
$h_{rb} = \sigma \cdot (T_{sbi}^2 + T_{sbj}^2) \cdot (T_{sbi} + T_{sbj})$
σ = 5.67 10^{-8} W(m^2.K^4) (Stefan-Boltzmann constant)
T_{sbi} = θ_{sbi} + 273.16 [K] (absolute temperature of black surface i)
T_{sbj} = θ_{sbj} + 273.16 [K] (absolute temperature of black surface j)
The black radiation heat transfer coefficients are recalculated at the start of each new iteration cycle based on the temperatures obtained in the last iteration cycle.

Grey radiation (BC_FREE, BC_SKY, BC_NOSKY, TRANSMAT)
Real surfaces are not black (emissivity ε = 1) but grey (emissivity ε < 1).
In the RADCON module each grey surface is connected to a black surface node. All black surface nodes are connected to each other in a star diagram.
The radiative heat flow between the grey surface with given emissivity and the corresponding black surface is:
$$Q_r = A \cdot \frac{\varepsilon}{1-\varepsilon} \cdot h_{rb} \cdot (\theta_{sb} - \theta_s)$$
Q_r = radiative heat flow between grey surface and black surface [W]
A = surface area [m^2]
ε = surface emissivity (0 ≤ ε < 1)
h_{rb} = black radiation heat transfer coefficient [W/(m^2.K)]
θ_{sb} = black surface temperature [°C]
θ_s = (real) surface temperature [°C]
For non-linear radiation:
$h_{rb} = \sigma \cdot (T_{sb}^2 + T_s^2) \cdot (T_{sb} + T_s)$
T_{sb} = θ_{sb} + 273.16 [K]
T_s = θ_s + 273.16 [K]
The black radiation heat transfer coefficients are recalculated at the start of each new iteration cycle based on the temperatures obtained in the last iteration cycle.

Iteration cycles for non-linear radiation (BC_FREE, BC_SKY, BC_NOSKY, TRANSMAT)
Iteration cycles are used to calculate non-linear radiative heat transfer. At the start of each iteration cycle the black radiation heat transfer coefficients are updated using the local temperatures available at that moment.
For the first iteration cycle the black radiation heat transfer coefficients have a constant value as defined in the Calculation Parameters dialog box.
The total number of iteration cycles is defined in the Calculation Parameters dialog box. Normally 5 iteration cycles are sufficient. A low number of iteration steps in the last iteration cycle ensures that the number of iteration cycles is OK.

View factors (BC_FREE, BC_SKY, BC_NOSKY, TRANSMAT)
The view factors are calculated for all elementary surfaces (corresponding to edges in the mesh triangulation) bordering the environment (type BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT). Several environments of the same type (e.g. with different convective heat transfer coefficients) may touch one another. The view factors are calculated for the union space of these adjacent

environments.
Adjacent environments of different type are not allowed. Then an error message is displayed at the start of the system calculation (*Calc → Calc System*).
A boundary condition of type BC_FREE, BC_SKY, BC_NOSKY or TRANSMAT is not allowed to occur in different zones (separated by a material). Each zone must be considered as a separate environment (having a different colour). An error message is displayed at the start of the system calculation, when this condition is not satisfied.
First the view factor between two (elementary) surfaces, not obstructed by other surfaces, is calculated using an exact analytic formula. A very small view factor (i.e. smaller than the calculation parameter *smallest accepted view factor*) is neglected (rounded to 0). Then possible obstruction by other surfaces is estimated using 10 test rays between random points of both surfaces. The number of test rays is proportional to the unobstructed view factor.
After calculation of all view factors a correction is made to smooth away possible errors (e.g. due to the limited number of visibility test rays), so that the sum of view factors always equals 1, and the view factor reciprocities are respected.
The total number of calculated view factors (and hence the calculation time and required memory space) is a <u>quadratic</u> function of the number of elementary surfaces (= triangulation edges) in the largest view factor zone.

H.3. Table for black radiation heat transfer coefficient

The following table shows the black radiation heat transfer coefficient.
The values are obtained using the formula:

$$h_{rb} = \sigma \cdot (T_i^2 + T_j^2) \cdot (T_i + T_j)$$

with σ = 5.67*10^{-8} W/(m^2.K^4) (Stefan-Boltzmann constant)

black radiation heat transfer h_{rb} [W/m^{2}K]		temperature difference between the surfaces i and j $\Delta\theta_{ij}$ [°C]										
		0.00	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
mean temp. θ_m [°C]	-20.00	3.68	3.68	3.68	3.68	3.69	3.69	3.69	3.70	3.70	3.71	3.72
	-15.00	3.90	3.90	3.90	3.91	3.91	3.91	3.92	3.92	3.93	3.93	3.94
	-10.00	4.13	4.13	4.13	4.14	4.14	4.14	4.15	4.15	4.16	4.16	4.17
	-5.00	4.37	4.37	4.37	4.38	4.38	4.38	4.39	4.39	4.40	4.40	4.41
	0.00	4.62	4.62	4.62	4.63	4.63	4.63	4.64	4.64	4.65	4.65	4.66
	5.00	4.88	4.88	4.88	4.88	4.89	4.89	4.90	4.90	4.91	4.91	4.92
	10.00	5.15	5.15	5.15	5.15	5.16	5.16	5.16	5.17	5.17	5.18	5.19
	15.00	5.43	5.43	5.43	5.43	5.43	5.44	5.44	5.45	5.45	5.46	5.47
	20.00	5.71	5.71	5.72	5.72	5.72	5.72	5.73	5.73	5.74	5.75	5.76
	25.00	6.01	6.01	6.01	6.02	6.02	6.02	6.03	6.03	6.04	6.05	6.05
	30.00	6.32	6.32	6.32	6.32	6.33	6.33	6.33	6.34	6.35	6.35	6.36
	35.00	6.64	6.64	6.64	6.64	6.64	6.65	6.65	6.66	6.66	6.67	6.68
	40.00	6.96	6.97	6.97	6.97	6.97	6.98	6.98	6.99	6.99	7.00	7.01
	45.00	7.30	7.30	7.31	7.31	7.31	7.32	7.32	7.33	7.33	7.34	7.35
	50.00	7.65	7.65	7.66	7.66	7.66	7.67	7.67	7.68	7.68	7.69	7.70

H.4. Table for emissivities

The table below contains values of the long-wave emissivity ε of some building materials taken from:

- H.C. Hottel, Heat Transmission, 1954
- J.S. Cammerer, Wärme- und Kälteschutz in der Industrie, 1962
- Stichting Bouwresearch, Eigenschappen van bouw- en isolatiematerialen, rapport 9, 1974

building material	long-wave emissivity at T = 300K ε [-]
black surface	1
aluminium, polished	< 0.07
aluminium, oxidised	0.11 à 0.3
brass, polished	0.038
copper, smoothed	0.09
copper, oxidised	0.78 - 0.79
cast iron	0.44
iron, oxidised and rusted red	0.61
lead, gray oxidised	0.28
tin	0.043 - 0.064
zinc, galvanised	0.23
zinc, oxidised	> 0.11
asbestos board	0.96
bitumen	0.92
brick, red, rough but no gross irregularities	0.92 - 0.93
concrete	0.88
glass	0.94
cement-tiles	> 0.85
roofing-tiles, red	0.85
roofing paper	0.91
rubber, hard and glossy	0.94
wood	0.86
aluminium painting	0.42
enamel, white	>0.90
metal paint, black	0.88
water	0.95 - 0.96
other materials (approximation) white, yellow, green, red, blue, grey, black	0.85 à 0.95

The table below contains values of the long-wave emissivity ε from EN ISO 10077-2:2017:

description	ε [-]
Untreated aluminium surfaces	0.1
Slightly oxidized aluminium surface (up to 5 μm)	0.3
Metallic surfaces (general, including galvanized)	0.3
Anodized, painted or powder coated surfaces	0.9

H.5. Tables for convective heat transfer coefficient

The convective heat flow density is calculated using the following formula:

$q_c = h_c \cdot (\theta_a - \theta_s)$ with q_c= convective heat flow density [W/m²]
h_c = convective heat transfer coefficient [W/(m².K)]
θ_a= air temperature [°C]
θ_s = surface temperature [°C]

Table 1 lists values of h_c for air cavities according to EN ISO 10077-2, depending on the temperature difference $\Delta\theta$ over the cavity and the depth *d* of the cavity. Above the bold line, the h_c-value depends only on the cavity depth (same h_c-values on each row), while underneath the bold line the h_c-value depends only on the temperature difference over the cavity (same h_c-values in each column). Above the bold line there is in fact only conduction (still air). Below the line natural convection is considered.

Table 1: convective heat transfer coefficient (surface-to-surface) for air cavities (EN ISO 10077-2)

convective heat transfer h_c [W/(m².K)]		temperature difference over the cavity $\Delta\theta$ [°C]									
		0.500	1.000	1.500	2.000	3.000	4.000	5.000	6.000	8.000	10.000
depth of the cavity *d* [m]	0.001	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
	0.002	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000
	0.003	16.667	16.667	16.667	16.667	16.667	16.667	16.667	16.667	16.667	16.667
	0.004	12.500	12.500	12.500	12.500	12.500	12.500	12.500	12.500	12.500	12.500
	0.005	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
	0.006	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333
	0.007	7.143	7.143	7.143	7.143	7.143	7.143	7.143	7.143	7.143	7.143
	0.008	6.250	6.250	6.250	6.250	6.250	6.250	6.250	6.250	6.250	6.250
	0.009	5.556	5.556	5.556	5.556	5.556	5.556	5.556	5.556	5.556	5.556
	0.010	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
	0.011	4.545	4.545	4.545	4.545	4.545	4.545	4.545	4.545	4.545	4.545
	0.012	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167
	0.013	3.846	3.846	3.846	3.846	3.846	3.846	3.846	3.846	3.846	3.846
	0.014	3.571	3.571	3.571	3.571	3.571	3.571	3.571	3.571	3.571	3.571
	0.015	3.333	3.333	3.333	3.333	3.333	3.333	3.333	3.333	3.333	3.333
	0.016	3.125	3.125	3.125	3.125	3.125	3.125	3.125	3.125	3.125	3.145
	0.017	2.941	2.941	2.941	2.941	2.941	2.941	2.941	2.941	2.941	3.145
	0.018	2.778	2.778	2.778	2.778	2.778	2.778	2.778	2.778	2.920	3.145
	0.019	2.632	2.632	2.632	2.632	2.632	2.632	2.632	2.653	2.920	3.145
	0.020	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.653	2.920	3.145
	0.025	2.000	2.000	2.000	2.000	2.106	2.318	2.497	2.653	2.920	3.145
	0.030	1.667	1.667	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.035	1.429	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.040	1.250	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.045	1.159	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.050	1.159	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.060	1.159	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.070	1.159	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.080	1.159	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.090	1.159	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145
	0.100	1.159	1.460	1.671	1.839	2.106	2.318	2.497	2.653	2.920	3.145

Table 2 lists values of h_c for exterior surfaces, depending on the air velocity v and the temperature difference $\Delta\theta$ between surface and environment (from "Informatiemap voor bouwfysici", 1991).

Table 2: the convective heat transfer coefficient for exterior environments

convective heat transfer h_c [W/(m^2.K)]		temperature difference object – $\Delta\theta$ [°C]			
		5	10	20	40
air velocity v [m/s]	0.5	7	8	9	11
	1	9	10	11	13
	2	12	13	15	16
	3	19	20	21	23
	4	25	26	27	28
	5	30	31	32	34

The following formulas define the convective heat transfer coefficient for interior environments (from "Element 29: Wärmeschutz und Energie im Hochbau", 1990). Table 3 lists the h_c-values according to these formulas.

$h_c = 1.31 \cdot \sqrt[3]{\Delta\theta}$ for vertical constructions (walls) with a horizontal heat flow

$h_c = 1.77 \cdot \sqrt[4]{\Delta\theta}$ for vertical constructions (window) with a horizontal heat flow

$h_c = 1.52 \cdot \sqrt[3]{\Delta\theta}$ for horizontal constructions (walls) with an upward heat flow

$h_c = 0.59 \cdot \sqrt[4]{\Delta\theta / L}$ for horizontal constructions (walls) with a downward heat flow

with h_c = convective heat transfer coefficient [W/(m^2.K)]
$\Delta\theta$ = temperature difference object – environment [°C]
L = ½ (length x width) of the construction [m^2]

Table 3: the convective heat transfer coefficient for interior environments

convective heat transfer coefficient h_c [W/(m^2.K)]		vertical constructions horizontal heat flow		horizontal constructions	
		walls	windows	upgoing heat flow	downgoing heat flow
temperature difference object – environment $\Delta\theta$ [°C]	1	1.31	1.77	1.52	0.39
	2	1.65	2.10	1.92	0.47
	3	1.89	2.33	2.19	0.52
	4	2.08	2.50	2.41	0.56
	5	2.24	2.65	2.60	0.59
	6	2.38	2.77	2.76	0.62
	7	2.51	2.88	2.91	0.64
	8	2.62	2.98	3.04	0.66
	9	2.72	3.07	3.16	0.68
	10	2.82	3.15	3.27	0.70
	11	2.91	3.22	3.38	0.72
	12	3.00	3.29	3.48	0.73
	13	3.08	3.36	3.57	0.75
	14	3.16	3.42	3.66	0.76
	15	3.23	3.48	3.75	0.78

* using L = 5 m