THE CONCEPT OF SURFACE ORIENTATION OF AIR CAVITIES IN ISO 15099 IN BISCO (V13) AND THERM (V7.8)

1. Introduction

This document examines heat transfer in unventilated, non-rectangular cavities in accordance to ISO 15099. The standard provides a method for converting such cavities into equivalent rectangular ones, allowing a practical approach for the calculation of heat transfer by convection and infrared radiation (type EQUIMAT (ISO 15099) in Physibel tools). In this process, equivalent vertical and horizontal surfaces are defined based on their surface orientation. In the heat transfer calculation, the mean surface temperatures of these surfaces are key parameter in the determination of the heat flow direction. This study investigates how minor changes in the surface inclination can lead to significant variations in equivalent cavity conductivities. The key elements addressed in this analysis include:

- Definitions for cavity surface orientation as specified in ISO 15099.
- Impact of surface orientation on equivalent thermal conductivity.
- Cross-comparison of BISCO and THERM simulations.
- Cross-comparison of the single equivalent thermal conductivity method (EQUIMAT) and the radiosity method (TRANSMAT) in BISCO for ISO 15099 and EN ISO 10077.

2. ISO 15099 – The single equivalent thermal conductivity method

According ISO 15099 for unventilated cavities,

$$\lambda_{eff} = (h_{cv} + h_r) \times d$$

where,

λ_{eff} is the effective conductivity;

h_{cv} is the convective heat transfer coefficient;

h_r is the radiative heat transfer coefficient

d is the thickness or width of the air cavity in the direction of heat flow.

The convective heat transfer coefficient, h_{cv}, is calculated from the Nusselt number, Nu, for which relations are given in ISO 15099.

$$h_{cv} = Nu \frac{\lambda ai}{d}$$

λ_{air} thermal conductivity of still air (0.025 W/mK)

Surface orientation refers to the inclination of cavity surfaces with respect to their normal.

Step 1: Define whether the surface is vertical or horizontal.

According to ISO 15099, for an unventilated and irregularly shaped frame cavity, the geometry shall be converted into the equivalent of a rectangular cavity with the procedure in EN ISO 10077-2. The surfaces should also be determined either belong to **vertical** or **horizontal** surfaces of equivalent rectangular cavity, which are:

a) any surface whose normal is between 315° and 45° is a left vertical surface;

b) any surface whose normal is between 45° and 135° is a bottom horizontal surface;

c) any surface whose normal is between 135° and 225° is a right vertical surface;

d) any surface whose normal is between 225° and 315° is a top horizontal surface.

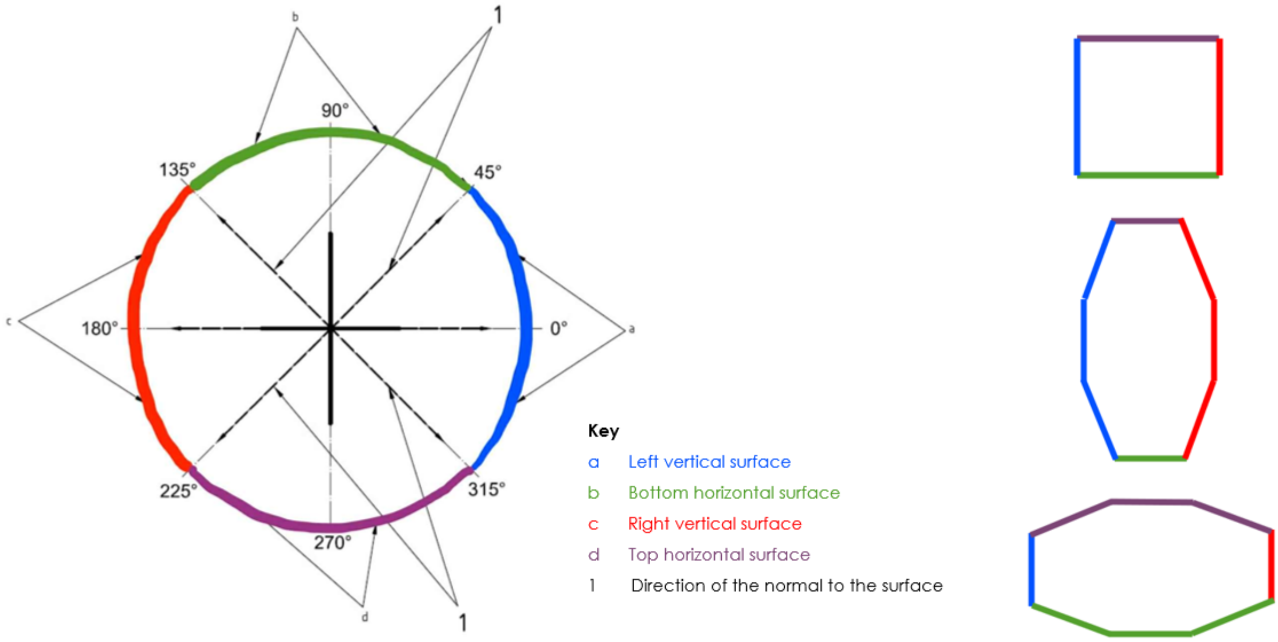


Figure 1. Illustration of surface orientation in frame cavities

Step 2: Define per surface mean temperature.

Step 3: The heat flow direction is determined by the greater of the two temperature differences between the vertical and horizontal surfaces.

In some cases, small differences in geometry will lead to relatively large differences in total heat transfer, which will show as examples below.

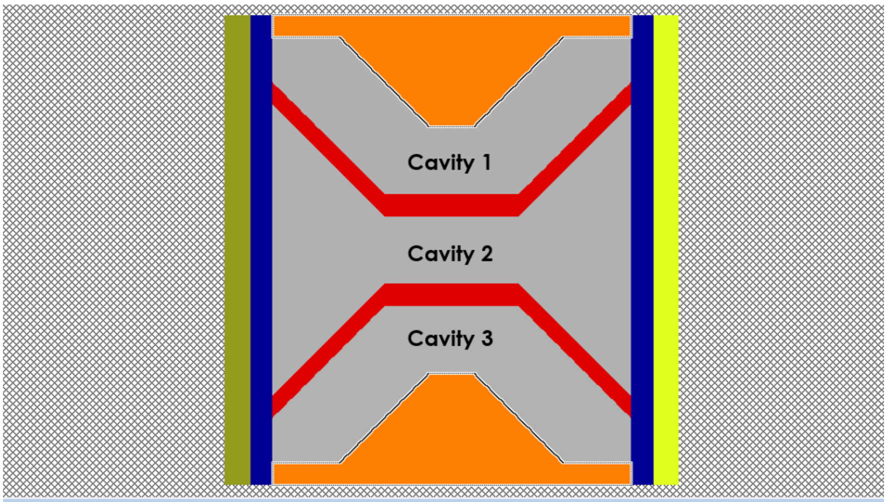
3. Simulations

The example presents a frame configuration consisting of three cavities. The material properties used in the model are provided below.

Boundary conditions:

- Indoor: Temperature 21°C, fixed global surface heat transfer coefficient: 10 W/m²K.

- Outdoor: Temperature -18°C, fixed global surface heat transfer coefficient: 30 W/m²K.



Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [- / -]	λ [W/mK]
18		MATERIAL				soda lime		1.000
28		MATERIAL				insulation panel		0.035
36		MATERIAL				polyamid nylon		0.300

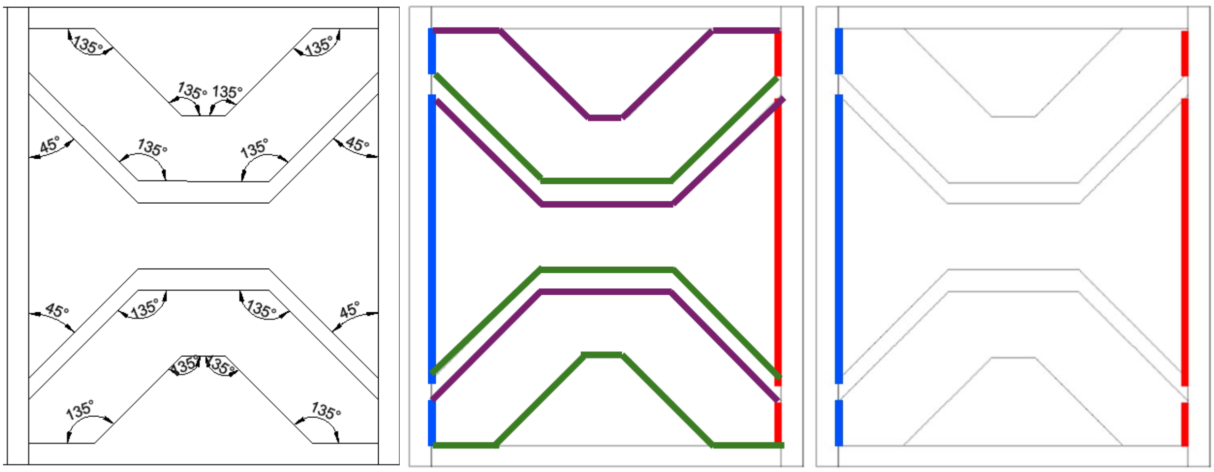
Figure 2. Model and material properties

The base model is defined with cavity surfaces sloped at angles of 45°, 135°, 225°, and 315°. To investigate the impact of surface orientation on thermal performance, four additional models are introduced, each with a slight variation in cavity surface inclination. These variations include angles of 43°, 44°, 46°, and 47°, providing incremental changes of ±1° and ±2° relative to the base configuration.

All five models are initially simulated in THERM to evaluate the effect of surface orientation on the results. Subsequently, the same configurations are analysed using BISCO, and the outcomes are compared with those obtained from THERM.

3.1. Base model (45°)

In this example, the angles of the sloped surfaces are 45°, 135°, 225° and 315° as a baseline.



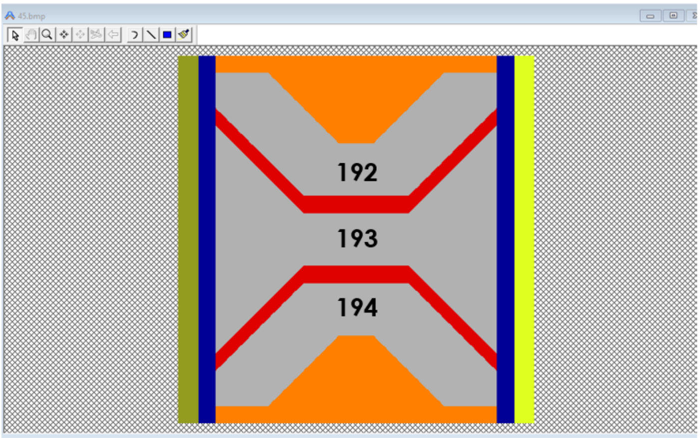
As illustrated in Figure 1 with a corresponding colour legend, the vertical and horizontal surfaces of the cavities are identified accordingly. Based on these orientations and the applied boundary conditions, the direction of heat flow is determined by the temperature gradient between the vertical and horizontal surfaces.

The below figures show the effective conductivities of the cavities as well as the U-value for the given section in THERM.

U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation		Heat Flow W
Interior	1.7849	39.0	105	N/A	Projected Y	7.3093

The below figures show the equivalent conductivities of the cavities as well as the U-value for the given section in BISCO.



Colours

Col.		Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε1 / ε2 [-/-]	λ [W/mK]
36		MATERIAL				polyamid nylon		0.300
167		BC_SIMPL	NIHIL			Indoor, center of glass (Automatic Enclosure Model)		
171		BC_SIMPL	NIHIL			Outdoor NFRC 100 (blackbody)		
192		EQUIMAT	CAVITY	HOR	X		0.90 / 0.90	0.284
193		EQUIMAT	CAVITY	HOR	X		0.90 / 0.90	0.273
194		EQUIMAT	CAVITY	HOR	X		0.90 / 0.90	0.283

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Equivalent thermal transmittance: Ueq1 (jamb section, height 1.00 m)
Ueq1 = (Qe1/(ti-te) / we1 = 1.740 W/(m².K)
Thermal coupling coefficient
L2D = Q/(ti-te) = 0.1827 W/(m.K)
  Q = 7.126 W/m
  ti = 21.00°C
  te = -18.00°C
  Qe1 = 7.126 W/m
  we1 = 0.1050 m          (distance no. 1)
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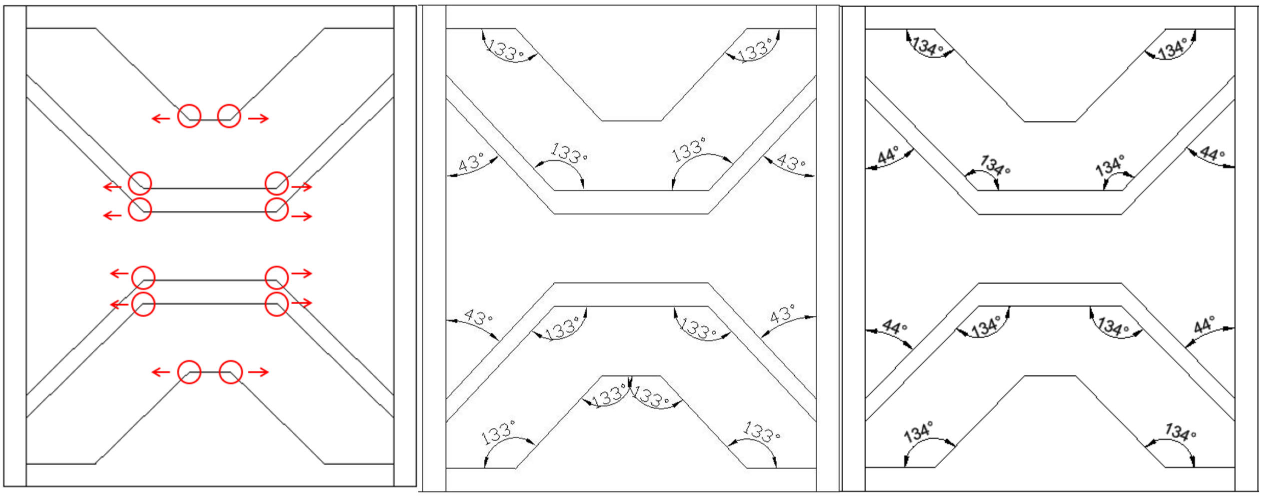
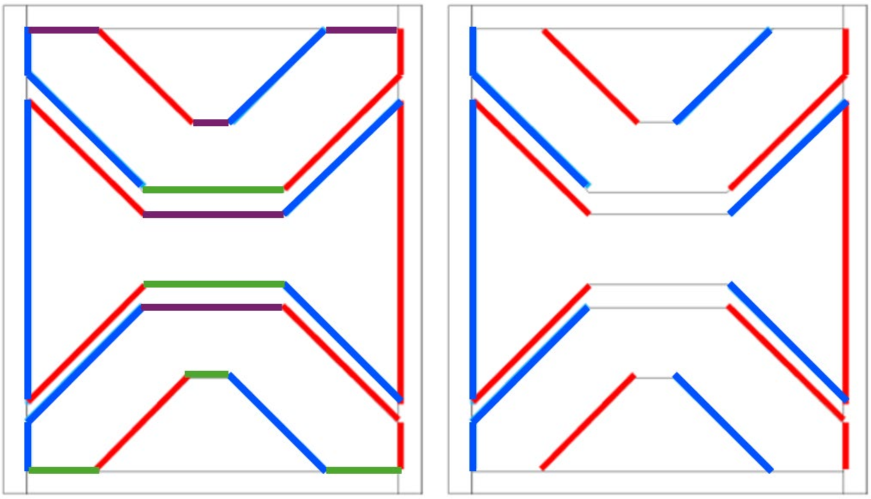
3.2. 43° & 44°

The marked points are moved outwards along the X-axis, creating an inclination of 43° and 44° for one of the cavity surfaces.

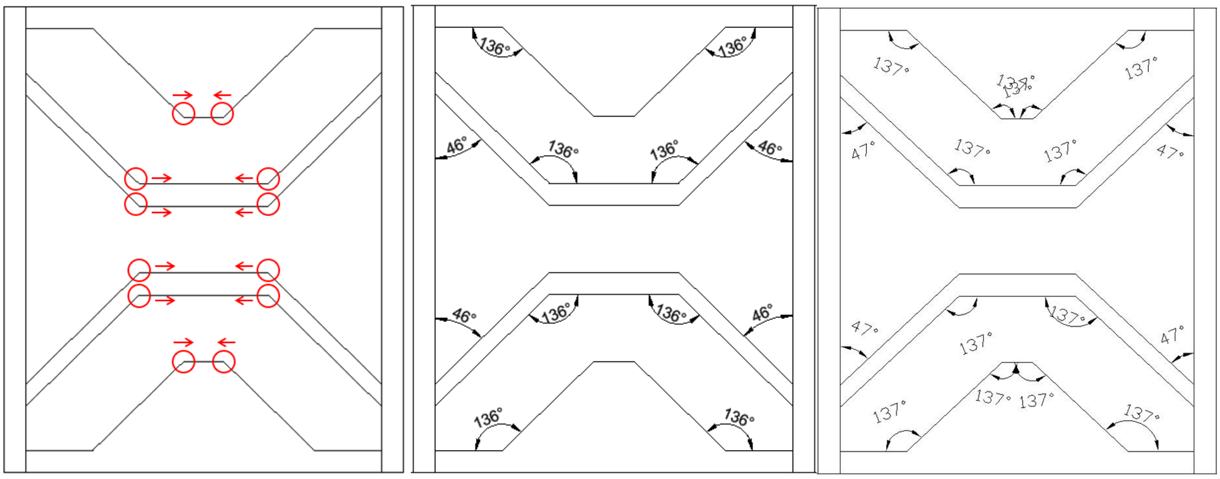


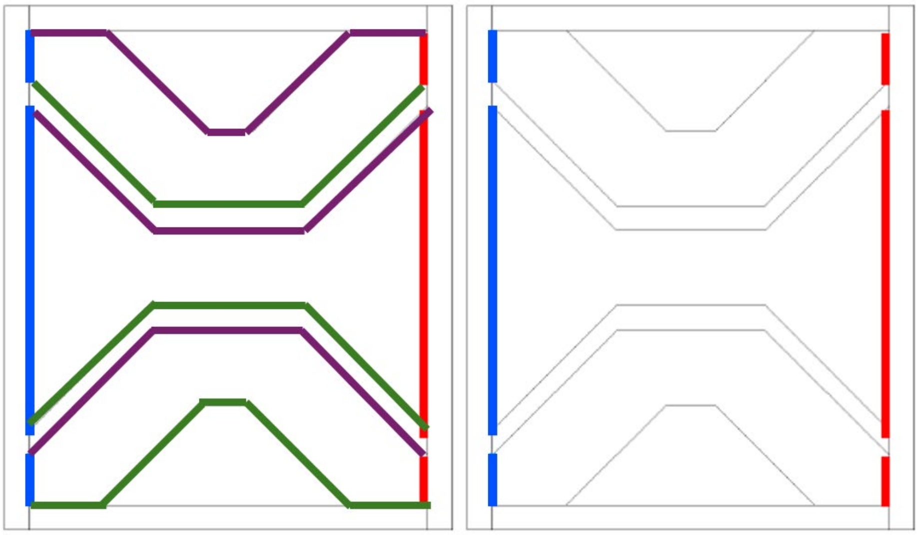


Similarly, the heat flow direction was defined with more vertical surfaces being recognized in this case.

3.3. 46° and 47°

The marked points are moved inwards (towards the centre, along the X-axis), creating an inclination of 46° and 47° for one of the cavity surfaces.





The vertical surfaces and heat flow direction were detected similarly to the base case (45°).

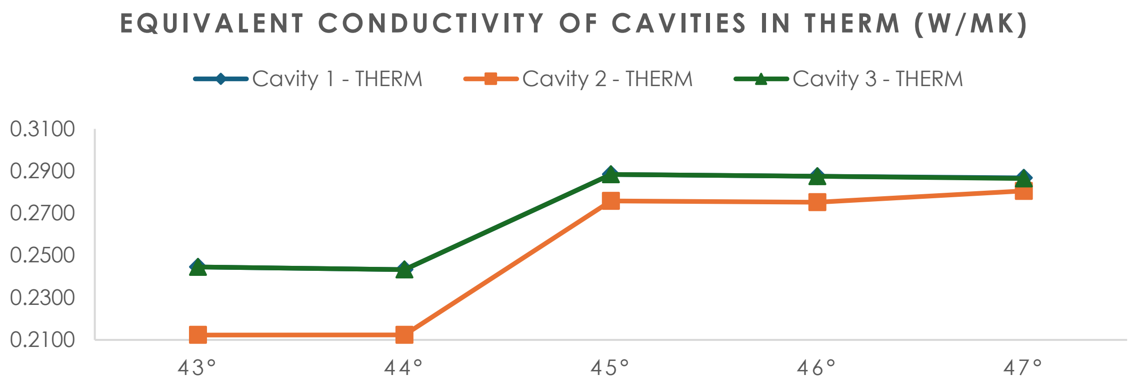
4. Results of all models

4.1. THERM

Cavity 1 and 3 have similar values across all models. As shown in Table 1, the equivalent conductivities in the 43° and 44° models showed significant deviation from the base model (45°). Furthermore, Table 2 shows the mean temperatures of the surfaces of the cavities for all the models. It can be seen that, the change in the T_{ch} and T_{cc} values from model 44° to model 45° is of about 10°C.

File	Model	Inclination °	λ for Cavities (W/mK) Cavity 1 - THERM	Cavity 2 - THERM	Cavity 3 - THERM	U value W/m²K
43.THM	1	43°	0.2445	0.2123	0.2445	1.6594
44.THM	2	44°	0.2433	0.2124	0.2433	1.6669
45.THM	3	45°	0.2884	0.2758	0.2884	1.88444
46.THM	4	46°	0.2876	0.2753	0.2876	1.8943
47.THM	5	47°	0.2868	0.2806	0.2865	1.8033

Table 1. Results in THERM



Model	Cavity 1		Cavity 2		Cavity 3	
	Side 1	Side 2	Side 1	Side 2	Side 1	Side 2
43°	3.489	-4.791	0.9950	-2.3520	3.4910	-4.778
44°	3.435	-4.748	0.9370	-2.3120	3.4360	-4.746
45°	13.772	-15.535	12.9800	-14.9580	13.7680	-15.536
46°	13.735	-15.522	12.9360	-14.9420	13.7320	-15.524
47°	13.691	-15.511	12.8890	-14.9230	13.6930	-15.512

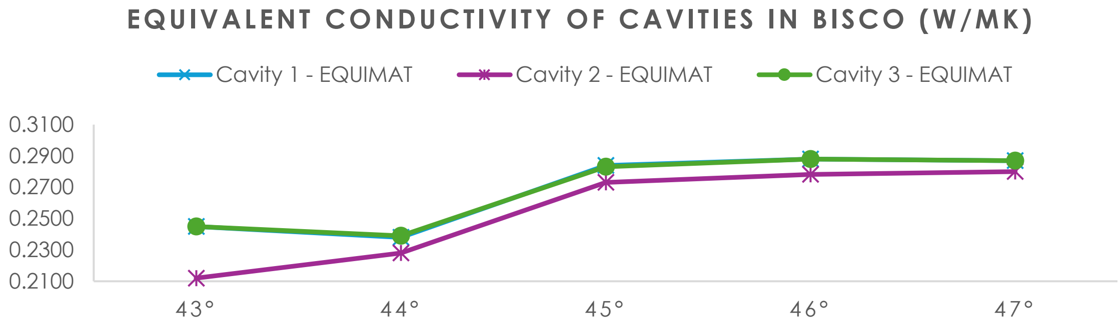
Table 2. Average temperature of cavities' sides (°C)

4.2. BISCO

Similar results were expected in BISCO – EQUIMAT.

File	Model	Inclination °	λ for Cavities (W/mK)			U value W/m²K
			Cavity 1- BISCO	Cavity 2 - BISCO	Cavity 3 - BISCO	
43.bsc	1	43°	0.2450	0.2120	0.2450	1.655
44.bsc	2	44°	0.2380	0.2280	0.2390	1.676
45.bsc	3	45°	0.2840	0.2730	0.2830	1.863
46.bsc	4	46°	0.2880	0.2782	0.2880	1.886
47.bsc	5	47°	0.2870	0.2800	0.2870	1.9

Table 3. Results in BISCO – EQUIMAT



Model 43° **Model 45°** **Model 47°**

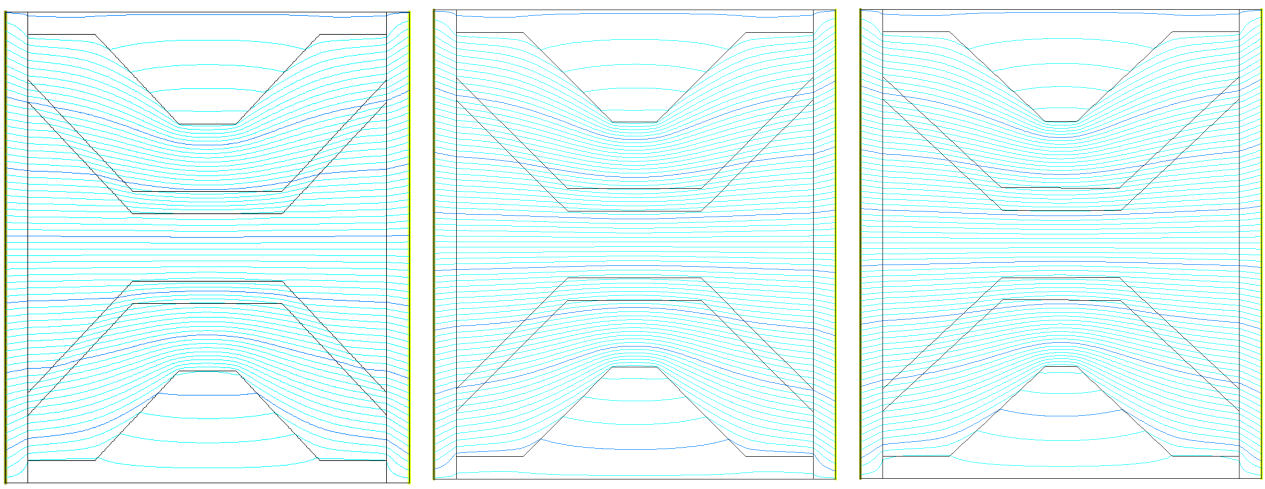
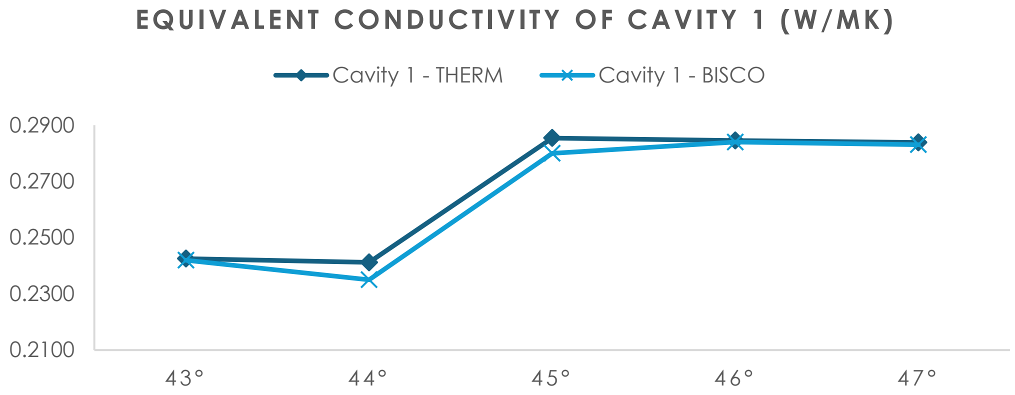
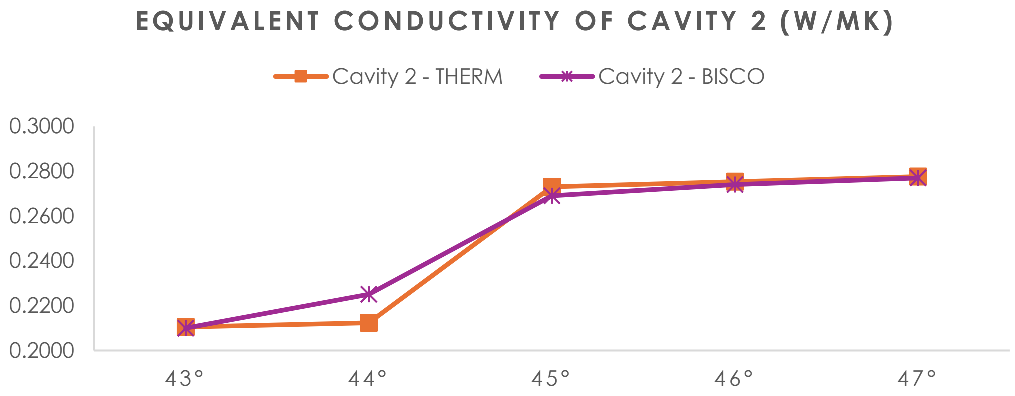


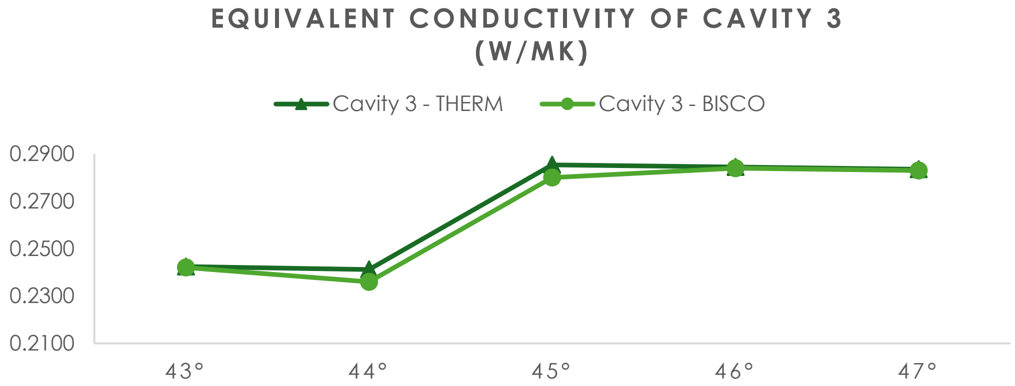
Table 4. Heat flow lines from BISCO

4.3. Comparison between THERM and BISCO.

The same trend with a discontinuity at 45° is observed in both THERM and BISCO results.



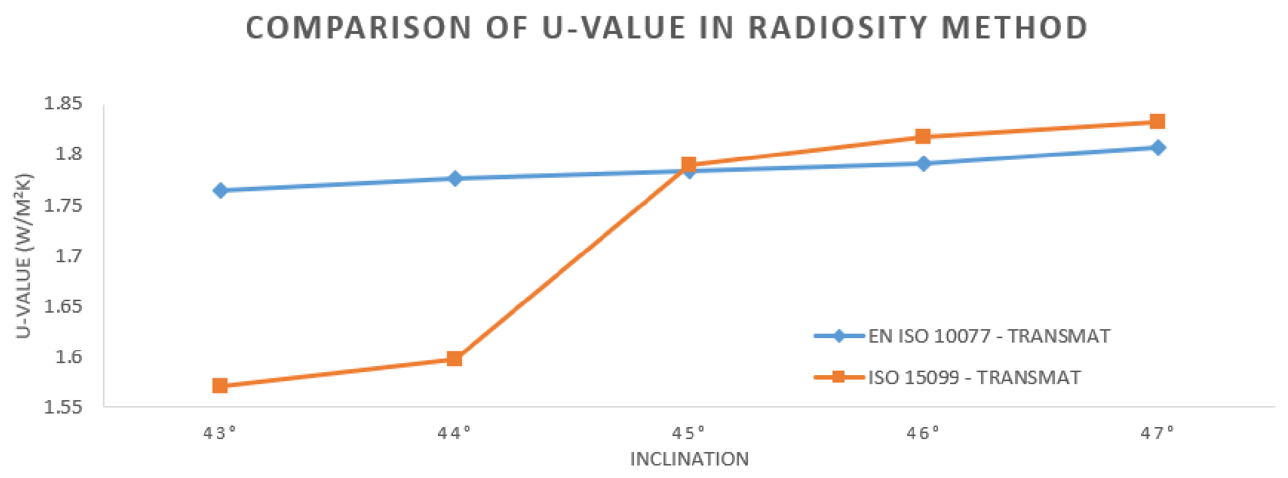




4.4. Radiosity method in ISO 15099 and EN ISO 10077

In the Radiosity method, convective and radiative heat transfers are treated separately. In BISCO, this is implemented through the TRANSMAT type for cavities. According to ISO 15099, the heat flow within a cavity is considered only in either the X or Y direction, whereas EN ISO 10077 correctly accounts for the actual orientation of heat flow (indicated with 'DIR 'in BISCO).

The comparison of overall U-values for the same example using the TRANSMAT type in BISCO clearly shows that the Radiosity method following EN ISO 10077 provides more accurate results than ISO 15099, as it does not impose a sudden transition between the X and Y directions.


COMPARISON OF U-VALUE IN RADIOSITY METHOD
U-VALUE (W/M²K)
1.85
1.8
1.75
1.7
1.65
1.6
1.55
EN ISO 10077 - TRANSMAT
ISO 15099 - TRANSMAT
43°
44°
45°
46°
47°
INCLINATION