

1. Introduction

When the material surfaces around a cavity have a low infrared emissivity, for example if they are covered by an aluminium foil, the radiation heat transfer is reduced. Using an example, it is shown how to deal with such reduced cavity heat transfer in the Physibel software.

2. Example data

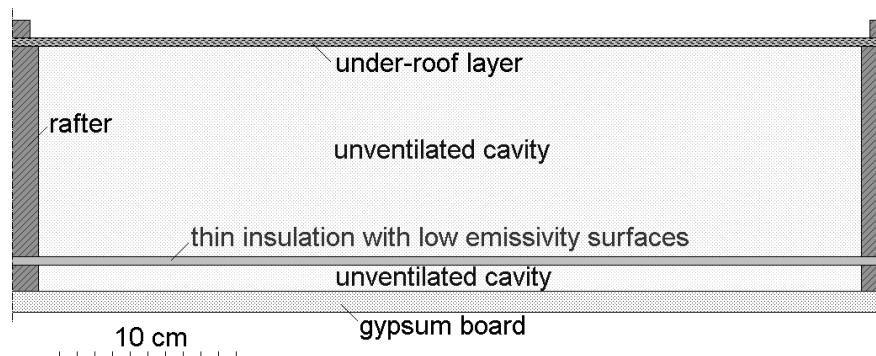


Figure 1. Section through a roof containing a thin insulation layer with low emissivity surfaced.

Figure 1 shows a section through a sloped roof¹. Left and right borders correspond to symmetry axes. A thin insulation layer with low emissivity surfaces ($\varepsilon = 0.1$) is installed, resulting in 2 unventilated air cavities.

Materials thermal conductivity:

- | | | | |
|----------------|-------------------------------|-------------------------|--------------------------------|
| - wood | $\lambda = 0.17 \text{ W/mK}$ | - under-roof layer | $\lambda = 0.23 \text{ W/mK}$ |
| - gypsum board | $\lambda = 0.25 \text{ W/mK}$ | - thin insulation layer | $\lambda = 0.040 \text{ W/mK}$ |

Boundary conditions:

- interior: temperature $\theta_e = 20^\circ\text{C}$, surface heat transfer coefficient $h_i = 10 \text{ W/m}^2\text{K}$ (EN ISO 6946, upwards heat transfer)
- exterior: temperature $\theta_e = 0^\circ\text{C}$, surface heat transfer coefficient $h_e = 10 \text{ W/m}^2\text{K}$ (EN ISO 6946, strongly ventilated cavity).

To simulate the heat transfer through the cavities 3 methods are available in the Physibel software:

1. Assuming an equivalent thermal conductivity, using the Physibel type EQUIMAT.
2. Splitting the radiation and convection, using the Physibel type TRANSMAT (convection as equivalent conduction).
3. Splitting the radiation and convection, using the Physibel type BC_FREE (convection with single air node).

In the 3 methods formulas from EN ISO 6946 are used.

¹ The tiles are omitted in the drawing. The cavity under the tiles is considered as strongly ventilated and therefore the tiles don't need to be considered in a thermal simulation according to EN ISO 6946.

3. Method 1. Using equivalent thermal conductivities, Physibel type EQUIMAT.

TRISCO data [T_roof_with_low_e_foil EQUIMAT.trc](#)

BISCO data [B_roof_with_low_e_foil EQUIMAT.bsc](#)

In simulations, the heat transfer by convection and/or conduction and by infrared radiation is often replaced by a so-called equivalent heat transfer by conduction. Formulas for the equivalent thermal conductivity are given by several standards, for example annex D of EN ISO 6946.

The formulas are based on:

- Empirical convection formulas. The convection depends on the *cavity thickness* (in the direction of the heat transfer) and on the *temperature difference* over the cavity. The formulas take into account that for thin cavities there is no convection (still air) but conduction instead.
- Simplified radiation formulas. The radiation depends on the *cavity thickness* (in the direction of the heat transfer), on the *cavity width*, on the *infrared emissivity of the warm and cold surface*.

The EN ISO 6946 formulas are embedded in the Physibel software. To apply them (Figure 2):

- *Settings* → *Default Standards...* and select EN ISO 6946 as default.
- The type EQUIMAT needs to be assigned to the colour assigned to the cavity. According to the definition in EN ISO 6946 the upper cavity should be of subtype CAVITY and the bottom cavity of subtype LAYER (for this cavity both the width and length are ten times its thickness).
- The physical heat flow direction (up) and geometrical flow direction (Y) needs to be defined.
- The infrared emissivity of the warm and cold surface should be defined in the column 'ε₁/ε₂' by double clicking. In case the values differ from the standard 0.9/0.9, they are highlighted in red.
- In Calculation Parameters, the use of the solution temperature in the equivalent thermal calculation should be checked (if not a default ΔT of 5°C is assumed).

As a result the equivalent thermal conductivities of the cavities are calculated (Figure 2).

Colours														
Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	ε ₁ / ε ₂ [- / -]	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θ _a [°C]	hc [W/m²K]	Pc [W/m]
254	EQUIMAT	CAVITY	UP	Y	cavity upward heat transport	0.90 / 0.10	0.294							
255	EQUIMAT	LAYER	UP	Y	cavity upward heat transport	0.10 / 0.90	0.037							
														Standard
														EN6946
														EN6946

Figure 2. EQUIMAT cavity definitions (BISCO data [B_roof_with_low_e_foil EQUIMAT.bsc](#)).

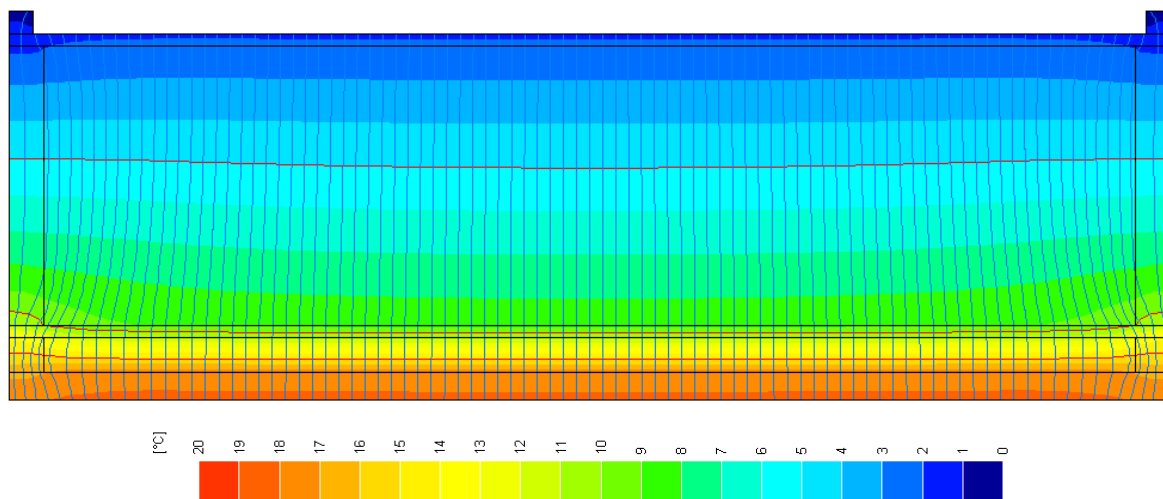


Figure 3. Isotherms (colour increment 1 °C, line increment 5 °C) and heat flow lines (increment 0.1 W/m).

Figure 3 shows the isotherms and the heat flow lines in the roof section.

The U-value of the roof is $U_{\text{roof}} = 0.89 \text{ W/m}^2\text{K}$.

4. Method 2. Using split radiation and convection, Physibel type TRANSMAT.

TRISCO data [T_roof_with_low_e_foil_RADCON_TRANSMAT.trc](#)

BISCO data [B_roof_with_low_e_foil_RADCON_TRANSMAT.bsc](#)

The Physibel type TRANSMAT allows a simulation with split heat transfer by radiation and conduction through a still gas (as in physical reality).

The radiation simulation is based on non-linear or linear view factor based radiation laws (Stefan-Boltzman's law, Lambert's Cosine Law, view factor based heat exchange)

The conduction simulation is based on the thermal conductivity of the gas (for air $\lambda = 0.025 \text{ W/mK}$). Also for a flowing gas, in case of convection, equivalent conduction can be considered using a thermal conductivity equal to the gas thermal conductivity multiplied with the Nusselt number. The Nusselt number can be calculated according to EN ISO 6946.

Note: more information on the determination of the Nusselt number can be found in the Physibel Knowledge base document 'THERMAL SIMULATION OF NON-VENTILATED CAVITIES USING THE RADCON MODULE.pdf').

Even though this method is physically more correct than the single equivalent thermal conductivity method (see paragraph 3), EN ISO 6946 does not include this method. Therefore, no TRANSMAT type with STANDARD EN ISO 6946 exists in the Physibel software.

However, it is possible to use the convection formulations of EN ISO 6946 in combination with radiosity method for infrared radiation.

A trick to derive in BISCO or TRISCO the thermal conductivity required in the TRANSMAT type is the following:

- Define the cavity first as EQUIMAT as described in method 1. The equivalent thermal conductivity contains now both a convection and a radiation part.
- Change the emissivity of both surfaces to $\varepsilon = 0.001$. Now the equivalent conductivity contains only the convection part. This is the value required by TRANSMAT. The Nusselt number equals the value found divided by 0.025 W/mK (λ_{air}).
- Change the type from EQUIMAT to TRANSMAT with Standard NIHIL. The value of the thermal conductivity is kept (Figure 4).

The infrared emissivity of each material colour needs now to be specified.

Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	$\varepsilon_1 / \varepsilon_2$ [- / -]	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θ_a [°C]	h_c [W/m²K]	P_c [W/m]	θ_r [°C]	Standard
254	TRANSMAT	NIHIL			cavity Nu = 9.36		0.234									NIHIL
255	TRANSMAT	NIHIL			cavity Nu = 1.16		0.029									NIHIL

Figure 4. TRANSMAT cavity definitions (data [B_roof_with_low_e_foil_RADCON_TRANSMAT.bsc](#)).

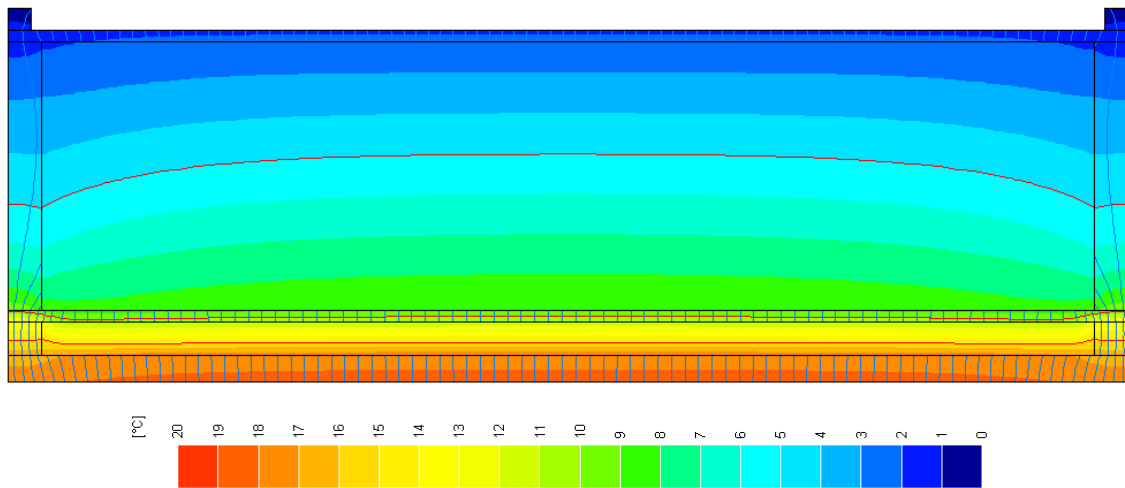


Figure 5. Isotherms (colour increment 1 °C, line increment 5 °C) and heat flow lines (increment 0.1 W/m).

Figure 5 shows the isotherms and the heat flow lines in the roof section. In the cavities no heat flow lines occur, as this is physically impossible due to the split radiation and conduction. The U-value of the roof is $U_{\text{roof}} = 0.88 \text{ W/m}^2\text{K}$.

5. Method 3. Using split radiation and convection, Physibel type BC_FREE.

TRISCO data [T_roof_with_low_e_foil_RADCON_BCFREE.trc](#)

BISCO data [B_roof_with_low_e_foil_RADCON_BCFREE.bsc](#)

The Physibel type BC_FREE allows a simulation with a split heat transfer by radiation and convection (as in physical reality).

The radiation simulation is identical to the one of method 2.

The convection simulation assumes a homogeneous air temperature in the core zone of the cavity. Between the core zone and the cavity surfaces the convective heat transfer is simulated using the equation: $q_c = h_c (\theta_{\text{air}} - \theta_{\text{surface}})$. The convective heat transfer coefficient h_c can be calculated according to EN ISO 6946 (see Physibel Knowledge base document 'THERMAL SIMULATION OF NON-VENTILATED CAVITIES USING THE RADCON.pdf').

To apply the method (Figure 6):

- The type BC_FREE needs to be assigned to the colour assigned to the cavity.
- The physical heat flow direction (up) and geometrical flow direction (Y) needs to be defined.
- The convective heat transfer coefficient is automatically calculated according to the convective heat transfer formula's in EN ISO 6946 (see EN ISO 6946 and Physibel software manuals).
- The infrared emissivity of each material colour needs now to be specified.
- In Calculation Parameters, the use of the solution temperature in the equivalent thermal calculation should be checked.

As a result the convective surface heat transfer coefficient is calculated (Figure 6).

Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	$\varepsilon_1 / \varepsilon_2$ [- / -]	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θ_a [°C]	h_c [W/m²K]	P_c [W/m]	θ_r [°C]	Standard
254	BC_FREE	CAVITY	UP	Y	cavity upwards heat transfer						0		4.27	0		
255	BC_FREE	CAVITY	UP	Y	cavity upwards heat transfer						0		4.27	0		

Figure 6. BC_FREE cavity definitions (data [B_roof_with_low_e_foil_RADCON_BCFREE.bsc](#)).

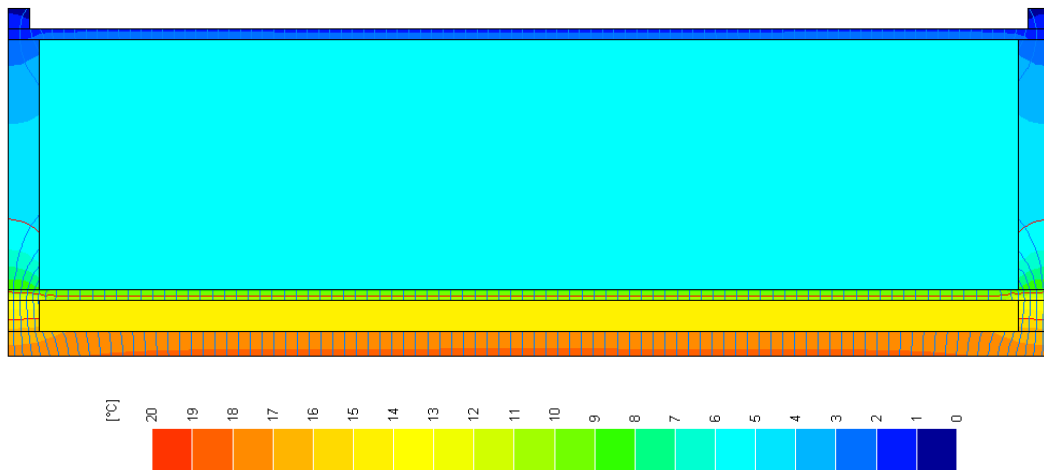


Figure 7. Isotherms (colour increment 1 °C, line increment 5 °C) and heat flow lines (increment 0.1 W/m).

Figure 6 shows the isotherms and the heat flow lines in the roof section. In the cavities no heat flow lines occur, as this is physically impossible due to the split radiation and conduction. The cavity is coloured in a homogeneous way, corresponding to the assumed homogeneous core air temperature.

The U-value of the roof is $U_{\text{roof}} = 0.93 \text{ W/m}^2\text{K}$.

6. Discussion

Compared to the EQUIMAT and TRANSMAT methods, the BC_FREE method results in a slightly higher thermal transmittance U. The assumption of a homogeneous cavity air temperature is probably too pessimistic. An air temperature gradient is probable for cavities of that scale. The BC_FREE type is more appropriate for situations where an isothermal core zone can be expected, e.g. for large enclosures such as rooms or double skin façades. In fact, EN ISO 6946 states in annex D to use a single zone heat balance according to EN ISO 13789 (= type BC_FREE) for air layers thicker than 0.3m.

It should not be concluded that there will always be a good correspondence between the EQUIMAT method and the TRANSMAT method. The EQUIMAT method is designed for rectangular cavities, and in case of non-rectangular cavities, it can be expected that the TRANSMAT method will give more reliable results.

7. References

EN ISO 6946: 2017: Building components and building elements – Thermal resistance and thermal transmittance – Calculation method

Physibel Pilot Book version 2. Document “Thermal simulation of non-ventilated cavities using the RADCON module”. File PPB_non_ventilated_cavities.pdf.

EN ISO 13789: 2017 : Thermal performance of buildings - Transmission and ventilation heat transfer coefficients - Calculation method

Incropera & DeWitt, Introduction to Heat Transfer, 1996, ISBN 0-471-30458-1