Modeling the Heat Exchange in Cavities of Building Constructions Using COMSOL Multiphysics®

Bram Kersten and Jos van Schijndel*
Eindhoven University of Technology,
*P.O. Box 513 Eindhoven, Netherlands, A.W.M.v.Schijndel@tue.nl

Abstract: In Europe a lot of dwellings are built with exterior cavity walls. These double walls provide stability to the structure and separate the controlled indoor climate from the outdoor fluctuating environment. In this study we want to receive more insight in the heat exchange between the walls through the cavity in between, by computer simulations and verifications. Simulations and calculations with several variants of the cavity wall should give information about the effects of influence factors to the different heat transfer mechanisms: radiation, convection and conduction. The main problem could be the accuracy of the simulated airflow in the cavity and the accompanying heat exchange near the cavity surfaces. In the paper we present a systematic approach and some guidelines for modeling the heat exchange in cavities of building constructions.

Keywords: Cavity, building construction, heat transfer

1. Introduction

In the Netherlands almost all dwellings are build with exterior cavity walls. These double walls provide stability to the structure and separate the controlled indoor climate from the outdoor fluctuating environment. In this study we want to receive more insight in the heat exchange between the walls through the cavity in between, by computer simulations and hand calculations. Simulations and calculations with several variants of the cavity wall should give information about the effects of influence factors to the different heat transfer mechanisms, named: radiation, convection and conduction.

As we mentioned above, the heat exchange between the two walls through the air cavity occurs by radiation, convection and conduction. The parameters that have influence to these mechanisms are given in Figure 1 (see appendix). In earlier times the air cavity had three main functions: thermal insulation, drying of the outer leaf by air ventilation and acting as a capillary break to prevent liquid transmission. Ventilation in the cavity occurs by butt joints in the outer leaf, which connect the cavity with outdoor air.

Nowadays most cavity walls are well insulated, so the contribution of the air cavity through the thermal resistance of the construction is small. Also the contribution to the drying process is greatly diminished. Even though the butt joints are present, the ventilation flow is greatly reduced by an insulated inner leaf. This can be explained using Figure 2. Due to temperature differences, air density differences occur in a ventilation flow through the cavity. These differences in air density are caused by the warm inner leaf, which warms up the incoming cool air.

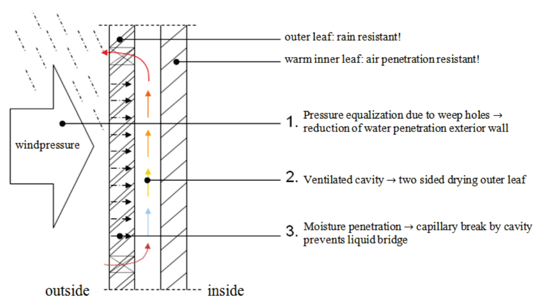


Figure 2. Mechanisms of moisture prevention in a cavity wall

Because nowadays the inner leaf is mostly insulated, the driving factor behind the ventilation flow is removed. The air temperature in the cavity will also be lower, which results in less absorption capacity of water vapor. The outdoor wind hardly influences the ventilation flow in the cavity. A study by Silberstein (2006) demonstrated that the air velocity in the cavity is hardly influenced by the external wind speed.

Figure 3 shows the measurements of air velocity in a cavity belonging to various external wind speeds. The average air velocity is about 0.06 m/s.

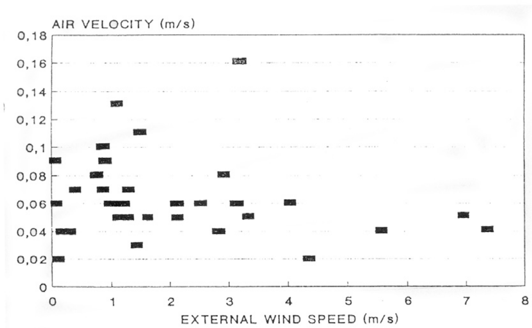


Figure 3. Measured air velocity as function of the external wind speed Silberstein (2006)

Another study by Künzel (1998) has shown that the contribution of the air cavity to the total resistance of the cavity wall construction, is only about 5%. Figure 4 compares the heat loss of a double wall with and without an air cavity.

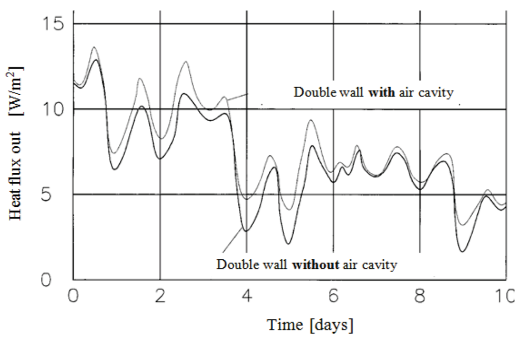


Figure 4. Heat flux through a double wall, with or without air cavity Künzel (1998).

In this study the focus is on the thermal resistance properties of the air cavity between a double wall. The NEN-EN-ISO 6946 includes a table with reference thermal resistance values for air cavities, depending on its thickness and heat flow direction. These values are presented in Figure 5 (see appendix). On the right side the heat transmittance of an air cavity is divided into the three heat flux mechanisms: radiation (r), convection (cv) and conduction (cd), as function of the cavity thickness. The way we want to examine the influence of some variations of the cavity wall, is mentioned in the 'method' section below:

2. Method

We used the software program COMSOL Multiphysics 4 to make computer simulations of the heat flow problems in variants of cavity wall constructions. Herewith we try to find out which influences several factors have on the thermal resistance of the cavity wall construction. Beside computer simulations we also use some hand calculations to examine some variants.

The influence factors that were considered in this study are: (1) Cavity filled with air versus vacuum (simulated); (2) Various amounts of ventilation volume flows by changing incoming air speed (simulated); (3)Variations in cavity width (simulated); (4) Effect of reflective foil inside the cavity (calculated). The different simulation case studies with their main properties in this study are visualized in Figure 6 (see appendix). Figures 7 (see appendix) presents the case studies which will be examine by (hand)calculations.

3. Modeling

The physical modules in COMSOL that are applied in this study, to solve the heat problems are Surface to surface radiation, Heat Transfer in fluids and solids & Non-Isothermal (laminar) Flow. The dimensions are: Indoor 'air' cavity equals 0.14m (Variants: 1&2) or 0.04m (Variants: 3-9); Thickness inner and outer leaf equals 0.1m; Thickness insulation equals 0.1m (Variants: 6 & 7); Construction height equals 10m (Variants: 1,2,3,6,7) or 5m (Variants: 4,5). The mesh of the 2D construction model which include an insulation material consists of 2067 elements. Figure 8 shows the mesh statistics of this model and also the mesh geometry of the lowest 2.5 meter is visualized at the right side.

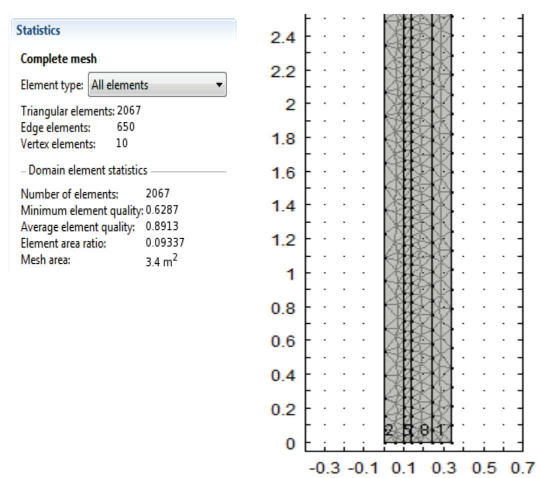


Figure 8. Mesh statistics (left) and geometry (right) of the simulation model (variants 6 &7)

The air temperature outdoor equals 263.15K; the surface heat transfer coefficient outside equals 25 W/m^2K; the air temperature inside equals 293.15 K; the surface heat transfer coefficient inside equals 7.7 W/m^2K; the air inlet temperature (in case of ventilation) equals 263.15 K; the emissivity surfaces ε equals insulation: 0.9, bricks:0.94, reflective foil: 0.1; the ambient temperature equals 283 K; the inlet air velocity (bottom air cavity) equals 0.05 m/s (variant 5), 0.2 m/s (variant 4); the outlet boundary condition (top air cavity) equals 0 Pa; the thermal conductivities k of the outer leaf; brick equals 1.1 W/mK; inner leaf limestone equals 1. 3 W/mK; insulation material equals 0.04 W/mK; the density ρ of the outer leaf; brick equals 1800 kg/m^3; inner leaf limestone equals 1800 kg/m^3; insulation material equals 40 kg/m^3; heat capacity at constant pressure Cp equals 840 J/(kgK); the solver settings are: stationary solver; PARDISO; 'Non-isothermal flow (nitf)' in case of airflow, else 'Heat Transfer (ht)'; maximum iterations:100; Relative tolerance 0.001

4. Results

The results of all case studies are presented in Figure 9 (see appendix) and summarized in Figure 10 (see appendix). We observe that the results of the simulation variants and calculations for a 'standard' air cavity of 4cm width, are in good agreement with the reference thermal resistance value, given by the NEN-EN-ISO 6946. This standard mentioned a thermal resistance of 0.18 m^2K/W for such an air cavity. The simulation of the variant with an airflow of 0.05 m/s, according to the measurements in the study of Silberstein, results in a thermal resistance of 0.17 m^2K/W for the air cavity. The calculated thermal resistance for a not ventilated air cavity (without reflective foil) is also 0.18 m^2K/W. The thermal conductivity of the air cavity increases with approximately the same value when the incoming airspeed is changed from 0 m/s to 0.05 m/s, as when it changed from 0.05 m/s to 0.2 m/s. Both simulations as hand calculations show that nowadays the thermal heat flow through the cavity is mainly caused by radiation. So influencing this mechanism has the most potential to increase the thermal resistance of the air cavity. Also the results of the calculated variants that incorporate reflective foil, emphasize this. In our case, results show that placing a reflective foil against the insulation material improves the thermal resistance of the air cavity with 317%. The variant with reflective foil on both sides of the insulation material, which is placed in the middle of the cavity, improves the cavity resistance with 633%. Note that resistances of construction and insulation materials are not incorporated in this value. The results of the simulation variants that incorporate ventilated air cavities are dependent of the construction height. When the ventilated volume flow is the same in a small wall as in a high wall, the average air temperature will be closer to the outdoor temperature in the small wall. So this parameter should have some influences to the thermal resistance. The models we have used for variants with a ventilated cavity are 5 meter high. With implementation of a reflective foil, the thermal resistance of the air cavity will increase a lot. When it is possible to increase the thermal resistance of the air cavity, the isolation material could be thinner so the whole cavity wall construction should become smaller.

5. Conclusion

We may conclude that Comsol is useful for modeling the heat transfer in cavities. The results are based on the assumption that air flow in the cavity is laminar. The effect of turbulence modeling is left over for future research.

References

Wit, M.H.,de (2009). Heat, air and moisture in building envelopes. Course book Eindhoven University of Technology.

Silberstein, A., and H. Hens, (1996). 'Effects of Air and Moisture Flows on the Thermal Performance of Insulations in Ventilated Roofs and Walls.' Journal of Building Physics 19 (1996): 367-385.

Künzel, H. (1998). 'Zweischlaiges Mauerwerk –mit oder ohne belüftung?', wksb 43. Jahrgang (1998), Heft 42, blz. 9-14

List of Figures

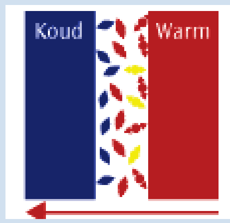
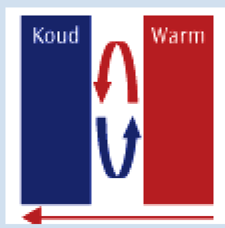
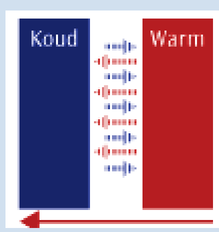
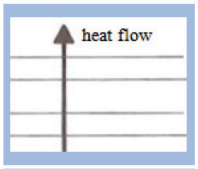
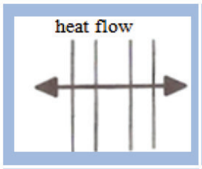
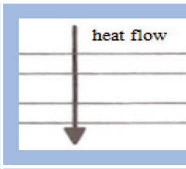
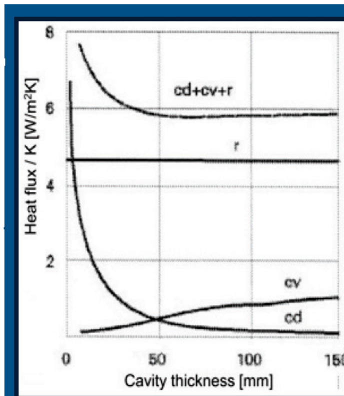
	Visualization	Influence parameters
Conduction	Heat flow through a material due to temperature differences	
		• Thickness • Thermal conductivity material, λ • Temperature difference
Convection	Heat exchange due to a flowing fluid	
		• Gas properties (ρ,ν,Cp) • Cavity volume (with and high) • Surface coefficient of heat transfer • Air velocity • Temperature difference
Radiation	Heat exchange by electromagnetic waves from a warm to cold surface	
		• Gas properties (ρ,ν,Cp, K_r) • Surface emissivity • Surface area • Temperature • Temperature differences

Figure 1 Influence parameters of heat transfer mechanisms (partly from:www.mi.nl)

Thickness of the air cavity [mm]	Thermal resistance [m².K/W] depending on heat flow direction		
			
0	0,00	0,00	0,00
5	0,11	0,11	0,11
7	0,13	0,13	0,13
10	0,15	0,15	0,15
15	0,16	0,17	0,17
25	0,16	0,18	0,19
50	0,16	0,18	0,21
100	0,16	0,18	0,22



Ratio of heat transfer mechanisms

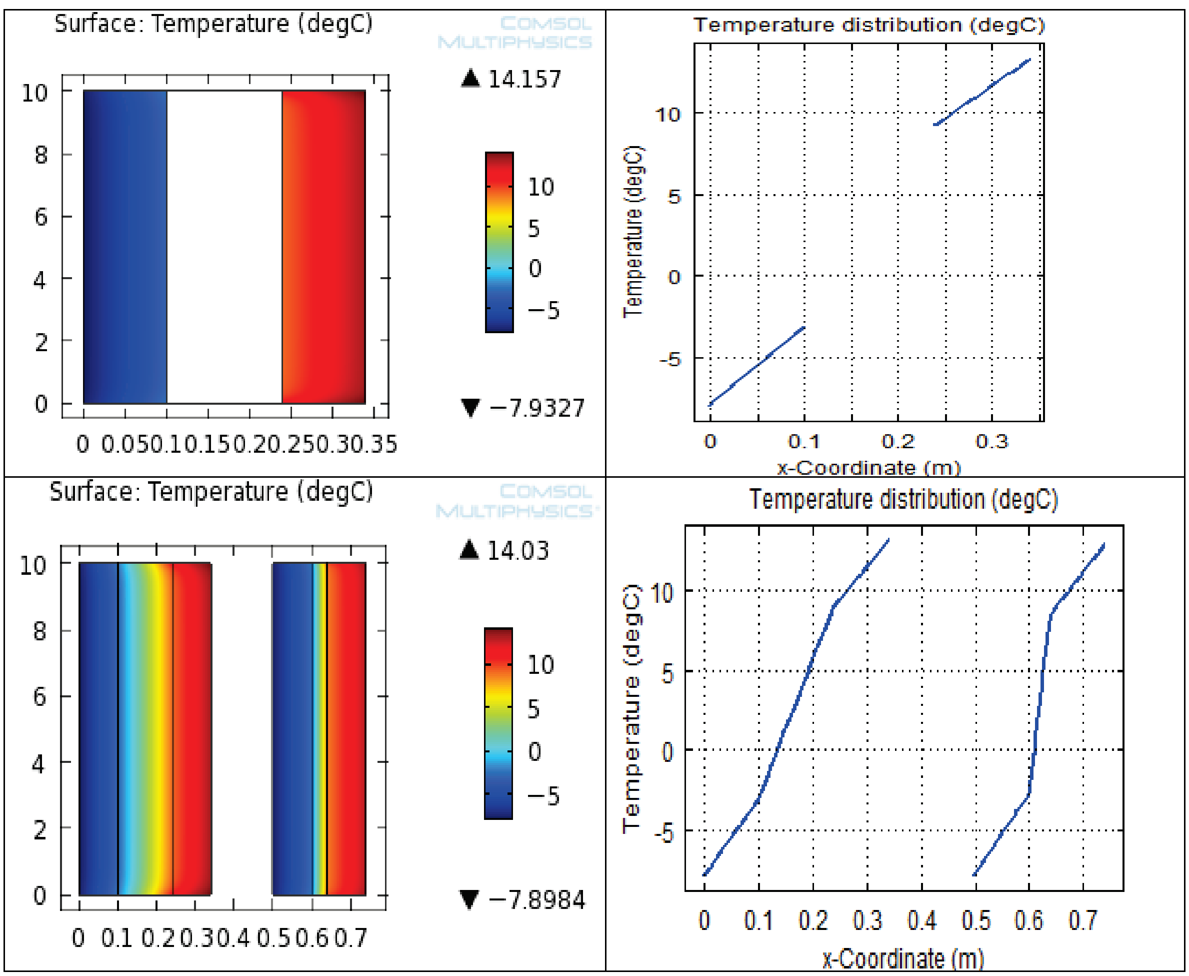
Figure 5. Thermal resistance of an air cavity (source: NEN-EN-ISO6946)

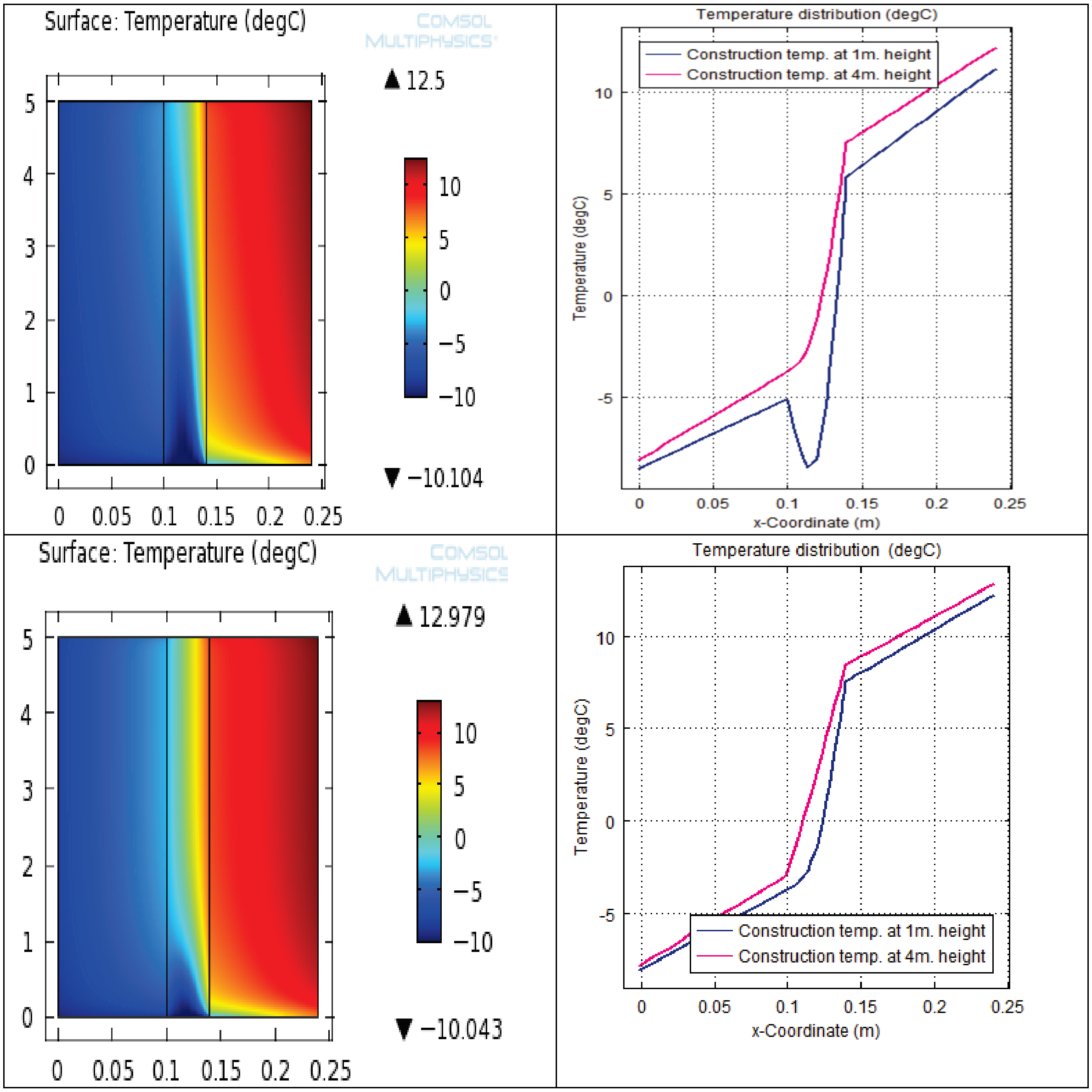
Nr.	Cavity thickness	Air velocity	Heat exchange by	Insulated
1	14 cm	No air in cavity	Radiation	No
2	14 cm	Stagnant, 0 m/s	Conduction Radiation	No
3	4 cm	Stagnant, 0 m/s	Conduction Radiation	No
4	4 cm	0,2 m/s	Conduction Radiation Convection	No
5	4 cm	0,05 m/s	Conduction Radiation Convection	No
6	4 cm	Stagnant, 0 m/s	Conduction Radiation	Against inner leaf 10 cm thick
7	4 cm	No air in cavity	Radiation	Against inner leaf 10 cm thick

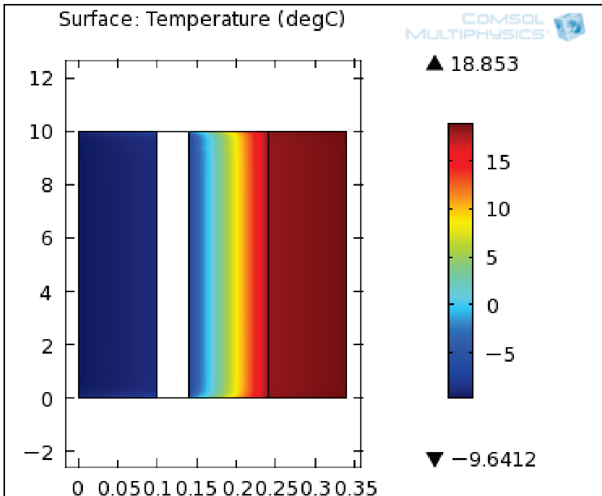
Figure 6. Simulated case studies

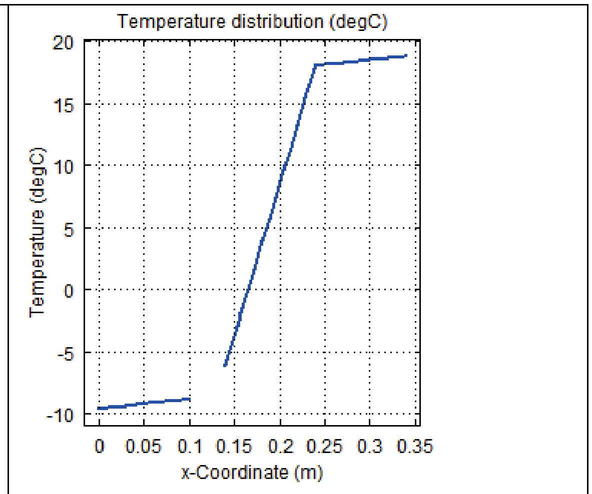
Nr.	Cavity thickness	Air velocity	Reflective foil	Insulated
8	4 cm	No ventilation	Not incorporate	Against inner leaf 10 cm thick
9	4 cm	No ventilation	Placed against insulation	Against inner leaf 10 cm thick
10	5 cm	No ventilation	Placed on both sides of the insulation	In middle of cavity 5 cm thick

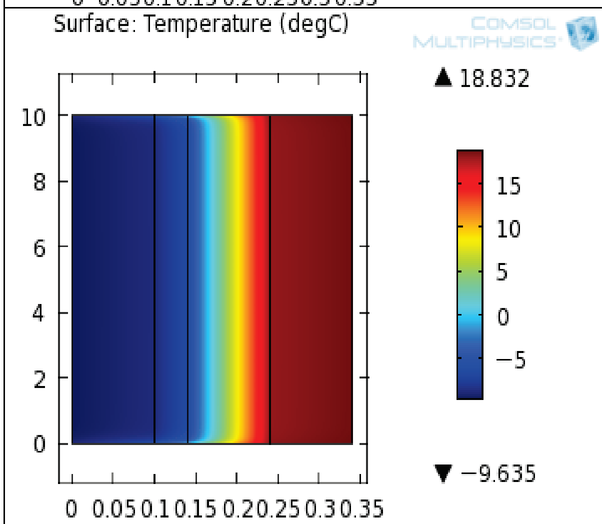
Figure 7. (Hand)Calculated case studies

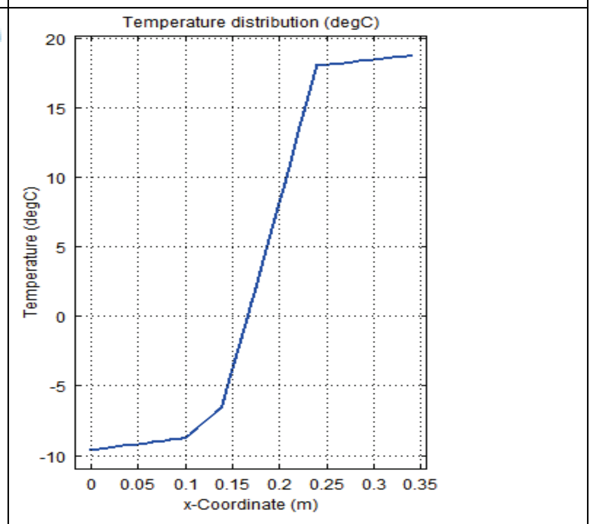


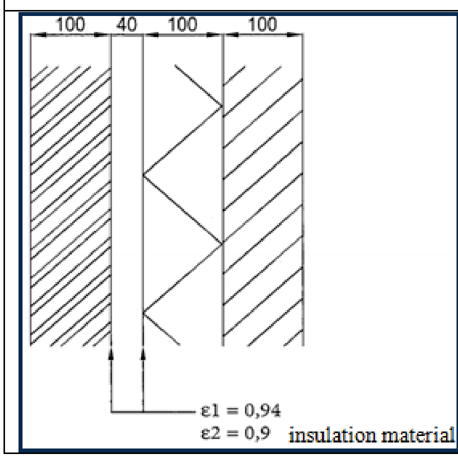

Surface: Temperature (degC)
COMSOL MULTIPHYSICS
▲ 12.5
▼ −10.104
Temperature distribution (degC)
Construction temp. at 1m. height
Construction temp. at 4m. height
Temperature (degC)
x-Coordinate (m)
Surface: Temperature (degC)
COMSOL MULTIPHYSICS
▲ 12.979
▼ −10.043
Temperature distribution (degC)
Construction temp. at 1m. height
Construction temp. at 4m. height
Temperature (degC)
x-Coordinate (m)











This means for the air cavity on the left side that:

$$E = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{1}{\frac{1}{0{,}94} + \frac{1}{0{,}9} - 1} = 0{,}85$$

$h_{ro} = 5.1$ at ambient temperature of $10\,^0$C, so

$$h_r = 0{,}85 \cdot 5{,}1 = 4{,}335 \frac{W}{m^2 \cdot K}$$

$$h_a = \frac{0{,}025}{0{,}04} < 1{,}25 \quad \text{thus } 1{,}25 \frac{W}{m^2 \cdot K}$$

So the thermal resistance of the air cavity is:

$$R_g = \frac{1}{h_a + h_r} = \frac{1}{1{,}25 + 4{,}335} = \mathbf{0{,}18} \frac{\boldsymbol{m^2 \cdot K}}{\boldsymbol{W}}$$

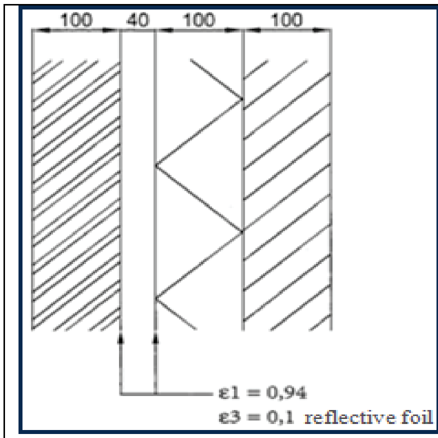
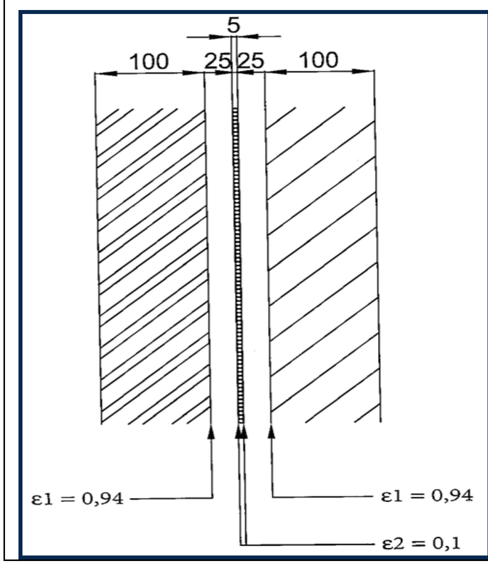
	These parameters results in: $E = \frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1} = \frac{1}{\frac{1}{0{,}94}+\frac{1}{0{,}1}-1} = 0{,}1$ $h_{ro} = 5.1$ at ambient temperature of $10\,^0$C, so $h_r = 0{,}1 \cdot 5{,}1 = 0{,}51 \frac{W}{m^2 \cdot K}$ $h_a = \frac{0{,}025}{0{,}04} < 1{,}25 \quad \text{thus} \;\; 1{,}25 \frac{W}{m^2 \cdot K}$ So the thermal resistance of this <u>air cavity</u> is: $R_g = \frac{1}{h_a + h_r} = \frac{1}{1{,}25 + 0{,}51} = \mathbf{0{,}57} \frac{\mathbf{m^2 \cdot K}}{\mathbf{W}}$
	These parameters results in: $E = \frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1} = \frac{1}{\frac{1}{0{,}94}+\frac{1}{0{,}1}-1} = 0{,}1$ $h_{ro} = 5.1$ at ambient temperature of $10\,^0$C, so $h_r = 0{,}1 \cdot 5{,}1 = 0{,}51 \frac{W}{m^2 \cdot K}$ $h_a = \frac{0{,}025}{0{,}025} < 1{,}25 \quad \text{thus} \;\; 1{,}25 \frac{W}{m^2 \cdot K}$ So the thermal resistance of these <u>air cavities</u> is: $R_g = 2 \cdot \frac{1}{h_a + h_r} = 2 \cdot \frac{1}{1{,}25 + 0{,}51} = \mathbf{1{,}14} \frac{\mathbf{m^2 \cdot K}}{\mathbf{W}}$

Figure 9. The results of all case studies

Nr	Cavity thickness	Insulation	Air velocity	Cavity heat exchange		Cavity thermal resistance	Overall thermal resistance
1	14 cm	No	Without air	Radiation:	1,73 $W/m^2.K$	0,24 $m^2.K/W$	0,58 $m^2.K/W$
2	14 cm	No	Stagnant, 0 m/s	Conduction: Radiation:	0,07 $W/m^2.K$ 1,70 $W/m^2.K$	0,23 $m^2.K/W$	0,57 $m^2.K/W$
3	4 cm	No	Stagnant, 0 m/s	Conduction: Radiation:	0,22 $W/m^2.K$ 1,60 $W/m^2.K$	0,21 $m^2.K/W$	0,55 $m^2.K/W$
4	4 cm	No	0,2 m/s	Conv.+cond.: Radiation:	0,67 $W/m^2.K$ 1,51 $W/m^2.K$	0,12 $m^2.K/W$	0,46 $m^2.K/W$
5	4 cm	No	0,05 m/s	Conv.+cond.: Radiation:	0,41 $W/m^2.K$ 1,56 $W/m^2.K$	0,17 $m^2.K/W$	0,51 $m^2.K/W$
6	4 cm	Yes	No air in cavity	Radiation:	0,32 $W/m^2.K$	0,30 $m^2.K/W$	3,14 $m^2.K/W$
7	4 cm	Yes	Stagnant, 0 m/s	Conduction: Radiation:	0,04 $W/m^2.K$ 0,28 $W/m^2.K$	0,26 $m^2.K/W$	3,09 $m^2.K/W$

Nr	Cavity thickness	Insulation	Air velocity	Heat exchange by	Reflective foil	Cavity thermal resistance
8	4 cm	Yes	No ventilation	Conv.+cond. +Radiation	Not incorporate	0,18 $m^2.K/W$
9	4 cm	Yes	No ventilation	Conv.+cond. +Radiation	Placed against insulation	0,57 $m^2.K/W$
10	5 cm	Yes	No ventilation	Conv.+cond. +Radiation	Placed on both sides of the insulation	1,14 $m^2.K/W$

Figure 10. Summary of the results of all case studies