U-VALUE ESTIMATIONS BASED ON MEASURED TEMPERATURES - INTERNAL SURFACE HEAT TRANSFER

Introduction

The theory of 1D steady state heat transfer learns that the thermal transmittance U of a wall with parallel layers easily can be derived from the environmental temperatures θ_i and θ_e, the internal surface temperature θ_{is} and the internal surface heat transfer coefficient h_i using the formula:

$$U = h_i \frac{\theta_i - \theta_{is}}{\theta_i - \theta_e} \quad [1]$$

Therefore, from measured temperatures θ_i, θ_e, and θ_{is} the U-value could be derived.

Important issues to obtain a correct U-value are:

1) What is the value of the internal surface heat transfer coefficient to be used ?
   E.g. values from EN ISO 6496 (h_i = 7.7 W/m^{2}K for vertical walls, h_i = 10 W/m^{2}K for roofs, h_i = 5.9 W/m^{2}K for floors) ?
2) Where the indoors temperature needs to be measured ?
   Air temperature, comfort temperature ?
3) Where the outdoors temperature needs to be measured ?
   Air temperature, sky temperature ?

In a case study a temperature distribution in steady state conditions for a well-defined building zone is generated numerically. The detailed numerical heat transfer simulation, based on 3D conduction, view factor based radiation (radiosity method) and empirical convection, guarantees a quite realistic temperature distribution. From the obtained temperature distribution the usefulness of the formula and the issues mentioned are discussed.

Case study data

TRISCO data building_part_6_bc_free_vwf_grid.trc

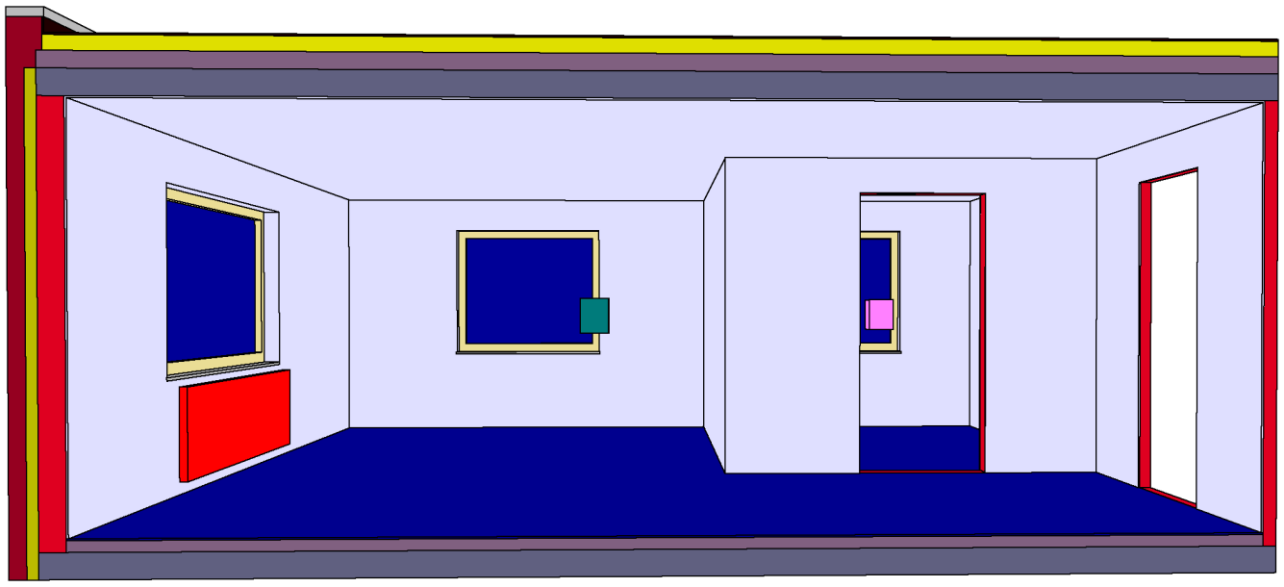

Figure 1. Perspective of building zone (view from side wall).

A building zone with 2 rooms, a heated one and an unheated one, is shown in Figure 1. Figure 2 and Figure 3 show the floor plan, a vertical section and the relevant junction sections.

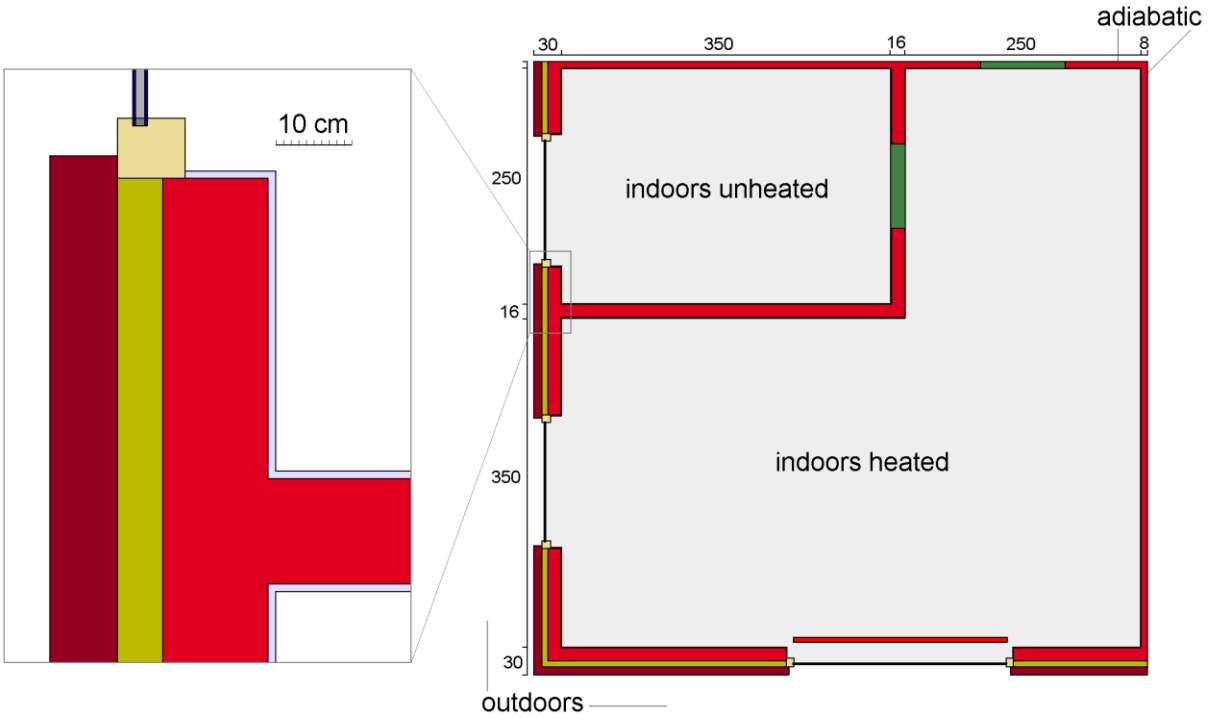

Figure 2. Floor plan of building zone / horizontal section of window-wall junction

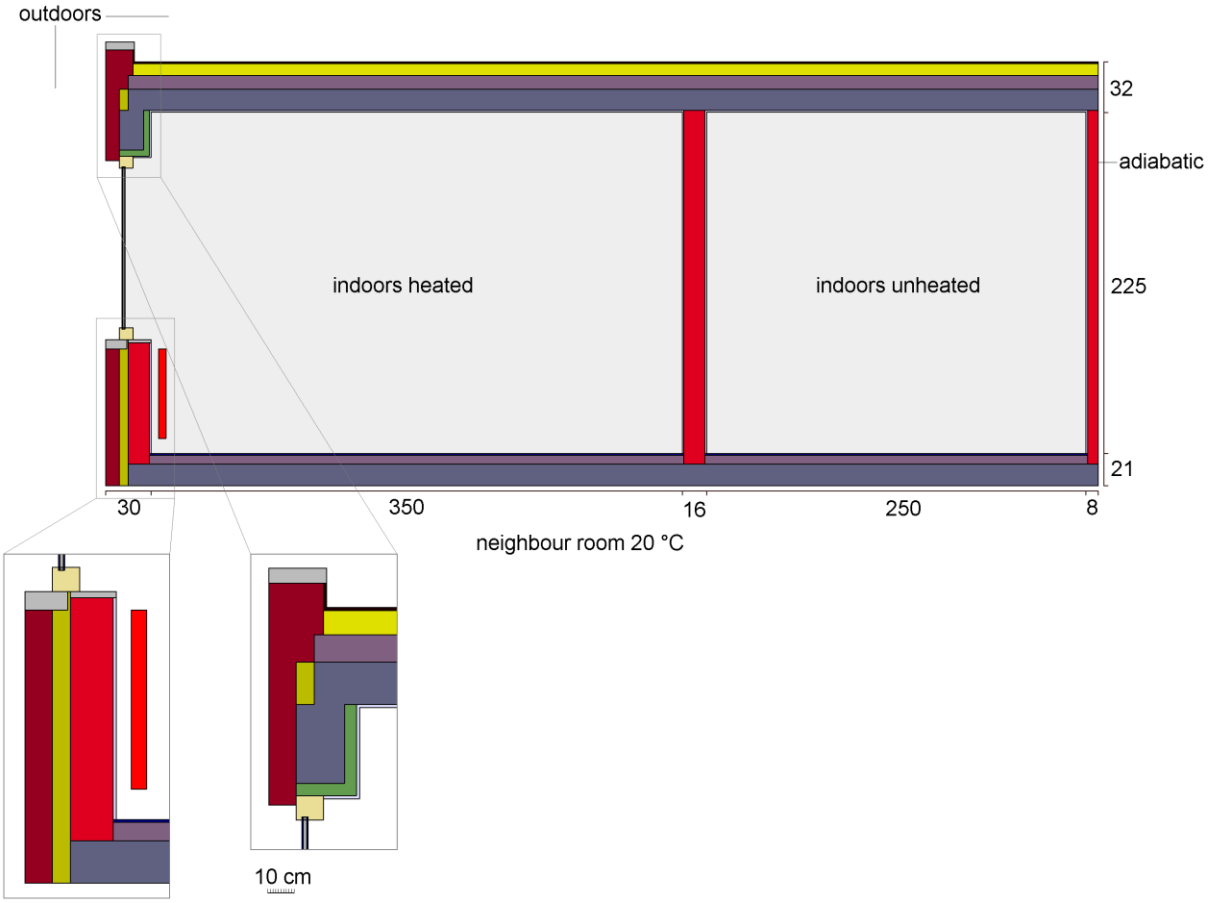

Figure 3. Vertical section of building zone / vertical section of window-wall-floor junction / vertical section of window-wall-roof junction

The program TRISCO is used to simulate the 3D steady state heat transfer in the building zone. As discussed further the simulation is done in 2 steps for which the data are in the files building_part_6_bc_free_vwf_grid.trc and building_part_6_no_sky_vwf_grid.trc.
Table 1 lists the material thermal conductivities and boundary conditions as used in the first file. In the second file other boundary conditions will be used.
All material surfaces are assumed to have an emissivity of 0.9.

The thermal transmittance U for wall, double-glazing and roof according to EN ISO 6496 are:

U_{wall} = 0.444 W/m²K $U_{glazing}$ = 1.70 W/m²K U_{roof} = 0.279 W/m²K. [2]

Coul.		Type	Règle CEN	Nom	Pat.	λ [W/mK]	ε [-]	θ [°C]	h [W/m²K]	q [W/m²]	θa [°C]	hc [W/m²K]	Pc [W]
4		MATERIAL		copper		380.000	0.90						
8		MATERIAL		aluminium		160.000	0.90						
13		MATERIAL		comfort sensor 1		50.000	0.90						
14		MATERIAL		comfort sensor 2		50.000	0.90						
15		MATERIAL		wood		0.130	0.90						
17		MATERIAL		limestone		1.700	0.90						
18		MATERIAL		glass		1.000	0.90						
19		MATERIAL		wood		0.130	0.90						
26		MATERIAL		ceramic/porcelain tiles		1.300	0.90						
32		MATERIAL		bitumen sheet		0.230	0.90						
72		MATERIAL		concrete density 1800 kg/m3		1.150	0.90						
129		MATERIAL		gypsum		0.300	0.90						
135		MATERIAL		insulation 0.025 W/mK		0.025	0.90						
136		MATERIAL		reinforced concrete		2.500	0.90						
151		MATERIAL		thermal insulation		0.035	0.90						
155		MATERIAL		thermal insulation 0.045		0.045	0.90						
164		MATERIAL		masonry semi-heavy		0.600	0.90						
170		BC_SIMPL	HE	outdoors				0.0	25.00	0			
174		BC_SIMPL	NIHIL	heated lower room				20.0	7.70	0			
180		MATERIAL		masonry heavy		0.900	0.90						
191		BC_SIMPL	NIHIL	adiabatic				0.0	0.00	0			
192		EQUIMAT	NIHIL	equi U = 1.7 W/m2K		0.029	0.90						
208		BC_FREE	NIHIL	room 1 p1						0		3.00	0
209		BC_FREE	NIHIL	room 1 p2						0		3.00	0
210		BC_FREE	NIHIL	room 1 p3						0		3.00	0
211		BC_FREE	NIHIL	room 1 p4						0		3.00	0
212		BC_FREE	NIHIL	room 1 p5						0		3.00	0
213		BC_FREE	NIHIL	room 1 p6						0		3.00	0
214		BC_FREE	NIHIL	room 1 p7						0		3.00	0
215		BC_FREE	NIHIL	room 1 p8						0		3.00	0
216		BC_FREE	NIHIL	room 1 p9						0		3.00	0
224		BC_FREE	NIHIL	room 2 p1						0		3.00	0
225		BC_FREE	NIHIL	room 2 p2						0		3.00	0
226		BC_FREE	NIHIL	room 2 p3						0		3.00	0
227		BC_FREE	NIHIL	room 2 p4						0		3.00	0
228		BC_FREE	NIHIL	room 2 p5						0		3.00	0
229		BC_FREE	NIHIL	room 2 p6						0		3.00	0
230		BC_FREE	NIHIL	room 2 p7						0		3.00	0
231		BC_FREE	NIHIL	room 2 p8						0		3.00	0
232		BC_FREE	NIHIL	room 2 p9						0		3.00	0

Table 1. Material thermal conductivities and boundary conditions in the TRISCO-interface

An outdoor temperature of 0 °C with an external surface heat transfer of 25 W/m²K is assumed. This last value is a standard value based on a wind speed of 4 m/s and an air temperature that equals the radiation temperature. By this simplification, the case study doesn't focus on the issue of the external surface heat transfer.

The building zone has 2 adiabatic wall sides (or symmetry planes) and one zone below at 20 °C.

One of the rooms considered is heated by a radiator with a power of 800 W. The radiator is simulated as a massive block of well conducting material (copper) in which the power is dissipated.

Each of the 2 room zones are vertically subdivided in 25 cm high sub-zones (Figure 4). The target of these subdivisions is to bring in an air temperature gradient.

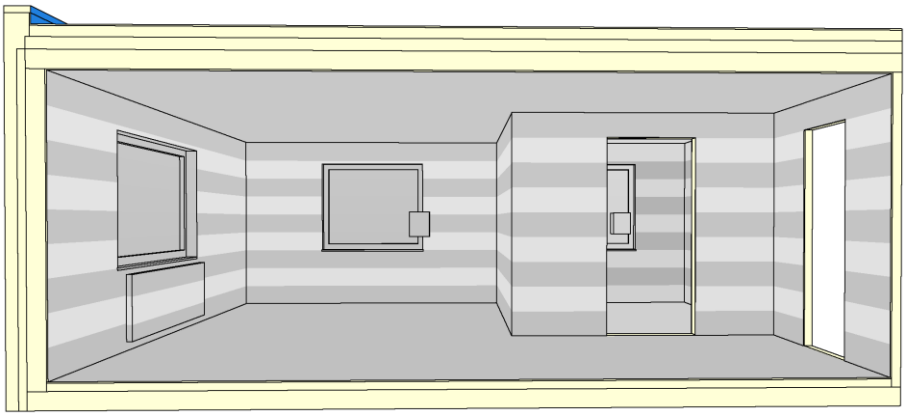

Figure 4. Perspective of building zone (view from side wall): indoor boundary conditions levels

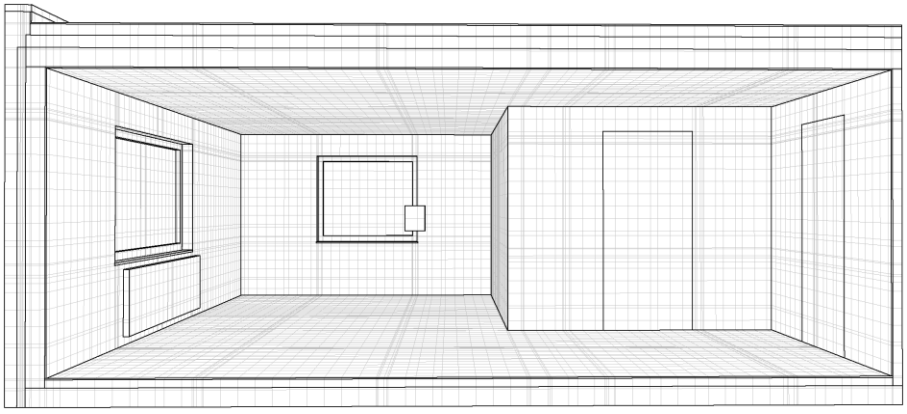

Figure 5. Perspective of building zone (view from side wall): calculation grid.

In the first simulation (data building_part_6_bc_free_vwf_grid.trc) the sub-zones get the type BC_FREE. As a result the air temperature in the sub-zones is obtained from a convection thermal balance between the unknown homogeneous air temperature and the elementary wall surfaces in touch with the indoor air. A homogeneous convection surface coefficient h_c = 3 W/m^{2}K is used. This could be improved, but it can be expected that this will not effect that much the conclusions drawn. The BC_FREE conditions cause the modelling of the long wave radiation according to the radiosity method. This method uses the view factors between all elementary wall surfaces. Figure 5 shows the calculation grid used.

No ventilation (by infiltration or mechanical one) is considered. It can be expected that a normal ventilation rate doesn't effect the global temperature distribution [1]. The rooms are separated by a door. In the graphs the door is sometimes clipped for reasons of clearness.

Two rectangular blocks are positioned about in the middle of the rooms. Their target is to measure the comfort or operative temperature.

[1] Of course infiltrations trough gaps will effect the local temperature distribution.

Case study: step 1 results > step 2 dataTRISCO data building_part_6_no_sky_vwf_grid.trc

Calculation step 1 results in a 3D temperature and heat flow distribution. From the modelling principles used it is clear that an identical air temperature is obtained for the 9 BC_FREE zones in the heated zone (20.13 °C) and for the 9 BC_FREE zones in the unheated zone (16.48 °C). In real situations an air temperature gradient occurs. In step 2 an estimated air temperature gradient is brought in.

To estimate the air temperature gradient, an empirical formula is used. In 'La climatisation par corps de chauffe statique' (Chaleurs et climates, J. Lebrun, 1972) an empirical relation is given between the air temperature gradient and the convective heat exchange. The relation is based on measurements in a hot box – cold box.

$$\theta_{air-h=1.5m} - \theta_{air-h=0.08m} = \frac{(0.29K.m^2/W)Q_{conv}}{S_{walls}} \quad [3]$$

$\theta_{h=1.5\ m}$	[°C or K]	air temperature at a level of 1.5 m
$\theta_{h=0.08\ m}$	[°C or K]	air temperature at a level of 0.08 m
Q_{conv}	[W]	convective part of the heat dissipated by the heating system
S_{walls}	[m^2]	total surface of the room walls.

The convective heat Q_{conv} is known from the step 1 results, and therefore an air temperature gradient can be estimated (Table 2, building_part_6_air_temperature_gradient.xls).

	room1	room2	
room convection (W)	940.48	169.64	result of simulation data building_part_6_bc_free_vwf_grid.trc
total wall surface (m2)	131.3	44.5	
air temperature gradient (K/m)	**1.46**	**0.78**	from empirical formula
h[m]	room1	room2	
1.00	21.59	17.26	
0.75	21.23	17.06	
0.50	20.86	16.87	
0.25	20.50	16.67	
0.00	20.13	16.48	result of simulation data building_part_6_bc_free_vwf_grid.trc
-0.25	19.76	16.29	
-0.50	19.40	16.09	
-0.75	19.03	15.90	
-1.00	18.67	15.70	

Table 2. Air temperature gradient estimation.

In the TRISCO step 1 data, the 2 x 8 BC_FREE types are changed into BC_NOSKY types. The BC_NOSKY type keeps the radiation heat exchange simulation identical to the BC_FREE type, but uses a known air temperature, for which the values of Table 2 are used. As a consequence a disequilibrium in the energy balance of each BC_NOSKY zone will probably occur (while in the BC_FREE zones a perfect energy balance occurs) but it can be expected (and controlled) that this disequilibrium is small.

Case study results and discussion

Figure 6 and Figure 8 show the temperature distribution on the internal surfaces.
Figure 7 and Figure 9 show the heat flow densities on the internal surfaces.

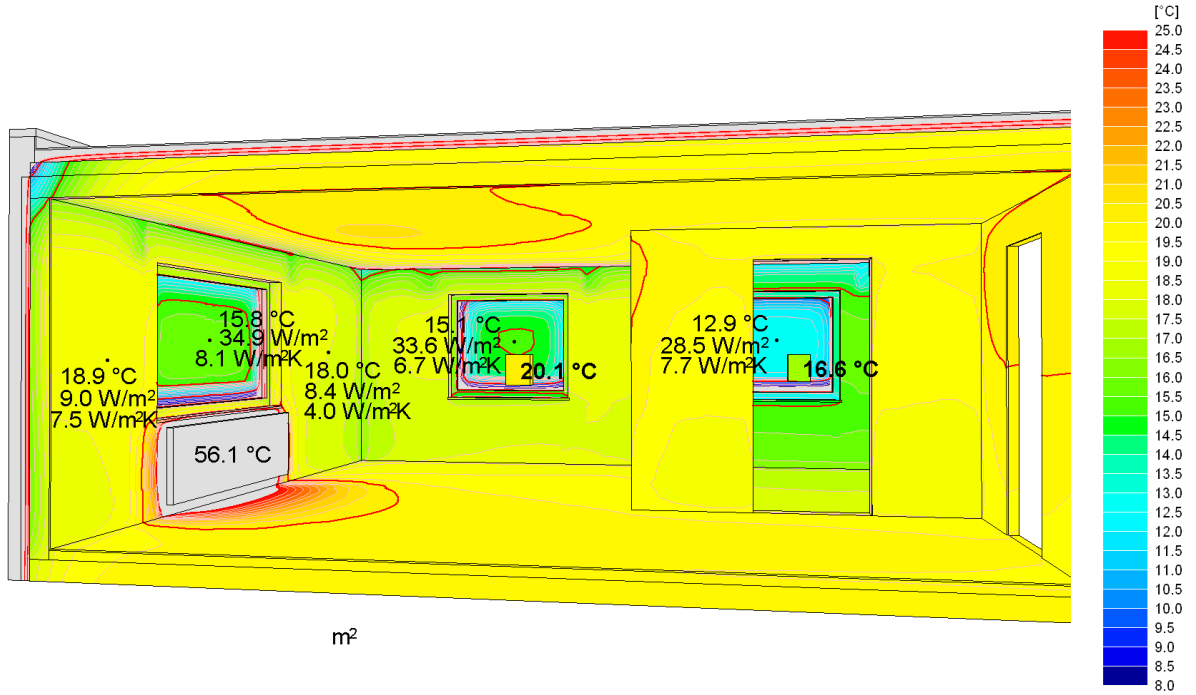

Figure 6. Isotherms on room surfaces (view from side wall)

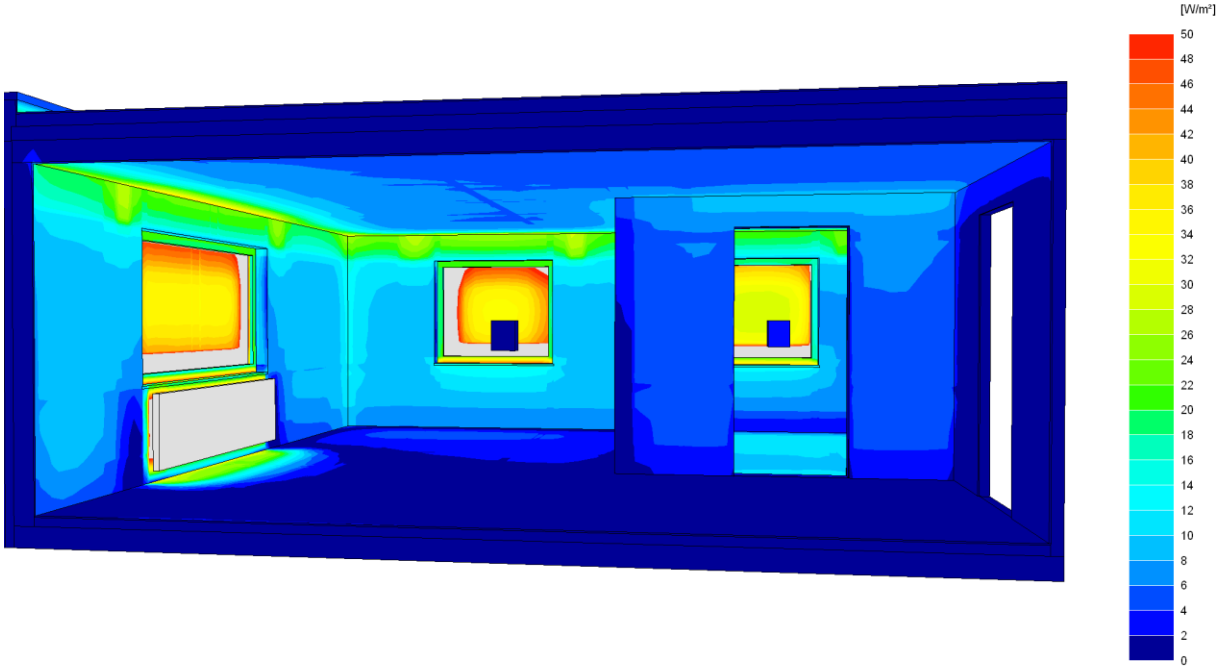

Figure 7. Heat flow densities on room surfaces (view from side wall)

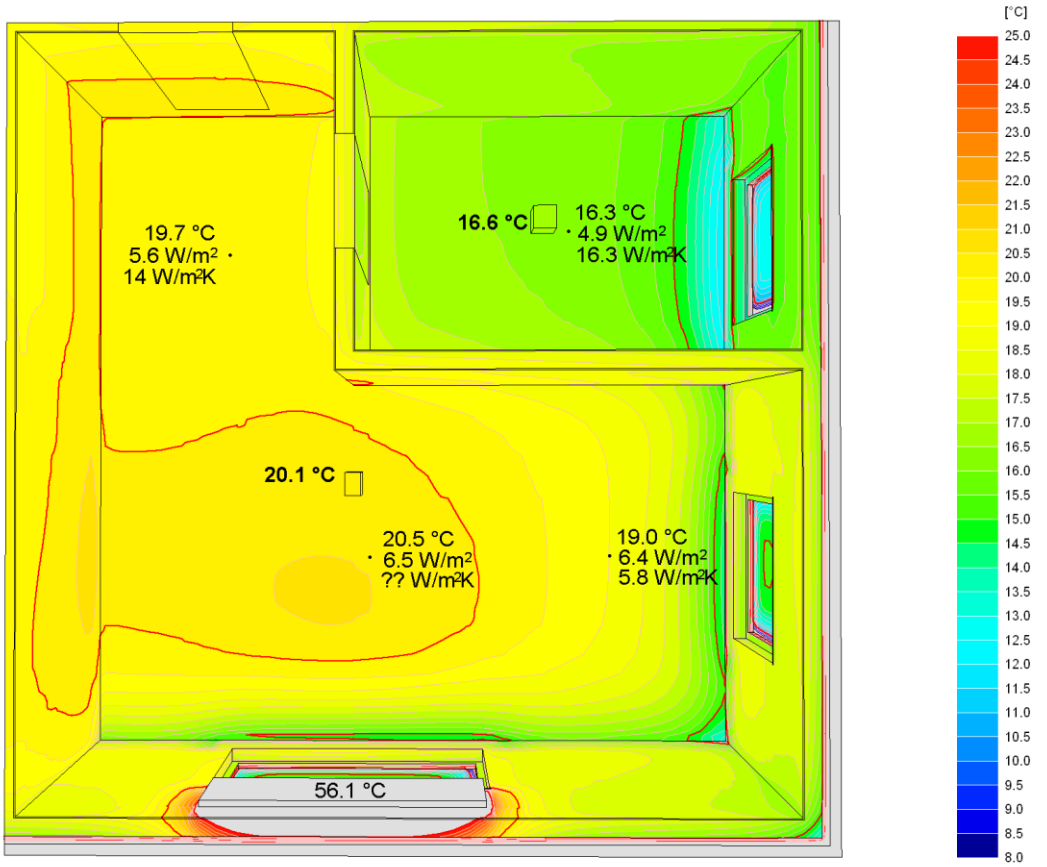

Figure 8. Isotherms on room surfaces (view from floor)

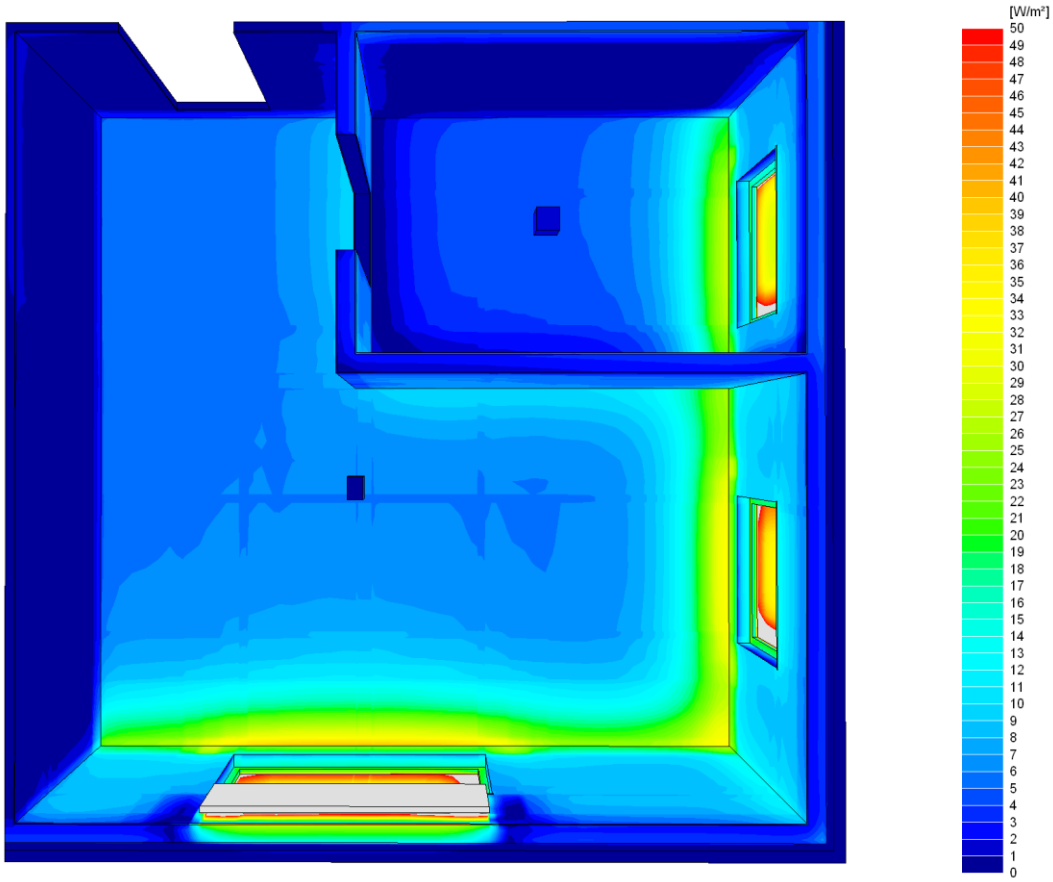

Figure 9. Heat flow densities on room surfaces (view from floor)

These results allow deriving local values of the internal surface heat transfer coefficient h_i using the formula

$$h_i = \frac{q_{is}}{\theta_i - \theta_{is}} \qquad [4]$$

h_i	[W/m²K]	local internal surface heat transfer coefficient
q_{is}	[W/m²]	local heat flow density
θ_i	[°C or K]	indoors reference temperature
θ_{is}	[°C or K]	local internal surface temperature

For the indoors reference temperature, the central block temperature is chosen: 20.1 °C for the heated room and 16.6 °C for the unheated room.
The purpose of the local h_i-values should be clear: using the h_i-value in formula [1] in combination with the indoors and outdoors reference temperature will result in a correct U-value.

Figure 6 and Figure 8 contain the h_i-values for relevant points, chosen in the centre of wall, glazing or roof surfaces.

For the 2 wall points selected:
- h_i = 7.5 W/m²K is found for the wall left of large window
- h_i = 4.0 W/m²K is found for the wall right of the large window
  This lower value is clearly due to the corner position.

For the 2 glazing points in the heated room
- h_i = 8.1 W/m²K is found for the large window (with radiator below)
- h_i = 6.7 W/m²K is found for the small window.

For the glazing point in the unheated room
- h_i = 7.7 W/m²K is found.

For the 3 ceiling points in the heated room
- h_i = 14.0 W/m²K on the ceiling far away from the 2 external walls
- h_i = 5.8 W/m²K on the ceiling close to the 2 external walls
- no relevant h_i-value can be found on the ceiling nearby the radiator:
  the ceiling temperature is higher than the reference temperature.

For the ceiling point in the unheated room
- h_i = 16.3 W/m²K

It can be concluded that the local h_i-values are close to the standard h_i-value of 7.7 W/m²K. Recommendations could be made to apply a slightly higher of lower value, as a function of specific situations (position of radiator, external wall configuration).

For the ceiling it is more difficult to estimate local h_i-values; this is due to the low (or even negative) temperature difference between the reference point and the surface, caused by the air temperature gradient.

For the floor no results are obtained, as the floor considered is an internal partition construction element. Another case study with a floor above an external environment (or with a floor on ground ?) needs to be done.