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Thermal calculation of ground contact structures: Correction factors of environment- and structure-dependent effects on the heat transfer coefficient

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Abstract: The heat loss at ground contact structures is taken into consideration in building heat loss calculations. However, the heat loss through the ground depends not only the soil and the building structure, but the environment as well. New calculation methods based on parametrized transient finite element thermal modelling are introduced in the preceding research article [3]. This paper is the further demonstration of the methods' environment- or structure-depending correction factors which describe the effect of changing climatic conditions, soil composition or the change of the floor's structure. These corrections are investigated by using finite element computer modeling tools. A comparative analysis of the initial results and the results corrected according to the different environmental- or structural conditions are represented, showing the impacts of the variable circumstances. The study also deals with the three-dimensional thermal effects from the geometric of the building, providing shape correction multiplying factors to the basic building forms of ground contact structures.

1. Introduction

In preceding research [5], a new simplified calculation method has been developed to determine the heat loss of ground contact structures. The new approximated calculations based on thousands results of parametrized transient finite element thermal analyses. For the analyses, Middle-Eastern European climatic conditions were used. The material and boundary properties were assumed according to EN ISO standards [2,3]. The simulated values are summarized and the calculated equivalent linear thermal transmittance of ground contact floor structures was organized in a table, as a function of the floor's thermal transmittance (U_{floor}) and the depth of the inner side floor level from the external ground level (z). The eqvivalent linear thermal transmittances of floor structures can calculated by the following equations according to [5]:

If z < 0.25 m, then:

$$\psi_t = (0.0168 \cdot z^2 + 0.0947 \cdot z + 0.3626) \cdot ln(U_{floor}) + (0.0362 \cdot z^2 + 0.2294 \cdot z + 0.9978) \quad (1)$$

If z ≥ 0.25 m, then:

$$\psi_t = 0.3027 \cdot z^{-0.216} \cdot ln(U_{floor}) + 0.899 \cdot z^{-0.151} \quad (2)$$

2. Correction factors of environment and structure dependent effects

However, it is still a question, how the linear thermal transmittances at ground contact structures are, if the external temperature, soil composition, or the floor structure change, or the length of the floor is less than 4 m. Instead of applying new methods, formulas or tables for all varying parameters, values presented in the previous paper [5] can corrected by correction factors. The correction factors represent the change in conditions, they are added to the original values (or in case of negative, i.e. decreasing linear thermal transmittance, they are subtracted). Correction factors were investigated between z = -2 m and z = 0.5 m, applying parameterizable transient finite element simulation software [1], in cases of the following

detailed environmental and structural conditions, which are graphically illustrated in Figure 1.
To determine the equations describing the correction factors, the values can be plotted as a function of heat transfer coefficients of the floor structure, and they have a logarithmic trend. The correction factor should give the exact difference with right sign between the original linear thermal transmittances of the floor structure and ground contact structures having given properties. The difference between the coefficients of the logarithmic equations based on the initial and changed conditions give the "a" and "b" coefficients, that can be applied to obtain the equations describing the difference.

2.1 External Temperature

The correction factor for change in external temperature, illustrated in Figure 1, shows that if the average temperature is 1 degree celsius less in a year, the linear thermal transmittances are higher; however, the difference depends on both the heat transfer coefficient of the floor structure as well as the position of ground floor level from the ground level. The equation describing the effect of change in temperature is:

$$\gamma_{mt} = (0.0044 \cdot z + 0.0209) \cdot ln\left(U_{floor}\right) + 0.0085 \cdot z^2 + 0.016 \cdot z + 0.0836 \ [\tfrac{W}{mK}] \qquad (3)$$

2.2 Soil

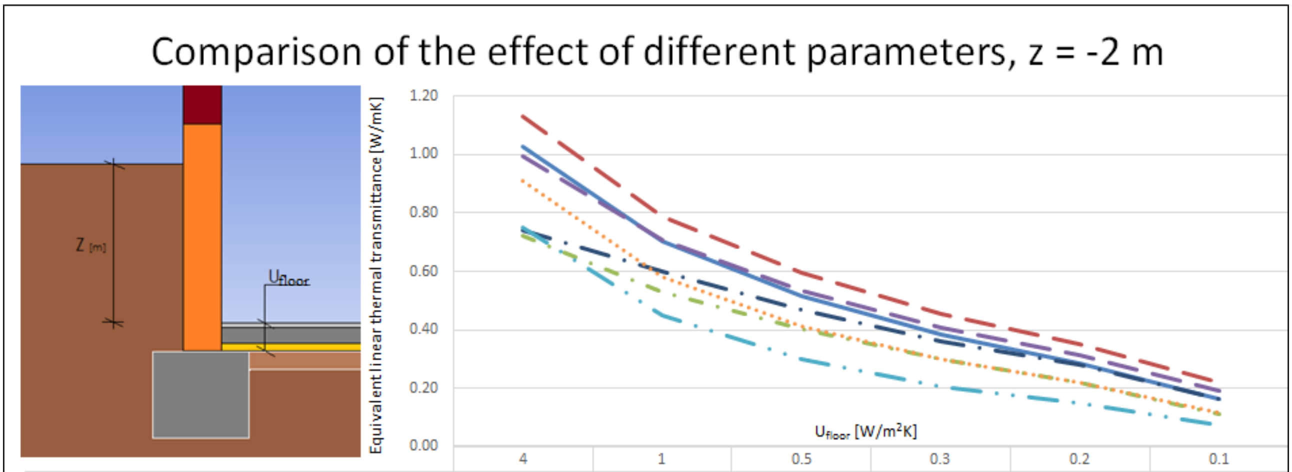
During the original calculation, sand and gravel soil was assumed to determine the linear thermal transmittances. In case of clay or silt soils, whose thermal conductivity is lower than a sand and gravel soils, the following correction should be applied:

$$\gamma_g = (0{,}0078 \cdot z^2 + 0{,}0013 \cdot z - 0{,}1) \cdot ln\left(U_{floor}\right) + 0{,}0059 \cdot z^2 + 0{,}0009 \cdot z - 0{,}2075 \ [\tfrac{W}{mK}] \qquad (4)$$

While the average temperature change of 1 degree celsius gives the highest eqv. linear thermal transmittances, the lower thermal conductivity of ground can significantly reduce the heat loss of ground contact strucutures.
If both the soil and the outside temperature change, the following correction should be applied:

$$\gamma_{mt,g} = (0.0313 \cdot z^2 + 0.0454 \cdot z - 0.1136) \cdot ln\left(U_{floor}\right) + 0.0428 \cdot z^2 + 0.064 \cdot z - 0.1795 \ [\tfrac{W}{mK}] \qquad (5)$$

If both effects prevails at the same time, the eqv. linear thermal transmittance will be almost the same as the original conditions.



	4	1	0.5	0.3	0.2	0.1
Original value (Tavg=10,5 °C, λ = 2,0 W/mK, insulation in between floor layers, l = 4 m)	1.03	0.70	0.52	0.38	0.29	0.16
Average yearly temperature 1°C lower (Tavg = 9,5 °C)	1.13	0.79	0.59	0.45	0.35	0.22
Thermal conductivity of soil 0.5 W/mK lower, clay or silt ground (λ = 1,5 W/mK)	0.72	0.53	0.40	0.30	0.22	0.11
Both two effects from above (Tavg = 9,5 °C and λ = 1,5 W/mK)	0.74	0.60	0.47	0.36	0.28	0.17
"Insulation on ground" slab on ground floor, floor structure changed	1.00	0.71	0.53	0.41	0.31	0.19
Length of floor l = 2 m	0.75	0.45	0.30	0.21	0.15	0.07
Length of floor l = 3 m	0.91	0.58	0.41	0.30	0.22	0.12

Figure 1. *Comparison of the effect of different environment- and structure-dependent parameters*

2.3 Floor structure

Values were determined so far for a floor structure, in which the thermal insulation was located between the floor slab and the top concrete layer. However, the thermal insulation of the floor can also be placed under the slab. In this case, the thermal insulation layer does not intersect the high thermal storage mass of concrete layers, but a thicker slab construction is necessary. During determining the correction factor, the lowest layer is the thermal insulation, and there is a 20 cm thick reinforced concrete floor slab and 6 cm top concrete layer above. Equation to calculate the correction factor between z = -2 m and z = 0.5 m:

$$\gamma_f = (-0.0014 \cdot z^2 + 0.0019 \cdot z + 0.0114) \cdot ln(U_{floor}) + 0.0106 \cdot z^2 + 0.0273 \cdot z + 0.0114 \ [\frac{W}{mK}] \qquad (6)$$

The equation of the correction factor for thermally insulated floor constructions gives a positive value, therefore during the heating season, a floor structure with thermal insulation between the floor slab and top concrete layer is a better solution than the investigated insulation on ground type ground contact floors.

2.4 Floor Length

The inner length of a ground contact floor was maximized in EN ISO standard [2], it is l = 4 m, which representes a building with 8 m total inner lenght. If the examined inner lenght are shorter, the heat loss through ground contact floors are reduced. For l = 2 m the following correction factor can be applied:

$$\gamma_{fw,2} = (-0.0053 \cdot z^2 - 0.0123 \cdot z - 0.0554) \cdot ln(U_{floor}) - 0.0095 \cdot z^2 - 0.0235 \cdot z - 0.2394 \ [\frac{W}{mK}] \qquad (7)$$

For l = 3 m and similar range of values, the following equation can be used:

$$\gamma_{fw,3} = (-0.002 \cdot z - 0.0242) \cdot ln(U_{floor}) - 0.0032 \cdot z - 0.1109 \ [\frac{W}{mK}] \qquad (8)$$

It is noticeable that the functions approximating the two lengths differ. In the case of l = 2 m the heat loss due to the thermal bridge at the connection of floor and wall is still dominant, and therefore, the coefficients are nonlinear; however, for l = 3 m it plays smaller role, the coefficients can be approximated linearly.

2.5 Effect of corners

If the heat loss factor is calculated for the whole perimeter of the floor structure, the heat losses at positive corners are calculated twice due to overlapping. To eliminate this phenomenon, a corrected internal edge length can be determined for each corner, considering the additional heat loss of the three-dimensional geometric thermal bridge; and applying it, the heat losses of the building will not be over- nor underestimated significantly. Effect of the corner connections on heat transfer coefficients is illustrated in figure 2. Correction factors at positive corners are:

If z < 0.25 m, then:

$$\gamma_{c,p} = [(-0.04 \cdot z^2 - 0.0761 + 0.8508) \cdot (0.0169 \cdot z^2 + 0.0949 \cdot z + 0.3623) \cdot ln(U_{floor}) + (-0.0352 \cdot z^2 - 0.0377 \cdot z + 0.7796) \cdot (0.0138 \cdot z^2 + 0.2408 \cdot z + 0.9978)]/[(0.0169 \cdot z^2 + 0.0949 \cdot z + 0.3623) \cdot ln(U_{floor}) + (0.0138 \cdot z^2 + 0.2408 \cdot z + 0.9978) \qquad (9)$$

If z ≥ 0.25 m, then:

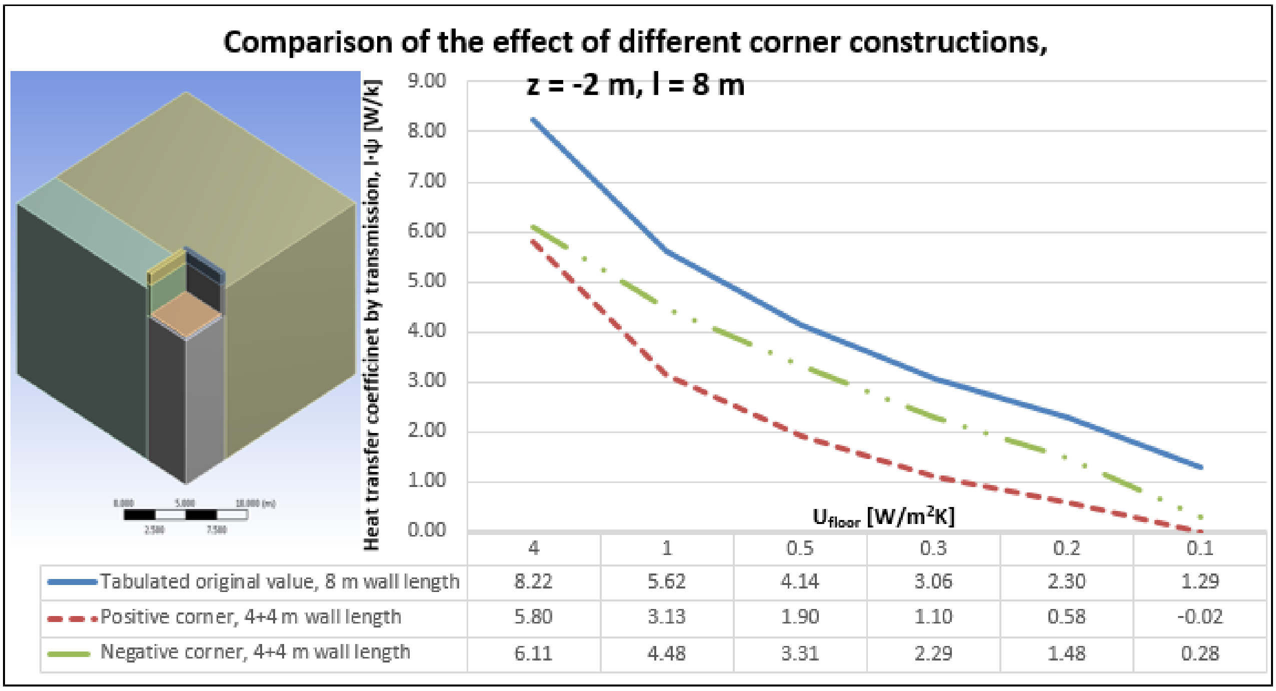
$$\gamma_{c,p} = [\ (-0.04 \cdot z^2 - 0.0761 + 0.8508) \cdot (0.3027 \cdot z^{-0.216}) \cdot ln(U_{floor}) + (-0.0352 \cdot z^2 - 0.0377 \cdot z + 0.7796) \cdot (0.899 \cdot z^{-0.151})]/[0.3027 \cdot z^{-0.216} \cdot ln(U_{floor}) + 0.899 \cdot z^{-0.151}] \qquad (10)$$

3. Equivalent thermal transmittance of basement wall

So far calculations for determining the heat losses of ground contact floor structures were presented. However, in case of heated basements, the heat losses of the basement walls also should be taken into consideration, that was not included in the basic method published in [5]. The equivalent heat losses of a basement wall can be calculated from the U_{bwall} heat transfer coefficient and the average of thermal conductivities of the soil next to the basement wall in a quarter circle till the surface according to [4], which approximates the heat transfer coefficient of a basement wall in a transient state, in the Central European climatic conditions:

$$U'_{bwall} = \frac{U_{bwall} + \frac{1}{\frac{1}{U_{bwall}} + \frac{\pi \cdot \frac{|Z|}{2}}{2 \cdot \lambda_{soil}}}}{2} \ [\frac{W}{m^2K}] \qquad (11)$$

Eq. 11. gives a good approximation to calculate the heat loss of a basement wall including the effect of the thermal bridge at the floor and the wall joint.



U$_{floor}$ [W/m^{2}K]	4	1	0.5	0.3	0.2	0.1
Tabulated original value, 8 m wall length	8.22	5.62	4.14	3.06	2.30	1.29
Positive corner, 4+4 m wall length	5.80	3.13	1.90	1.10	0.58	-0.02
Negative corner, 4+4 m wall length	6.11	4.48	3.31	2.29	1.48	0.28

Figure 2. *Comparison of the effect of different corner constructions on heat transfer coefficient of the floor*

4. Heat transfer coefficient of ground contact structures

The whole transmission heat losses at ground contact structures can be calculated by the following formula:

$$H_g = \sum(\psi_t + \gamma_i + \psi_e) \cdot l_i \cdot \gamma_{c,i} + l_i \cdot |z| \cdot U'_{bwall}\ \left[\frac{W}{K}\right] \qquad (12)$$

where: ψ_t is definable by applying eq. 1. and eq. 2. or the tabulated data given in previous research [5], and γ_i represents the correction factor for the local environment. The effect of insulating strip placed along the perimeter of the floor can be taken into consideration by adding ψ_e that can be calculated according to EN ISO 13370:2007 Annex B [2]. As shown in [5], structures close to the external ground can be calculated steady-state conditions, the Annexes calculation method gives good results compared to simulations for insulation strips, but for the heat loss of floors, the results can differ by up to 40%.

In case of changes in geometry, e.g. at the corners of the building the interior floor l_i edge length should be corrected by $\gamma_{c,i}$.

At undisturbed straight line $\gamma_{c,i}$ = 1,0. In the case of ground contact structures heat losses of vertical surfaces should be calculated separately according to eq. 12. However, surface heat losses of the floor structure are included in equivalent linear thermal transmittance.

4. Conclusions

This paper shows the effect of different environmental and structure-dependent factors on the heat loss of ground contact floor structures and gives an equation to calculate the heat transfer coefficient of ground contact structures. Better understanding of the environment-dependent reactions of a ground contact structure may help architects, civil engineers and mechanical engineers in energy conscious design.

References

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