HEAT LOSSES FROM LARGE BUILDINGS THROUGH THE GROUND

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I. INTRODUCTION

The heating demand of a building is strongly influenced by transmission heat losses through the ground, if the total thermal conductance of the building constructions in contact with the ground is in the same order as the thermal conductance of the building envelope in contact with the air. This will be the case in particular for such buildings, where the building constructions in contact with the ground take up a considerable part of the total area of the building envelope. On the one hand this situation is given for small buildings provided with a basement. On the other hand transmission heat losses through the ground are important for buildings with big floor areas in direct contact to the ground, e. g. for big halls.

Transmission heat losses from a basement of a residential building were investigated in [1] and [2]. This paper deals with heat losses through various slab on ground constructions normally used for big industrial halls.

Calculations of the heat flow through building constructions in contact with the ground are special cases on principle in that they cannot be done using the ordinary constant, onedimensional (1D) thermal model. On the one side the heat flow through the ground can be described only using two or three spacial coordinates. From this heat losses through the ground are to be calculated using two- and threedimensional (2D and 3D) thermal models. On the other side in most cases of interest the very big heat storage capacity of the ground involved in such heat flow calculations cannot be ignored, so that a non-steady calculation method is required.

For most slab shaped building constructions in contact with the air the thermal quality of the construction with regard to heat losses can be characterized by an U-value in good approximation. Contrary to this the declaration of a U-value alone makes no sense for slab on ground constructions. The well known fact that the heat loss through a slab-shaped building construction can be calculated in good approximation by multiplying the U-value of the slab with it's area and with the difference of the air temperatures between internal and external environment is no longer true for slab on ground constructions. The heat flow through slabs on ground is not only influences by the U-value and the area of the slab but also by the geometry of the building construction in contact with the ground and by the thermal characteristics of the surrounding soil. For that reason quantitative statements concerning the heat through the ground are only true for the specific building under consideration.

In this paper a case study concerning different insulation levels of a slab on ground construction is performed for an industrial hall with largely fixed geometry. From this study qualitative conclusions concerning the effectiveness of slab insulation is drawn.

II. CALCULATION CONCEPT

The conduction of heat in building constructions can be described with sufficient precision by a thermal model in which the heat loss Φ_m of a room *m* is connected with the air temperatures T_n of all environments (not only the internal environments but also the external ones) involved in the heat transmission process by a linear function [3]:

$$\Phi_m = -\sum_n L_{m,n} \cdot T_n \quad . \tag{1}$$

The factors of proportionality $L_{m,n}$ are the thermal conductances between environment *m* and *n*. For constant , i. e. time independent approach the relation

$$\sum_{n} L_{m,n} = 0 \qquad (2)$$

is valid so that equation (1) can be rewritten in the more familiar form

$$\Phi_m = \sum_{\substack{n \\ n \neq m}} L_{m,n} \cdot (T_m - T_n) \quad . \qquad (3)$$

In the constant notation of (3) the heat loss of environment *m* is proportional to the differences between the air temperature T_m of room *m* and the air temperature T_n of environment *n*, where the summation index *n* denotes all environments involved with the exception of the environment under consideration (index *m*).

For the special problem considered here the building - the industrial hall - can be treated as a single room so that only two environments - the internal (index *i*) and the external (index *e*) - occur and equation (3) gets the very simple form

$$\Phi_i = L_{i,e} \cdot (T_i - T_e) \quad . \qquad (4)$$

The transmission heat loss of the building Φ_i is caused by conduction of heat through the building envelope in contact with the air as well as by the heat flow through the ground. The thermal conductance $L_{i,e}$ can be split up in one part $L^a_{i,e}$ corresponding to heat conduction processes through the building envelope in contact with the air and one part $L^g_{i,e}$ corresponding to heat flow through the ground without making an appreciable error. Only the latter will be investigated here in detail.

It is well known that for building constructions in contact with the air the heat storage does not essentially effect the transmission heat losses. This is not true for building constructions in contact with the ground, because the heat storage capacity of the soil involved in the heat transmission process can never be ignored. So the question arises what meaning can be ascribed to the results of constant approaches in connection with the calculation of heat flows through the ground. The answer of this question will result from a discussion concerning non constant heat flow processes.

The solution of the (time dependent) heat flow equation requires not only the fixing of the course of air temperatures as boundary conditions but also the definition of the temperature field in the whole region under investigation at a fixed time point as starting conditions. The problem that the starting conditions are unknown in principle can be avoided by the restriction to heat flow processes, which are periodic in time. As shown in [4] the extension of the concept of thermal conductances to periodic heat flow processes leads to close anologies between constant and periodic calculation. In particular equation (1) can be rewritten in the form

$$\hat{\Phi}_m = -\sum_{n} \tilde{L}_{m,n} \cdot \hat{T}_n \qquad (5)$$

for periodic heat flow, where $\hat{\Phi}_m$ is the complex amplitude of the heat loss of environment *m* and $\hat{T}_n$ is the complex amplitude of the air temperature in environment *n*. The factors $\tilde{L}_{m,n}$ - called periodic thermal conductances [5] - are also complex quantities.

Since the relation (2) does not hold for the periodic case the heat loss amplitude $\hat{\Phi}_i$ from a building approximated as a single room has to be calculated according to equation (5):

$$\hat{\Phi}_i = -\tilde{L}_{i,i} \cdot \hat{T}_i - \tilde{L}_{i,e} \cdot \hat{T}_e \quad . \qquad (6)$$

Due to the very big thermal inertia of the ground short-time oscillations of the air temperatures - such as the daily variations - do not effect the heat transmission through the ground in a significant manner. But it is necessary to take into consideration the annual variation of the external and the internal air temperatures. This can be done by a harmonic analysis of the annual time dependencies.

From the harmonic analysis of the annual time dependence of the external air temperature based on monthly mean values representative for the average climatic situation over years it becomes apparent that the restriction to only one harmonic results already in a good approximation.

From these considerations can be deduced that the constant calculation as given in equation (4) applies to the annual mean value of the heat loss through the ground. For building constructions in contact with the ground it makes no sense to put in other temperatures for the internal and the external environment than annual mean values into equation (4).

Summing up it appears that the heat flow through the ground can be characterized by the conductance $L^g_{i,e}$ and the periodic thermal conductances $\tilde{L}^g_{i,i}$ and $\tilde{L}^g_{i,e}$. These conductances have to be calculated numerically using 2D and 3D thermal models. Since wide ranges of the surrounding ground have to be included in the thermal model, powerful programs are necessary to calculate the quantities used. For the case study presented below the PC-program WAEBRU [6,7] was used to calculate the needed conductances.

III. CASE STUDY: INDUSTRIAL HALL

The seasonal heat loss through a slab on ground construction is studied on a heated industrial hall with a floor area of $15.78\,\mathrm{m} \times 55.23\,\mathrm{m}$. Figure 1 shows a view and the ground plan of the hall.

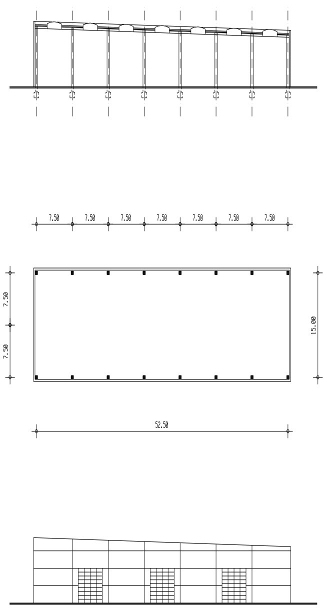

Figure 1: Cut, ground plan and view of the industrial hall investigated

The calculation of the thermal conductances requires the establishing of a thermal model including wide ranges of the surrounding soil. For the hall under consideration one 3D-calculation of the thermal conductances L^{3D} was performed for a thermal model including one corner of the building (floor area $7.89\,\mathrm{m} \times 7.89\,\mathrm{m}$; see figure 1) and a quadratic piece of soil with a lateral length of $46.91\,\mathrm{m}$, reaching $38.73\,\mathrm{m}$ below the ground level. A supplementary 2D-calculation (conductance L^{2D}) performed for a cut through builing and soil (cut A-A in figure 2) makes it possible to calculate the thermal conductance $L^g_{i.e}$ [1]:

$$L^g_{i,e} = 4 \cdot L^{3D} + 2 \cdot L^{2D} \cdot (l - l_0) \quad . \tag{7}$$

The relation (7) is valid in analogous form also for the periodic calculation.

The calculation of the heat loss through the ground was performed for the three various levels of insulation of the slab as shown in figure 2. Starting from the uninsulated slab (var. U) the effect of a horizontal edge insulation (8cm foam glass, width 2.0 m; var. E2) and an overall insulation of the slab (8cm foam glass; var. A) on the heat loss through the ground was investigated.

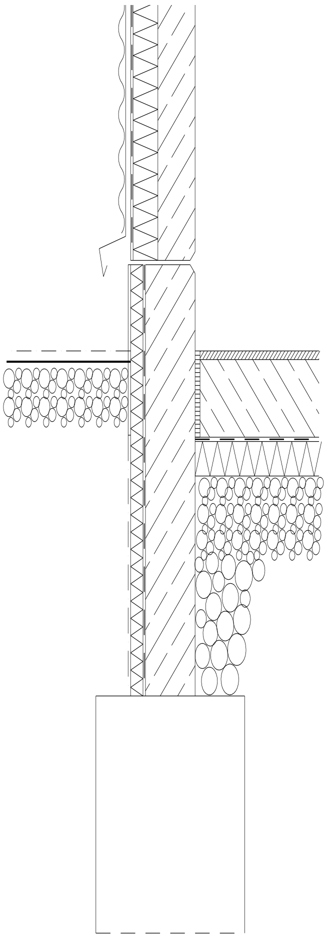

Figure 2. Vertical cut through the slab - wall connection

The conductances calculated for the three insulation variants are listed in table 1. The periodic conductances were calculated using the period length of one year and are of course complex quantities; in table 1 the symbol *j* denotes the imaginary unit.

	3D thermal conductances [W/K]			**2D** thermal conductances [W/m·K]		
		Period length: 1 year			Period length: 1 year	
Var.	$L_{i,e}^{3D}$	$\tilde{L}_{i,e}^{3D}$	$\tilde{L}_{i,i}^{3D}$	$L_{i,e}^{2D}$	$\tilde{L}_{i,e}^{2D}$	$\tilde{L}_{i,i}^{2D}$
U	27.13	8.43 - 5.20·*j*	-41.74 - 22.50·*j*	2.142	0.525 - 0.345·*j*	-4.731 - 3.039·*j*
E2	23.44	6.43 - 4.27·*j*	-35.74 - 19.00·*j*	1.963	0.396 - 0.295·*j*	-4360 - 2.808·*j*
A	20.46	6.25 - 3.56·*j*	-27.85 - 11.88·*j*	1.708	0.382 - 0.234·*j*	-3.038 - 1.543·*j*

Table 1. Calculated thermal conductances

For parameter studies concerning the size of the hall the width of the hall has to be kept constant, whereas the length *l* can be enlarged from $l_0 = 15.78$ m to arbitrary size (see equation (7)).

Figure 3 shows the dependence of the thermal conductance related to the floor area *A* on the length *l* of the hall for the three insulation levels under consideration. As discussed above this result is valid only for annual mean values. It appears that the annual mean value of the heat loss through the slab, which is proportional to the values given in figure 3, can be reduced to about 75% of the value for the uninsulated slab for quadratic floor and 79% for very long halls by all over insulation. For variant E2, i. e. horizontal edge insulation with a width of 2 m, a reduction to about 86% for quadratic floor and 91% for long halls is obtained.

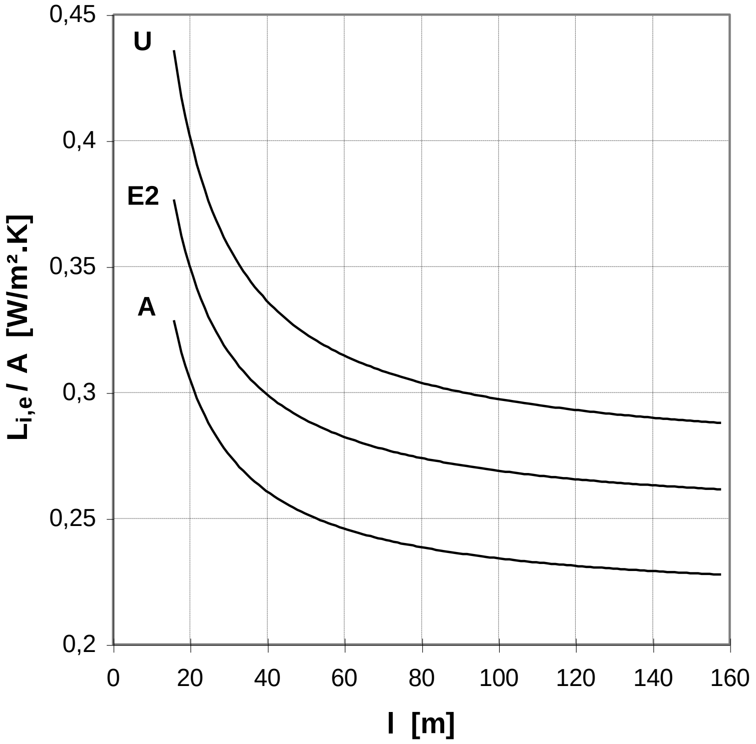

Figure 3: Dependence of the conductance $L^{g}_{i,e}$ related to the floor area A on the length of the hall *l* for the uninsulated slab (U), all over insulation (A) and 2 m horizontal edge insulation (E2)

The results of the constant calculation refer to the annual heat losses and impart already to a feeling concerning the effectiveness of an applied insulation. More detailed information results from the periodic calculation. To calculate the annual time dependence of the heat loss through the ground, the thermal conductances given in table 1 are inserted in equation (6). The amplitude of the external air temperature $\hat{T}_e$ is set to the value of $-5.059 + 1.356 \cdot j$ K, representing the annual up and down of the external air temperature for the mean climatic situation in Vienna. The internal air temperature of the hall is assumed to be constant over the year. Therefore the amplitude $\hat{T}_i$ is set to zero. The time dependence of the heat loss is obtained by *Fourier*-synthesis using the value of Φ_i calculated from equation (4) with $T_e = 9.84\,°C$ - the annual mean temperature in Vienna - and $T_i = 20\,°C$ and $\hat{\Phi}_i$ calculated according equation (6).

In figure 4 the result of these calculations is shown. It appears that the heat loss through the ground is positive all over the year for each variant. The maximum value of the heat loss through the ground is obtained - depending on the insulation variant - between the 15th and the 20th of feb-ruary. So the time shift beteewn the minimum of the external air temperature and the maximum of the heat loss amounts to about one month. It is conspicious that the heat loss for variant E2 in the summer season is only a little bit smaller than the heat loss obtained for the uninsulated slab. This fact may help to save energy for cooling in summer. So for the problem under consideration the horizontal edge insulation may be preferred to all over insulation.

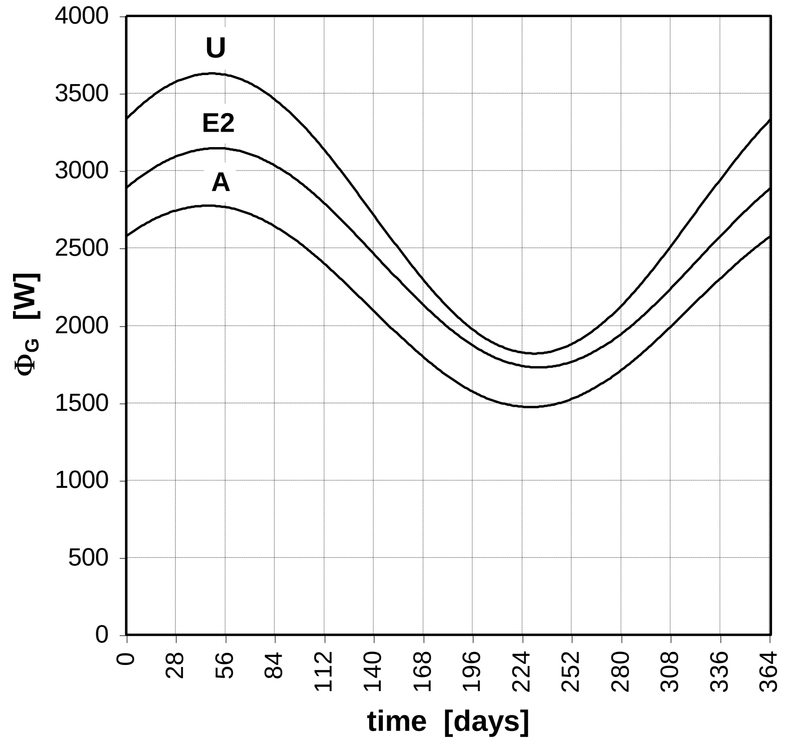

Figure 4. Annual time dependence of the heat loss through the ground Φ_G for various insulation levels of the slab

IV. CONCLUSION

The limitation of the heating demand of industrial halls often requires a reduction of the transmission heat losses through the ground. Generally calculations of heat losses through the ground require a threedimensional, non-steady treatment. The case study performed on an air conditioned industrial hall shows that the mean value of the annual heat flow through the slab on ground construction can be reduced to about 80% of the value of the uninsulated slab using 8 cm all over insulation. Taking into mind that a heat loss through the floor is disirable in summer, a horizontal edge insulation may like better than all over insulation.

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