Thermal Losses via Large Slabs on Grade

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ABSTRACT

Thermal losses via slabs on grade are usually calculated by simplified steady state calculations such as described in ISO 13370 or ASHRAE Fundamentals. In this research such standard methods were compared to transient simulations using a finite difference model coupled with building simulation software. The focus was on large slabs up to 10000 m^2 to analyze the thermal transport in particular under industrial buildings. To respect real conditions of such buildings also lower inside temperatures than in dwellings were assumed. Moreover different insulation types and soil qualities were compared. The simulations in general showed good accordance with the ISO-method for small horizontally insulated slabs like dwellings at 20 °C inside temperature. For large slabs and in particular for non-insulated slabs the losses seemed to be far overrated by the steady state method, in particular for large low heated buildings such as warehouses. Here a lot of energy from summer overheating of the building is stored under the slab and causes a heat flow from the ground back into the building during the first months of the heating period and not inverse. Therefore short vertical footer insulations appear most energy efficient for most large industrial buildings.

KEYWORDS

Thermal losses via ground, industrial buildings, large slabs, building simulation, transient ground modeling

INTRODUCTION

For building components above grade, thus adjacent to external climate (e.g. walls and roofs), it is simple to calculate the thermal transport during the year as inside and outside temperatures can be assumed easily. For slabs on grade or even below-grade components the outside conditions cannot be determined that easily. The temperature under the slab is different at every position and significantly depends on the slab dimensions, the distance to the perimeter, the climate, the heat storage capacity and conductivity of the soil, the quality of slab insulation, the buildings inside temperature and many more parameters. For buildings with a low ratio of ground-coupled floor area to heated building volume a precise assessment of the thermal transport via slabs is minor important. But for industrial buildings like large warehouses or production

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buildings the imprecision in assessing such losses can have a significant impact on the total energy balance. Due to the complex boundary conditions several simplified methods exist, reaching different accuracies in estimating the thermal transport via ground. The simplest way to consider the ground´s insulation effect is the use of correction coefficients, still used in some energy balance methods such as DIN V 18599 (2011) in Germany. Also more precise steady-state methods assuming a periodic thermal transport via soil can be used such as the American method introduced in ASHRAE (2001). In Europe a similar method is described in EN ISO 13370 (2007) which is mostly based on the findings in (Anderson 1991), (Claesson und Hagentoft 1991) and (Hagentoft und Claesson 1991).

With an increasing computational power the most precise methods were developed in recent years. These 3D finite difference models are able to couple the transient ground heat transfer with a building simulation software package. Such coupled slab-on-grade models allow the interaction of building and ground, recognizing storage effects and thermal properties of the soil. Overviews and comparisons of different ground coupling models are given in (Chen 2013) and (MCDowell et al. 2009). Unfortunately these references just outline small slabs of residential buildings up to 144 m². Large slabs of industrial buildings can arise some 10000 m² or more. Thus further comparisons were carried out in this project. Here the finite difference model implemented into TRNSYS 17 (type 49) is compared with the simplified method of EN ISO 13370 (2007) as imprecisions of the ISO-method for industrial buildings are already claimed in (Brinks et al. 2014). But the focus of this project is not in estimating the precision of existing steady-state methods but in finding best insulation solutions for large slabs on grade for the industrial building sector. Furthermore the variation of the inside temperature is an important parameter as temperatures in warehouses and production buildings usually are in a low range between typically 12 °C and 20 °C dependent on their usage. Hence the temperature difference between inside air and ground is often far lower than for residential buildings. Therefore it is to clarify if horizontal insulations are a reasonable solution for large slabs under low heated buildings, as often required by existing national energy regulations.

STEADY STATE METHOD VERSUS TRANSIENT SIMULATION

EN ISO 13370 (2007) gives an analytic approach that is implemented in many energy balance software packages to estimate thermal losses via ground for the European wide required energy performance certificates. Here the variation of the heat flow is described by cosine functions, representing the thermal flow oscillation due to changing in- and outside temperatures. Further the periodic shift, caused by the slow thermal transport via ground, is recognized by an interval of approximately 1-2 months. However in such steady state approaches it is not considered that energy is stored in the ground during summer. For the here carried out transient simulations type 49 of the TRNSYS 17 software package is used. This type is a 3D finite

difference model of the ground under a slab on grade. It is coupled with the thermal transport via slab and thus interacts with the transient building simulation. Therefore all gains from summer overheating of the building are considered in the model. The discretization of soil can be chosen as well as the dimensions of the ground cube under the building. The model accounts only for thermal transport by conduction, moisture effects as well as water movements in soil are neglected. Other thermal properties like conductivity and heat capacity can be chosen freely. All boundary conditions between the discretized ground (near field) and the ambient soil (far field) are assumed according to the Kusuda equation (Kusuda and Achenbach 1965) for undisturbed ground temperatures. The differential equations describing the thermal transport in this model are solved analytically. All discretized nodes are assumed with a cubic shape, why six heat transfers must be analyzed per node. For further description it is referred to the mathematical reference of type 49 (Solar Energy Laboratory 2012). Figure 1 shows the principle of the coupling between the discretized ground model and the slab as a part of the transient building simulation.
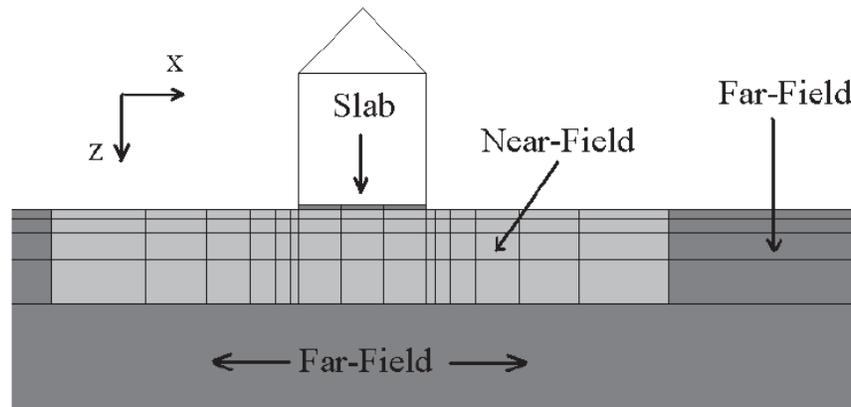
Figure 1. *Discretized finite difference soil model coupled with the slab of the transient building model of TRNSYS 17 (Solar Energy Laboratory 2012)*

Simulation settings
In all simulations the near field exceeds the slabs edges by 10 m in all horizontal directions and its deep boundary layer is assumed in 20 m depth. The smallest node size is 0.1 m with a growing factor of 2. Comparisons with smaller node sizes were carried out as well and confirmed a sufficient exactness of the here chosen discretization grid. The initial conditions are of course important. For the building erection time the ground temperature was assumed as the average air temperature of the year. After erecting the building the ground starts to heat up due to gains from the building and reduced losses at its surface. In the first years after erecting the building the ground heats up rapidly. As this is a long process, which can take up to 30 years, in particular for horizontally insulated slabs, a time for comparison has to be fixed.

Here all selected simulation results are shown in the fourth year. This seems to be a good compromise, as at this time the ground is already close to steady state condition but the simulation time is still acceptable.

Four different building sizes were chosen for simulation to represent a typical range of industrial building sizes (1000 m² - 10000 m²). The length/width ratio for all buildings is 2.2:1 and the buildings comply with the currently required thermal standard in Germany EnEV 2014 (2014). To represent typical summer overheating, all buildings have the same dome light area of 9% related to the ground area. Further the walls and roofs are made of light steel structure components (profiled sheeting and mineral wool insulation). All simulations were carried out with the German reference climate for the city of Potsdam (TRY 2010: average temperature 9.54 °C, amplitude 9.01 °C). The soil parameters conductivity and heat capacity have a significant impact on the thermal transport. EN ISO 13770 suggests standard values for clay, sand and rock, these values were used for the soil comparison in figure 6. For all other simulations a sand ground was assumed as it is also the standard assumption of EN ISO 13370. All thermal properties are listed in table 1.

**Table 1.** *Thermal properties of soil and rock according to ISO 13370 and ASHRAE*

	EN ISO 13370		ASHRAE 2013
	Thermal conductivity [W/mK]	Heat capacity [J/(m³K)]	Thermal conductivity [W/mK]
Clay	1.5	$3 \cdot 10^6$	0.9 - 1.6
Sand	2.0	$2 \cdot 10^6$	0.6 - 2.5
Rock	3.5	$2 \cdot 10^6$	0.5 -7.8

Ground water can also have an impact on the thermal transport via slabs. A simplified method for recognizing this effect is given in Annex H of EN ISO 13370 (2007). Hereafter the Groundwater can increase the thermal losses by up to 74 % dependent on the most influencing parameters depth and flow rate of the groundwater. A far higher increase is mentioned in (Dahlem 2000) where losses rise up to the factor 30 due to ground water under a cellar ground slab modelled with FE-simulation. The thermal transport influenced by groundwater was not analyzed in the here used models. It shall therefore just be mentioned that heat transport can significantly change if ground water exists in the upper soil layers. However in most cases the ground water level is far enough from the slab. Therefore in most cases the groundwater is not required to be considered as also claimed in EN ISO 13370 (2007).

RESULTS
The impact of the inside temperature of a building on the temperature under the slab is shown in figure 2 and 3. The comparison of both figures shows the difference

between using horizontal insulation or a vertical footer insulation. Due to the high conductivity of the concrete slab much more energy from summer overheating is stored under the building if no horizontal insulation exists. Thus during the heating period the temperature difference between the required inside temperature and the soil temperature is much lower when only footer insulation is used.
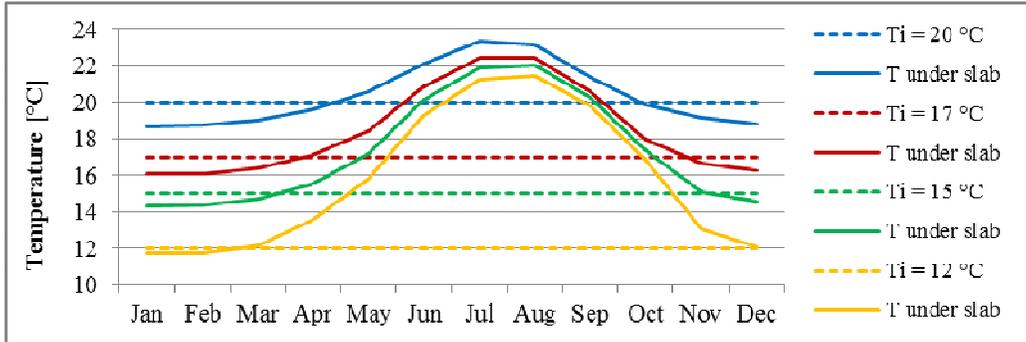

Figure 2. *Temperatures under the slab versus required inside temperatures, 1m vertical insulation, slab dimensions 65 m x 30 m*
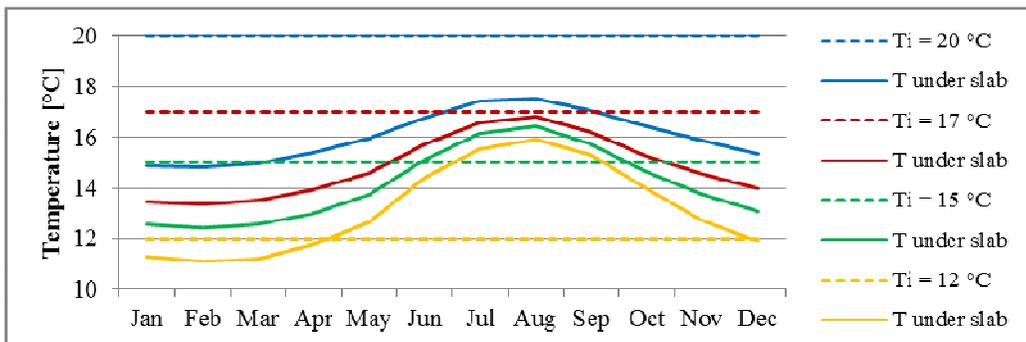
Figure 3. *Temperatures under the slab versus required inside temperatures, holohedral horizontal insulation, slab dimensions 65 m x 30 m*

Figure 2 shows that for a low heated building (12 °C) the required inside temperature is only in January and February higher than the soil temperature. For buildings with higher required inside temperatures and with a horizontal insulation the period where the soil temperature goes below the minimum inside temperature is longer. To better detect the energy losses and to compare them with the results according to ISO 13370 (2007) the heat flow via the slab was simulated. Figure 4 and 5 show these heat flows for buildings with different requirements on the inside temperature. The figures show that the ISO-method overrates the heat flow in winter mainly for non-insulated slabs but also for horizontally insulated slabs. Due to the energy stored in the ground from summer overheating, energy gains can also be used during the heating period for the low heated building, but only if the slab is not horizontally insulated. For this building almost no energy losses but gains are realized in the heating period.
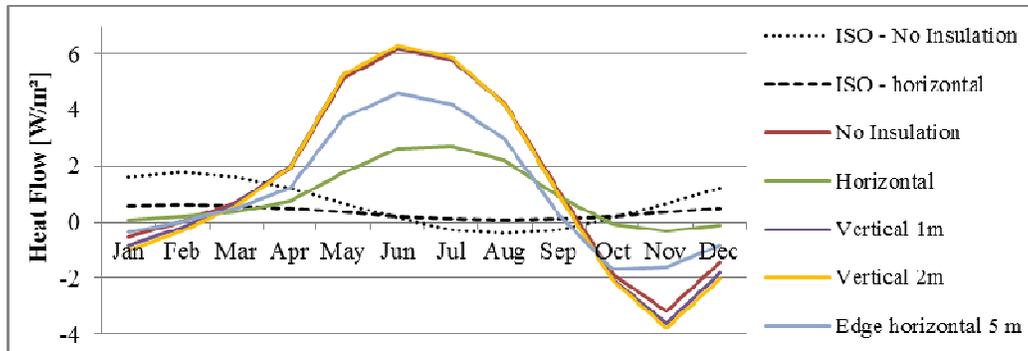
Figure 4. *Heat flow via slab (65 m x 30 m) with different insulation, $T_{i,min}$ = 12 °C*

A positive heat flow (from the building into the ground) almost only occurs after the short heating period. The vertical footer insulation shows the best performance, while differences between 1 m and 2 m length of this insulation are small. Even no insulation under the building is a better solution for the low heated building than a holohedral insulation. To use only horizontal edge insulation is already better as more summer gains can be stored in the ground but it cannot compete with the vertical solution.

Large buildings with higher inside temperatures (20 °C) perform differently (see figure 5). Here it is no option to leave out the insulation at all. Horizontal and vertical insulations are both options. With a vertical insulation the losses are lower in the first half of the heating period due to the storing effect. But when the soil is cooled down, the losses start to exceed those of a horizontal insulation after the turn of the year. In this example the 2m vertical insulation still has the best performance over the year.
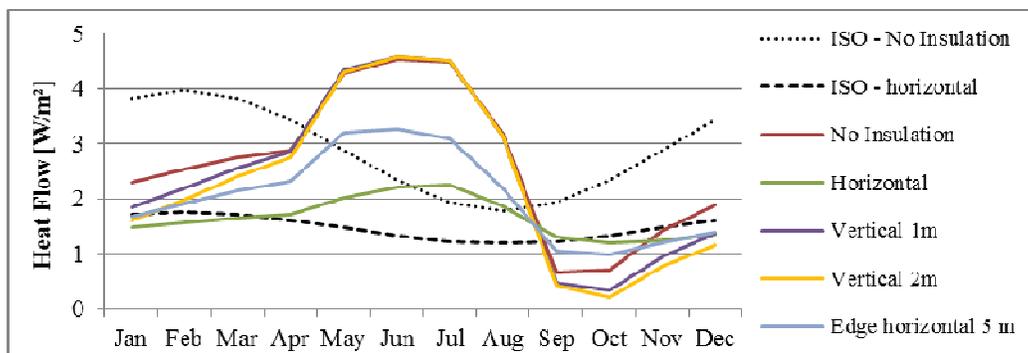
Figure 5. *Heat flow via slab (65 m x 30 m) with different insulation, $T_{i,min}$ = 20 °C*

Impact of different grounds

All shown simulations were carried out for sand ground. In practice the soil properties can vary. Hence also simulations for different grounds with properties given in ISO 13370 (2007), (see table 1) were carried out. Figure 6 shows the impact for a minimum inside temperature of 17 °C. Due to its high conductivity, rock has the highest heat flow while clay has the lowest.

Moreover the higher heat capacity of clay allows storing even more energy under the building. However the comparison shows that the general findings about energy storing under the building during summer is valid for all kinds of ground. Thus for a precise energy balance calculation the ground properties should be considered as precise as possible, but for the decision which insulation type is best, a detailed analysis of these properties is not required.
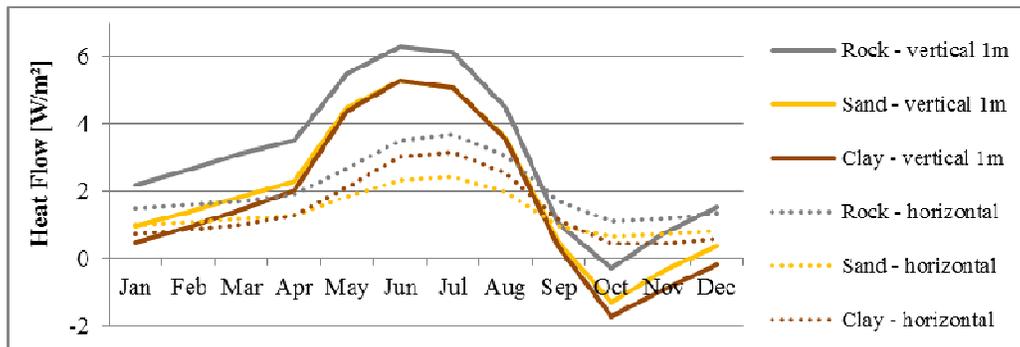

Figure 6. *Impact of the ground for horizontal and vertical insulation, $T_{i,min}$ = 17 °C*

DISCUSSION

The research showed that the current used ISO–method is not well applicable for low heated buildings with large slabs like e.g. most industrial buildings. According to that method the energy losses are far overrated as energy storing under the building is not considered. Moreover it was shown that vertical footer insulation is usually the best solution for large industrial buildings as it allows storing much more energy under the slab than with horizontal insulation even if it is only used at the edges of the slab. For very low heated warehouses the energy storing in the ground can even lead to energy gains from the ground into the building. These gains can also exceed the losses via slab in the yearly performance.

CONCLUSION AND IMPLICATIONS

The conclusion for building designers and constructors is that short vertical footer insulations should be preferred for large low heated industrial buildings. To analyze the energy performance for a specific project it is recommended to make a detailed simulation. For the construction industry and for their clients this means an enormous cost saving potential. Costly horizontal insulations should in future be replaced by short footer insulations that are easily applicable for buildings with strip foundations. Moreover design problems due to high loads on horizontal insulations can be avoided. It is recommended to also change the possibilities for assessing losses via slabs in national codes and building regulations. Otherwise the risk is to invest into worthless insulation instead of investing into more effective energy saving solutions.

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