The effect of groundwater flow on the heat loss from buildings to the ground

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Abstract

The heat loss of building parts in contact with ground surface or subsoil is compounded of a part through the ground to the outside air, a part into the subsoil and a part into the groundwater. In this paper the effect of the groundwater to these heat loss problems is described. The figured values are the results of a great number of calculations with the method of finite elements. There are shown the upper limits of the increasing of the heat loss to the the case without groundwater influence. This heat loss part depends above all on the groundwater parameters velocity and distance to the cellar floor. There can appear an increasing for the whole cellar heat loss of more than a factor 10. The geometry of the cellar and the heat transfer parameters are of less importance.

1. Introduction

The heat loss of building parts in contact with ground surface or subsoil is compounded of a part through the ground to the outside air Q_{AL}, a part into the subsoil Q_{Bo} and a part into the groundwater Q_{GW} (fig.1). These several parts usually appear simultaneously. In the cases of floor slabs on the ground or cellars the heat flow appears two- and threedimensional. For such heat loss problems general analytical solutions do not exist. Only for some special geometries and boundery conditions there are analytical solutions available. Such solutions that are given in literature are mostly without flowing groundwater, what means that only heat transfer without mass transfer is taken into account. The criticism on these solutions are closer described in /2,4,5/.

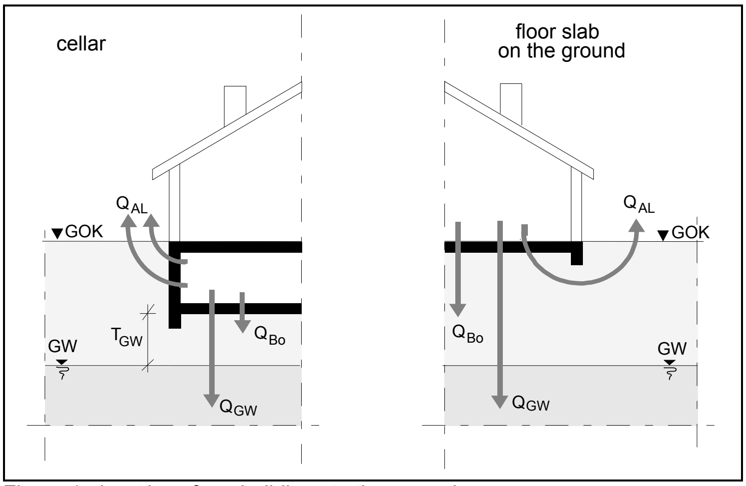

Figure 1 : heat loss from buildings to the ground

In most of the realistical cases the different parts of heat flow to the outside air, to the subsoil and to the groundwater are coupled. The amount and differentiation of these several components of heat flow are very strongly influenced by the ground structure. The most important factors for the heat flow to the groundwater are the groundwater level and the velocity.

2. Temperature in the subsoil

2.1 Temperature in the undisturbed subsoil

In the undisturbed subsoil the temperature curve is caused by two factors, by the temperature in the deep subsoil and the temperature of the outside air in contact with the ground. The temperature in greater depth is influenced by the geothermal gradient, what means a temperature rise with growing depth of about 1.5 to 4 K per 100 m. For the problems that refer to buildings this factor is very small.
On the other hand the outside air temperature has the greater influence to the upper subsoil

regions. The outside air temperature has two variations, a daily and a seasonal. The daily variation has only influence of the first 50 to 100 cm. Therefore the seasonal variation only is to study closely for the heat transfer problems of buildings.
Because of the seasonal temperature variation the ground surface can be seen as a sine curve. The temperature in the undisturbed subsoil can therefore be calculated as the temperature in a semi-infinite solid and is given by Erk/Gröber/Grigull /3/ with the following formula with the addition of the the geothermal gradient:

$$\vartheta_{E(z,t)} = \vartheta_0 + G \cdot z + \vartheta_1 \cdot e^{-z \cdot \sqrt{\frac{\pi}{a \cdot t_0}}} \cos\left(z \cdot \sqrt{\frac{\pi}{a \cdot t_0}} - 2\pi \cdot \frac{t}{t_0} \right) \qquad (1)$$

$\vartheta_{E(z,t)}$ .... subsoil temperature in the depth z at the time t
G .... geothermal gradient
ϑ_0 .... yearly average temperature of the ground surface
ϑ_1 .... amplitude of the temperature of the ground
t_0.......... period of the sine curve - here one year
a .... thermal diffusivity of the soil $a = \frac{\lambda}{c \cdot \rho}$

In this formula the influence of the temperature diffusivity of the soil is clearly given. So the depth of penetration of the seasonal variation is determined by the soil type. The influence of the outside air temperature can be of 10 m to 25 m. But it must be emphasized that not only the soil type but also his moisture and the groundwater are important.

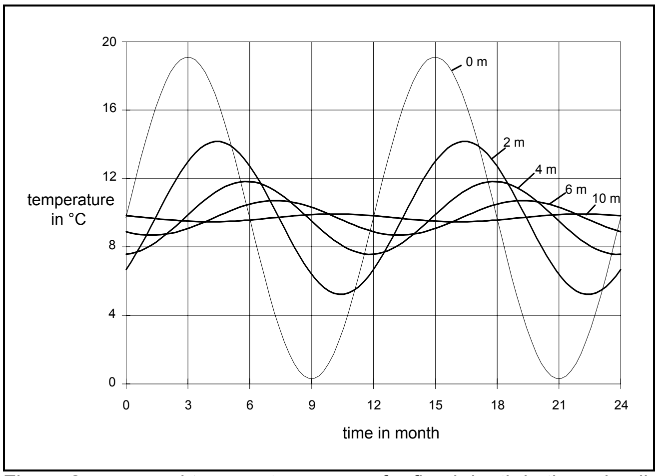

Figure 2 : seasonal temperature curves for fixed depth in the subsoil

The seasonal temperature curves for the undisturbed soil without groundwater for different fixed depths is shown in figure 2.
The curves show clearly the decrease of the temperature amplitude and the phase shift with increasing depth. These effects cause a decrease and a phase shift of the heat loss from building components in contact with the soil with growing depth in opposite to the outside air contacted components.
In figure 3 the temperature curves in the subsoil for fixed months are represented. These curves are simulated with the finite elemente method, because formula (1) only describes the case for a homogeneous material, but the case with groundwater means two stratified regions with different thermal conductivity and different specific heat capacity.

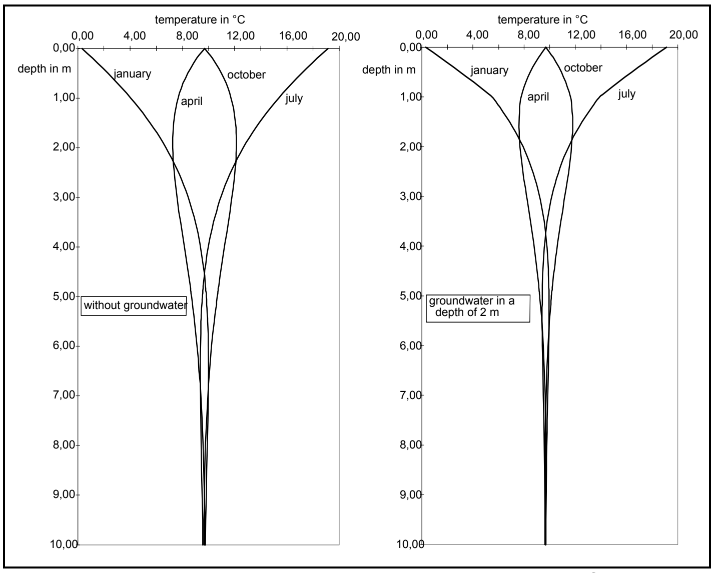

Figure 3 : depth dependent temperature curves in the subsoil for several months

The groundwater cause a smaller amplitude in its influence region and a decreasing of the penetration depth of the outside air temperature. Nevertheless there is an influence of the seasonal variation of the outside air temperature to the temperature in the subsoil and the groundwater. The phase shift is also varied with the groundwater influence.
The here shown conditions of the undisturbed subsoil show a temperature of the deeper groundwater (> 7m) with a very small seasonal variation. This is the reason for many calculation methods in which the groundwater temperature is seen as a fixed value.

2.2 Temperatures in subsoil with the influence of heated buildings

The upper explanations of the temperature conditions in the subsoil referred to the undisturbed case. When there is a heated building the temperature in the subsoil and the groundwater rises. The assumption of a fixed groundwater temperature causes then too great calculated heat loss especially when the velocity and the depth of the groundwater are small. Figures 4 and 5 show the isotherms under a cellar for two cases.

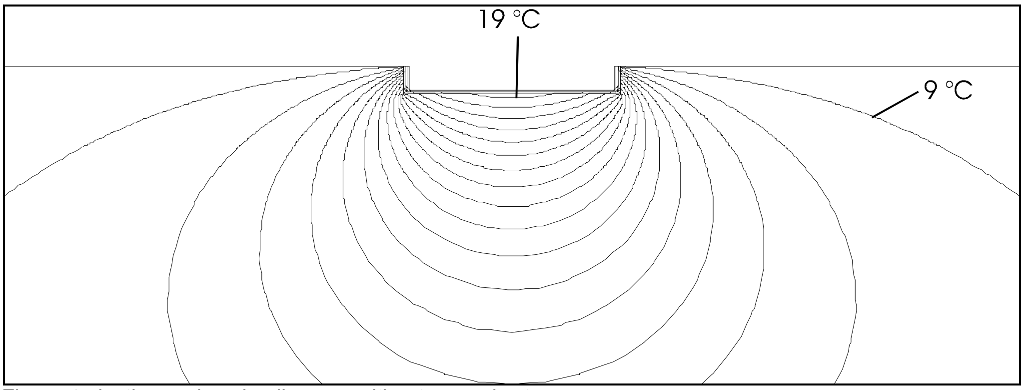

Figure 4 : isotherms in subsoil - case without groundwater

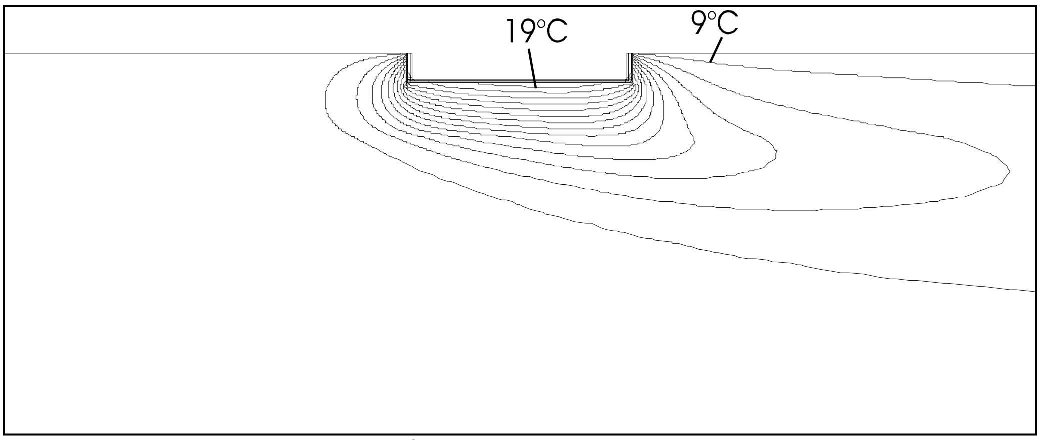

Figure 5 : isotherms in subsoil - case with flowing groundwater (10 cm/d)

It is obviously to see that the temperature in the subsoil is influenced by the heated building.

Also furthermore examinations of other groups /1/ show that the temperature of the groundwater normally is significantly influenced by anthropogenic effects such as the heat loss of buildings. The effect of the temperature rise of the groundwater just as that of the ground means a reduction of the heat loss compared to the case of a constant groundwater temperature.

3. Influence of groundwater

In the case of flowing groundwater the heat flow is not only caused by heat conduction but also by forced convection. In the groundwater there always occurs a coupled heat and mass transfer. The warmed groundwater is flowing away and colder groundwater follows. That effect causes a modification of the isotherms what is shown in figure 5 in opposition to the case without groundwater flow in figure 4.
Therefore it was necessary to prove in what dimensions the influence of the groundwater to the heat loss of building parts in contact with the subsoil occurs. The method that was here used to examine the effects of groundwater flow on the heat loss from buildings to the ground is the numerical method of finite elements. There have been carried out a lot of parameter studies with a great number of computations. The solution of the numerical computations is an extensive summary of the influence parameters of groundwater flow to the heat loss of buildings. The different influence parameters can be summarized what is shown in this chapter.
The rise of the heat loss caused by the groundwater is here represented as a factor f_{GW} for the floor, for the wall and for the whole cellar that must be used as a multiplier to the case without groundwater. This factor can be for the cellar floor up to 30 and for the cellar wall it is smaller than 2. In this paper there are shown the upper limits of the factor f_{GW}. These limits depend on the groundwater parameters (velocity of the groundwater and distance to the cellar), the geometrical parameters (height and breadth(width) of the cellar) and the heat transfer parameters (heat resistance of the building parts and thermal conductivity of the soil).

3.1 Groundwater parameters

The velocity v_{GW} of the groundwater and the distance of the groundwater level to the floor slab T_{GW} have the greatest influence to the factor f_{GW}. Figure 6 shows the upper limit of $f_{GW,f}$ in dependence of v_{GW} and T_{GW} to the heat loss of the floor. It is to see that the increase of v_{GW} from standing groundwater v_{GW} = 0 m/d to v_{GW} = 20 m/d means a great rising in form of

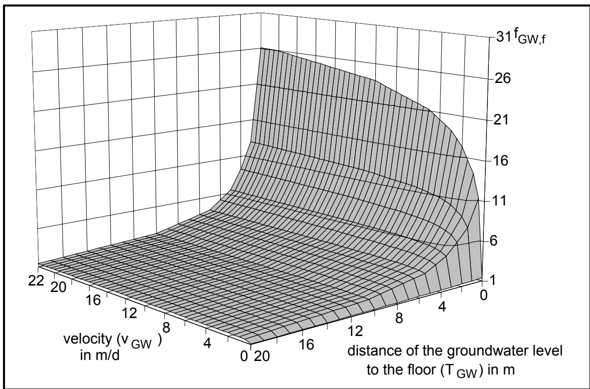

Figure 6 : factor $f_{GW,f}$ for a floor in dependence of the groundwater parameters

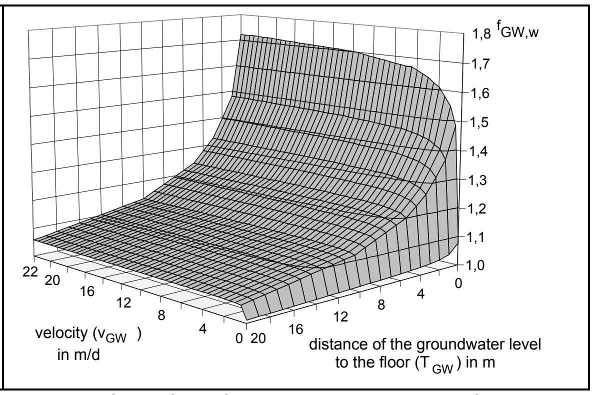

Figure 7 : factor $f_{GW,w}$ for a wall in dependence of the groundwater parameters

a logarithm curve. It is clearly to see that the distance of the groundwater level to the floor has also a very great effect. So for example the variation from the contacting groundwater (T_{GW} = 0 m) to a distance of 1 m results a halve factor. The influence of this parameter can be discribed with a hyberbolic function.

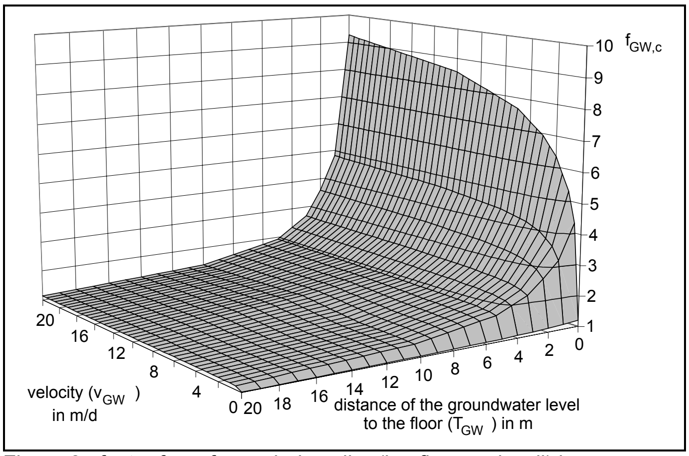

Figure 8 : factor $f_{GW,c}$ for a whole cellar (i.e. floor and wall) in dependence of the groundwater parameters

Figure 7 shows the factor $f_{GW,w}$ to the heat loss of a cellar wall. The influence parameters velocity and distance of the groundwater level to the cellar floor are of the same curve form, but for that case in opposite to the floor the factor is relativly small. This is caused above all of the greater influence of the outside air to this part of the heat loss. Therefore the influence to the whole heat loss must be regarded. This can be more than a factor 10 for extreme cases what is shown in figure 8.

3.2 Geometrical parameters

The geometry of the cellar has an influence to f_{GW} too. The geometry means the heigth and the width. Here are figured (fig.9 and 10) the extreme values for T_{GW} = 0 m an v_{GW} more than 20 m/d and them for T_{GW} = 1 m. These parameters (heigth and width) shows a linear influence the the floor heat loss and nearly no influence to the heat loss of the wall. Obviously the geometric effect to the heat loss must be respected for the extreme of T_{GW} = 0 m, but for greater distance it can also be seen as constant. In relation to the insecurity and the variation of the depth of groundwater level it is to neglect.

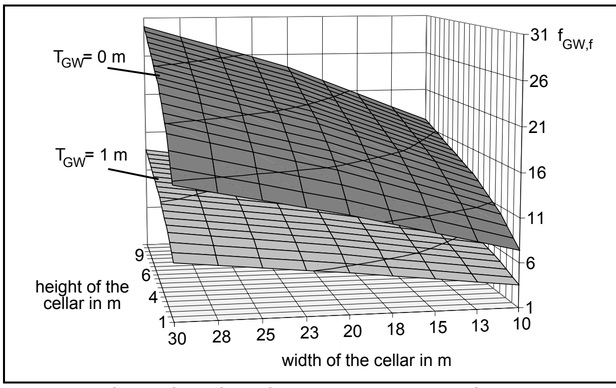

Figure 9 : factor $f_{GW,f}$ for a floor in dependence of the geometric parameters

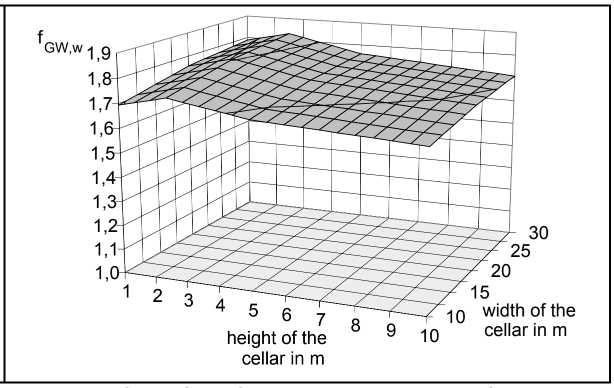

Figure 10 : factor $f_{GW,w}$ for a wall in dependence of the geometric parameters

3.3 Heat transfer parameters

As the heat transfer parameters are the thermal resistance of the construction and the thermal conductivity of the soil to be considered. The influence of these parameters to the upper limit of f_{GW} is represented in figure 11 and 12. Here again
are only figured the extreme values for T_{GW} = 0 m an v_{GW} > 20 m/d. For the wall on the one side these parameters show only a very small influence in form of a linear surface. For the floor on the other side the influence of the thermal resistance of the construction must be regarded closely. With a decreasing thermal resistance the factor is growing very steep. But here must be seen that for modern buildings the thermal resistance should be greater than 2 m²·K/W, so that this factor in most of the relevant cases is in a linear range with a small gradient.

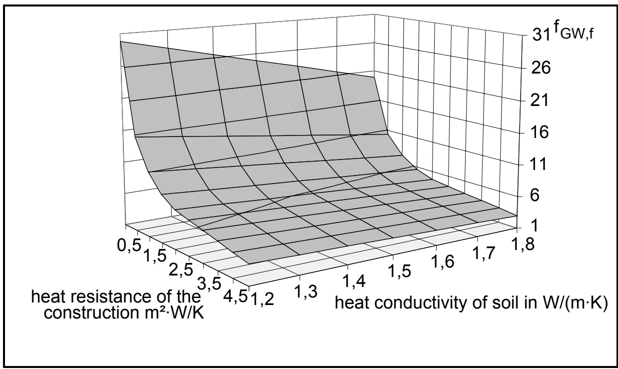

Figure 11 : factor $f_{GW,f}$ for a floor in dependence of the heat transfer parameters

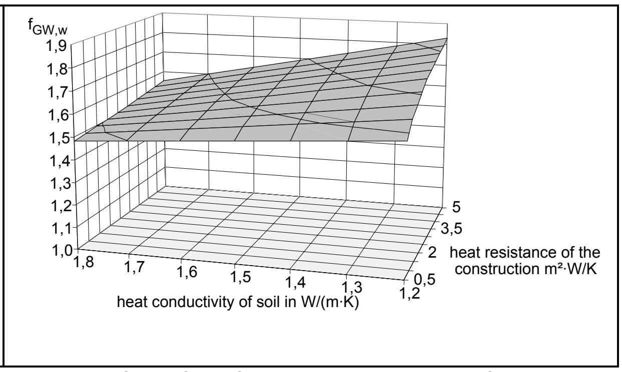

Figure 12 : factor $f_{GW,w}$ for a wall in dependence of the heat transfer parameters

4. Conclusion

The heat loss from building components in contact with the subsoil is combined of three parts, one to the ouside air, one to the ground and one to the groundwater. In this paper the effect of the groundwater to these heat loss problems is described. The figured values are the results of a great number of calculations with the method of finite elements. To demonstrate the quantity of the factor groundwater the upper limits of the increasing to the heat loss without groundwater influence are shown. This heat loss part depends on the groundwater parameters (velocity of the groundwater and distance to the cellar), the geometrical parameters (height and width of the cellar) and the heat transfer parameters (heat resistance of the building parts and thermal conductivity of the soil). The greatest influence is shown for the groundwater parameters. There can be an increase of the heat loss of a whole cellar by a factor greater than 10.

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