Moisture Conditions in a Slab on the Ground with Floor Heating

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1. INTRODUCTION

Slab on ground foundations with floor heating systems have recently increased in number. In new residential buildings in Sweden 30 – 50 % of the buildings are using floor heating as a primary heating source. Floor heating with the coil embedded in the concrete is common in such foundations.

A debate regarding high moisture levels in a concrete slab with risk for damage has been going on in Sweden. Questions have been raised: can there be risk of high levels of relative humidity in the slab? When the heat is turned off in the spring, moisture can migrate from the soil beneath the slab into the slab, driven by the temperature difference between the soil and the slab. Since the relative humidity of the soil is 100 %, a moisture flow will occur in the direction from the soil to the slab.

This paper is concerned with the occurrence of high moisture levels in the concrete slab under various conditions. The main emphasis of the work is concerned with steady-state conditions, and it does not consider the problem of possible long drying out times before steady-state conditions are achieved.

2. THEORETICAL SIMULATIONS

The aim of the theoretical simulation was to perform a parameter study in order to investigate how different parameters would affect the moisture levels in a concrete slab foundation. The simulations were performed in one dimension, at the middle section of the slab.

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The theoretical simulations have been performed for a building 10 m wide. Temperature conditions 0,5 m below the foundation have been simulated for different insulation thicknesses using HEAT2 (Blomberg, 1991), a two-dimensional computer program. The temperatures in the coil and in the indoor air were taken from measurements in a test house in Bromölla in Southern Sweden, and the ambient temperatures from Ronneby (a meteorological station not far away). In practice, the temperature in the coil is reduced somewhat as the thickness of the insulation is increased, due to the fact that less heat is required, but it has been assumed here that the coil temperature is not affected by varying heat losses to the ground.

The calculated temperature in the ground beneath the slab, the (measured) indoor temperature and relative humidity are used as boundary conditions for the moisture calculations. The temperature variation in the coil during the year is represented by a sine function as follows:

$$T_c = T_{mean} + A \cdot \sin(\omega \cdot t)$$

where
T_c is the water temperature in the coil (°C)
T_{mean} is the mean water temperature in the coil (°C)
A is the amplitude (°C)

The simulations assume that a layer of plastic floor covering has been applied directly to the upper surface of the concrete slab after a period of drying out. Using TorkaS (a computer program for the drying out of concrete [Hedenblad et al., 1989]), the initial values for the moisture simulation have been estimated at about 70 kg/m³ above the coil, and 90 kg/m³ below it.

Figure 1 gives an idea of the drying out phase. It takes over 80 months for the moisture to dry out to equilibrium conditions, whether the insulation is of mineral wool or of expanded polystyrene. The equilibrium moisture content is somewhat lower for mineral wool than for expanded polystyrene.

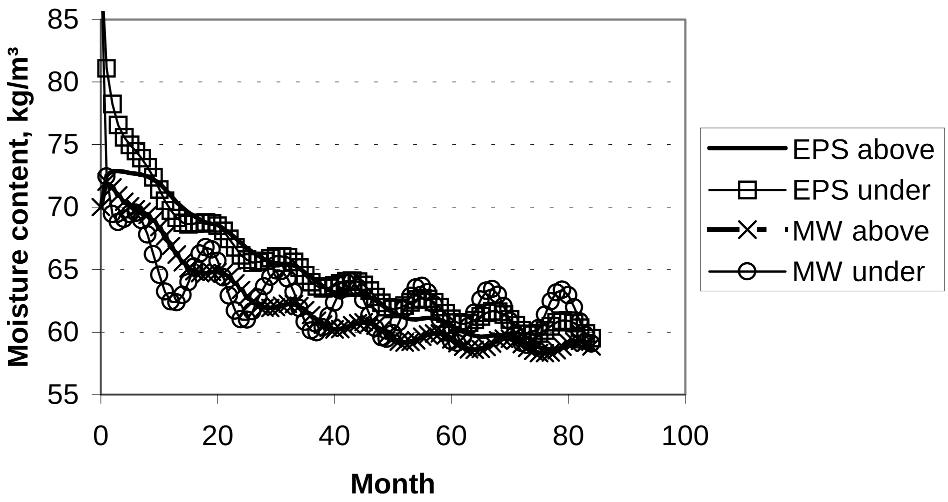

Figure 1 The moisture content in the concrete slab during the drying-out phase. The diagram shows the mean moisture content in the slab above and below the heating coil for both mineral wool insulation (MW) and expanded polystyrene (EPS). The insulation thickness is 100 mm.

2.1 Theory

The theoretical simulation of the transient moisture transport in one dimension is based on the simple equation

$$g = \delta_v \cdot \frac{\partial v}{\partial x} \qquad (1)$$

where

g is the moisture flow rate, kg/(m^{2}s)

δ_v is the vapour permeability, m^2/s

v is the moisture content by volume, kg/m^3

The model presupposes that moisture transport can be described by diffusion alone. As the main objective of the calculations was to investigate steady-state conditions with moisture contents in the hygroscopic range, the use of this simple model for moisture transport can be acceptable. Modelling of conditions in concrete at higher moisture contents is considerably more complicated, due to moisture transport in the liquid phase and chemical binding of moisture. In addition, concrete is not a single, clearly defined material, but one in which the moisture characteristics vary with the proportions of cement, water and aggregate. The sorption curves of the material have been simplified to straight lines.

3 CASE STUDIES

The relative humidity in a concrete slab with floor heating depends on the insulation thickness, the insulation vapour permeability, the temperature in the coil, the geometry of the slab etc. In this paper the relative humidity in a concrete slab with floor heating is simulated varying the following parameters:

- Insulation thickness; 50 – 200 mm
- Insulation vapour permeability; expanded polystyrene and mineral wool
- The water temperature in the coil; 22 – 28 °C
- The amplitude of the coil temperature; 2 –5 °C

The dimensions of the foundation and the used boundary conditions in the simulation are summarised in Figure 2.

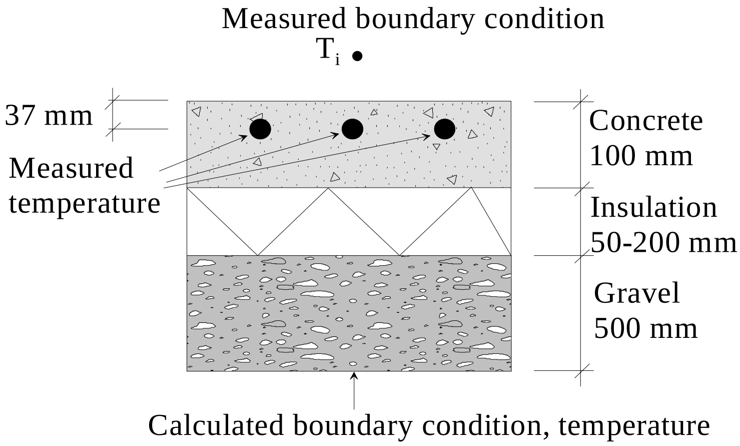

Figure 2 The dimensions of the foundation and the used boundary conditions in the simulation. The following boundary conditions have been measured: indoor temperature (T_i), indoor relative humidity and the temperature in the coils. The boundary temperature half a meter down in the gravel has been calculated.

The simulations have continued until equilibrium conditions (or very close to them) have been achieved, which have required periods of between five and twelve years.

4 THEORETICAL SIMULATIONS – RESULTS - DISCUSSION

The mean relative humidity in the concrete slab with 20 cm expanded polystyrene is approximately 53 % when the mean water temperature in the heating coil is 22°C and 40 % with 28 °C, se figure 3. This means that the relative humidity in the concrete changes approximately 2 % per °C. Higher temperature in the concrete slab will result in a lower relative humidity in the concrete and the type of insulation material seem to have only a minor effect on the relative humidity. The ground temperature may also be affected by the temperature in the coil, but this has not been considered in this paper.

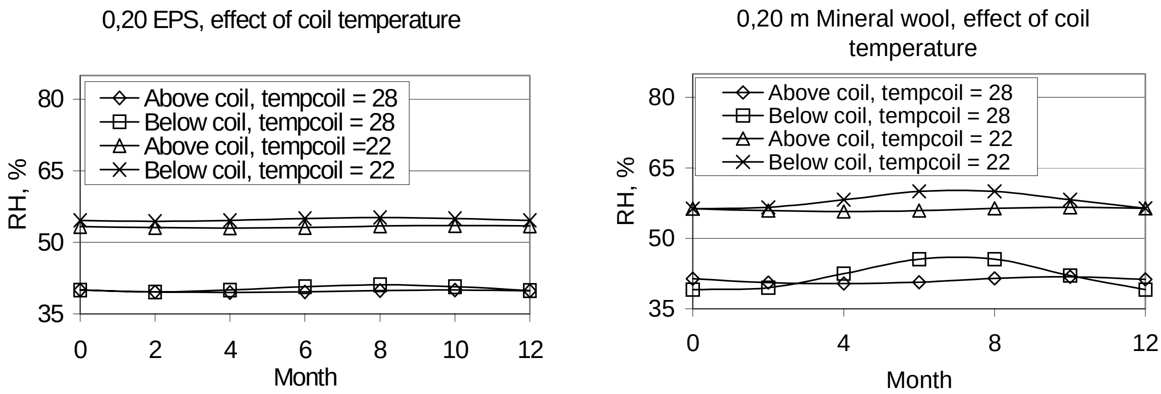

Figure 3 The relative humidity in the concrete slab above and below the coil for different water temperature in the heating coil. The insulation thickness is 20 cm of expanded polystyrene (EPS) and mineral wool (MW).

There are only moderate differences in relative humidity for different insulation materials, se figure 4. EPS and mineral wool gives nearly the same relative humidity in the concrete slab in the stationary case. With mineral wool as insulation material below the slab there are indications that moisture migrates into the slab at the beginning of the summer. This can be seen from the fact that the relative humidity increases in the concrete below the coil during the summer.

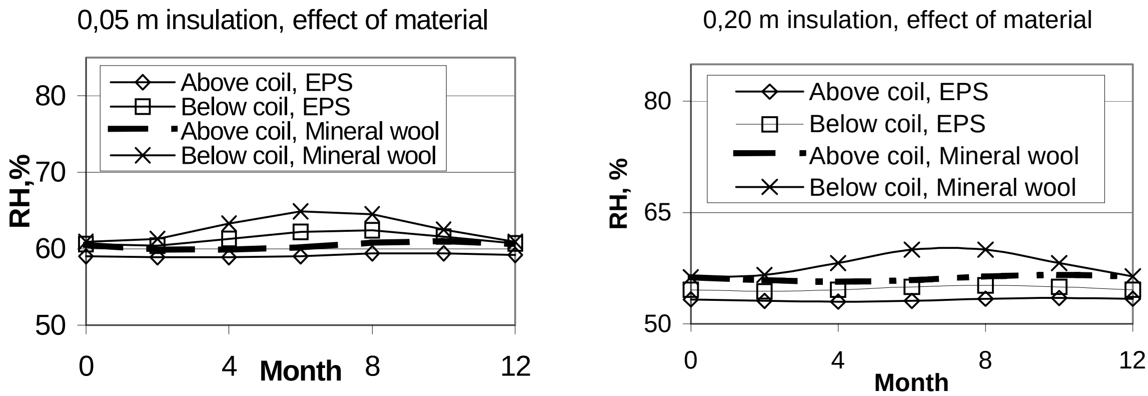

Figure 4 The relative humidity above and below the coil in the concrete slab with different insulation materials. Mean temperature of coil is 22 °C.

When the insulation thickness below the slab increases the relative humidity in the concrete will decrease. The type of insulation material has only a minor effect on this, see Figure 5.

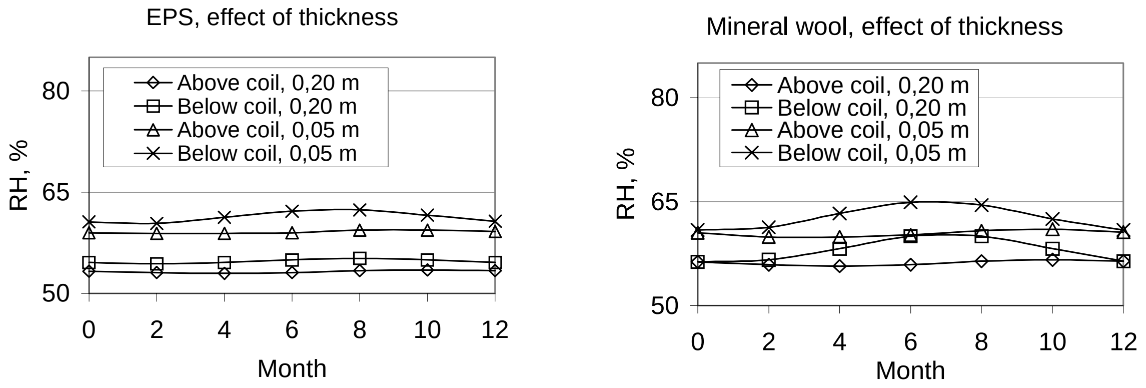

Figure 5 The moisture content in the concrete above the heating coil for different thicknesses of insulation. Mean temperature of coil is 22 °C.

Figure 6 shows the vapour concentration gradient (i.e. the driving force for diffusion) at the underside of the concrete slab. It varies considerably more over the year with mineral wool insulation than it does with expanded polystyrene insulation, due to the large difference in vapour resistance between the two types of insulation. It can also be seen that the vapour concentration gradient is as steep for 50 mm of mineral wool insulation as it is for 200 mm, while there is a difference in the corresponding gradients for different thicknesses of expanded polystyrene insulation.

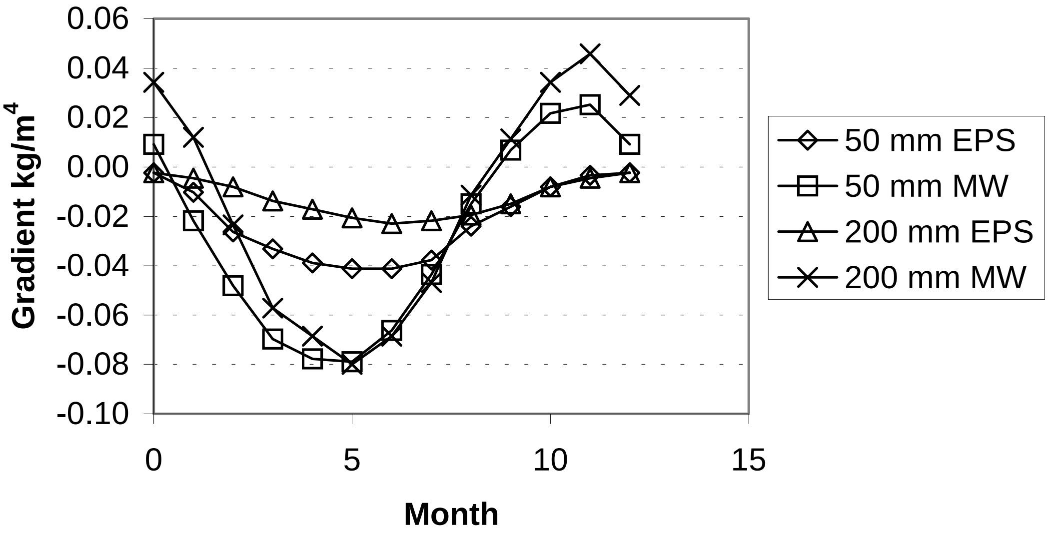

Figure 6 The vapour concentration gradient at the underside of the slab for different types and thicknesses of insulation.

Judging from the results, there is (on average over the year) a slight moisture transport from the ground to the indoor air, despite the fact that the floor covering consists of a relatively vapour-tight plastic sheet. The mean value of the gradient over the year is negative for both materials, which therefore means that there is a net moisture transport to the indoor air.

In summarising, it can be seen that there is little risk of dangerous moisture levels occurring in a detached house concrete slab foundation, 10 m wide and incorporating heating coils, with the other assumptions that have been made for the simulations. Judging from the simulation results, the choice of insulation material has little or no effect on the moisture conditions at the upper surface of the slab. It takes a long time - at least 80 months - for the slab to dry out to equilibrium conditions, regardless of whether mineral wool or expanded polystyrene insulation is used. The upper surface of the slab has a slightly higher moisture content with mineral wool insulation than it does with expanded polystyrene insulation, although not to the point of representing a danger. If the building's heat demand falls - i.e. if the coil temperature is reduced - the relative humidity at the upper side of the concrete is increased by about two percentage points per °C.

5. CONCLUSION

Simulations of the moisture conditions in and under a 10 m wide house in southern Sweden show that there should not normally be any problem with 'reverse' diffusion or humidification of the concrete slab during the summer. However, special conditions in respect of parameters such as the outdoor climate, the thickness of the slab and ground conditions, can increase the risk of moisture problems, and may require special investigation.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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