Moisture Conditions in a Concrete Slab on Grade with Floor Heating

Peter Roots, Ph.D. **Per I. Sandberg, Ph.D.**

ABSTRACT

Moisture conditions in a slab-on-grade foundation have been determined by measurements and theoretical simulations. The measurements were undertaken in a single-family house built in Bromölla in the south of Sweden. The temperature profile has been measured in the insulation and in the slab.

The simulations and the measurement show that there is no risk of high levels of relative humidity in a well-insulated (insulation thickness > 150 mm) concrete slab-on-grade foundation for normal residential buildings with different types of insulation and insulation thickness in a slab with embedded radiant heating.

INTRODUCTION

Slab-on-grade foundations with floor heating systems have recently increased in number. In new residential buildings in Sweden, 30% to 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. Questions have been raised due to the fact that there can be risk of high levels of relative humidity in the slab. In the spring, when the heat is turned off, moisture can migrate from the soil beneath the slab into the slab, driven by the temperature difference between the soil and the slab, with the soil temperature being higher than the slab temperature. If the volumetric relative humidity of the soil is 100%, a moisture flow will occur from the soil to the slab.

The magnitude of the moisture flow depends on the temperature difference between the soil and the slab and on the vapor resistance of the insulation. The temperature difference is a function of the heating power in the coil, the width of the slab, and the thickness of the insulation beneath the slab. With a large width of the slab, it could be difficult for a temperature difference to occur between the slab and the soil due to the fact that the soil has a high thermal resistance.

An investigation by Nilsson and Anderson (1981) shows that, with the moisture conditions in a slab-on-grade foundation with thin insulation thickness, there is a risk of moisture transport due to vapor diffusion from the ground to the slab. The moisture level can be high if insulation with a high vapor permeability is used. If the foundation is wide, a vapor barrier may be necessary in the insulation in order to avoid moisture transport from the soil to the slab. A vapor barrier is unnecessary if insulation with a low vapor permeability (such as expanded polystyrene) is used.

Elmarsson (1992) found that there is no problem with high levels of moisture in the slab with thick insulation. He also found that a vapor barrier beneath the slab is not necessary.

Johansson (2000) shows that the moisture level rises somewhat as a result of moisture migration between the ground and the slab, although there is no risk of moisture damage.

The moisture conditions in the slab depend also on the characteristics of the thermal insulation. If the insulation has a low vapor permeability, the drying-out time can be longer than it would be if insulation with a high vapor permeability is used. On the other hand, a more dense insulation material

---

Peter Roots is a researcher and **Per Sandberg** is a department head at the Swedish National Testing and Research Institute, Borås, Sweden.

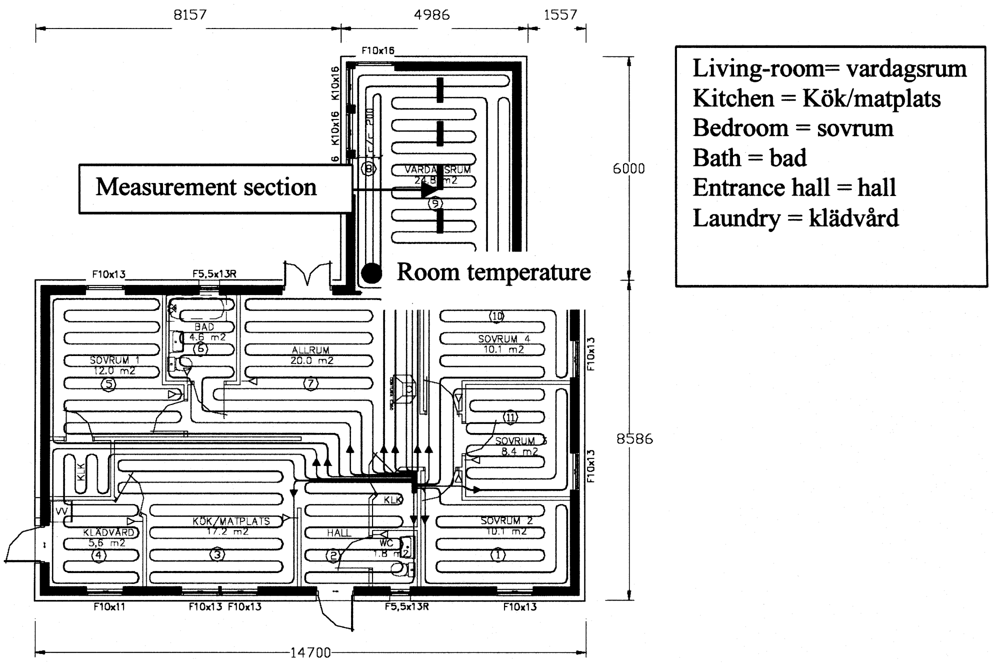

Figure 1 *The instruments are mounted in the middle of the living room. Indoor climate is measured 1.2 m above the floor. The moisture content, heat flow, and temperature are measured in the middle and at the edges of the slab (see Figure 2). (All lengths in mm.)*

reduces the moisture flow from the ground beneath the slab to the slab—an effect that is known as reverse moisture transport. In terms of life, it can be a good idea to use expanded polystyrene, while from the point of view of drying out it can be better to use mineral wool as the foundation insulation.

This paper is concerned with the occurrence of high moisture levels in the concrete slab under various conditions, particularly in the upper layers of the slab immediately beneath the plastic floor covering. It also describes investigation of the moisture distribution above and below the heating coil in order to see if there is any difference. The main emphasis of the work is concerned with steady-state conditions, and it does not consider the problem of possibly long drying-out times before steady-state conditions are achieved.

Both field measurements and theoretical simulations are described.

MEASUREMENTS

Measurements have been made in order to determine the moisture conditions in a slab-on-grade foundation in a single-family residential timber-frame house in Bromölla, in the south of Sweden (annual heating degree-days: 6900; compare with Minneapolis: 8310). The U-factor of the ceiling/loft space is 0.192 W/(m^2·K) from 400 mm of insulation, while that of the walls is 0.130 W/(m^2·K) from 240 mm of insulation. The floor insulation consists of 300 mm of expanded polystyrene beneath the center of the slab and 150 mm beneath the edges. The heating coils, using water as the heat carrier, are cast into a 100-mm-thick concrete screen, as shown in Figure 1.

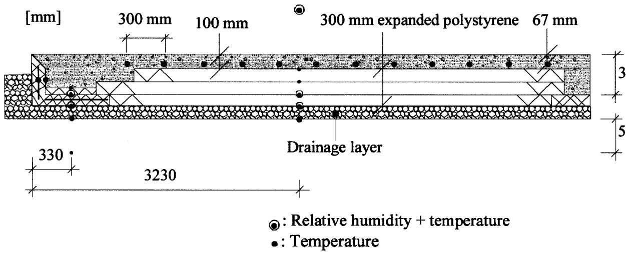

Figure 2 *Measurement points in the foundation.*

Measurements were made in the living room, an area not traversed by other services, such as water pipes, etc. (see Figure 1). The instruments were mounted in a vertical section in the middle of the slab.

The upper surface of the slab is covered by a fairly vapor-tight floor covering.

Heat flow is measured by a heat flow meter of cellular plastic and thermocouples. The temperature is measured by Pt 100 (platinum resistance) gauges, and the relative humidity is measured with a humidity transmitter with a capacitive sensor.

The outdoor and indoor climate were measured simultaneously (details are shown in an Appendix A).

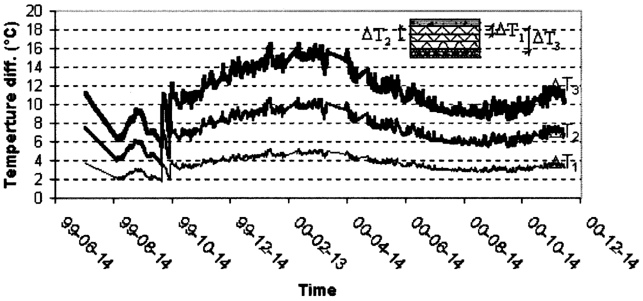

Figure 3 *The temperature difference between different layers in the middle of the slab.*

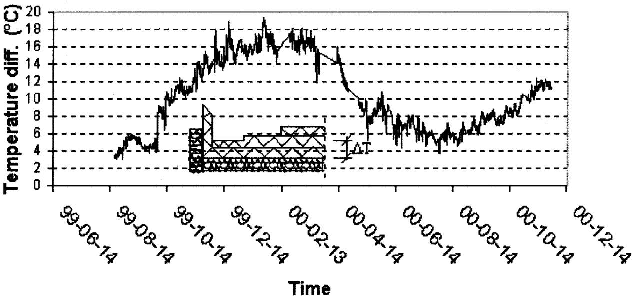

Figure 4 *The temperature differences at the edge of the slab.*

Measurements, Results, Discussion

The measurement results of the temperature difference across the insulation in the floor plan middle of the slab show that the difference is at least 8°C; see Figure 3 (ΔT_3). With such a high temperature difference, one can easily estimate the relative humidity in the concrete to be well below 70% (i.e., there is no risk of moisture damage in the slab).

At the edge, the temperature difference between the top and the bottom of the insulation is at least 4°C (see Figure 4, see ΔT). The risk of damage is bigger here but the concrete is thicker, and the moisture flow from the soil to the slab in the spring is probably slight, so that the risk of moisture damage could be considered low even in this area.

The measurements show that, for a slab with varying (between edge and middle section) insulation thicknesses, it is necessary to consider the risk of moisture damage in both the middle section and at the edge.

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.

The theoretical simulations were performed for a building 10 m wide. Temperature conditions 0,5 m below the foundation have been simulated using HEAT2 (Blomberg 1991), a two-dimensional computer program for different insulation thicknesses. All the simulations used actual measured temperatures in the coil and in the indoor air of the test house in Bromölla, coupled with ambient temperatures for 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 heating load of the house is unchanged.

The calculated temperature in the ground beneath the slab, the (measured) indoor temperature and relative humidity, and the (measured) coil temperature are used as the boundary conditions for the moisture calculations. The temperature variation in the coil during the year is based on the measured temperature in the test house. The temperature is a mean value based on several measurement points at the same level in the slab as the heating coil.

The curve is represented by a sine function as follows:

$$T_c = 24.5 + 2.5\sin(\omega \cdot t)°\mathrm{C}$$

where T_c is the mean water temperature in the coil.

The simulations assume that a layer of plastic floor covering (vapor resistance 8 ft^2 h in Hg/grain) has been applied directly to the upper surface of the concrete slab after a period of drying out. Using a computer program for the drying out of concrete (Hedenblad et al. 1998), the initial values for the moisture simulation were estimated as about 70 kg/m³ above the coil and 90 kg/m³ below it.

Theory

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

$$g = \delta_v \cdot \frac{\partial v}{\partial x}$$

where

g = moisture flow rate, kg/(m^{2}s),
δ_v = vapor permeability, m^2/s,
v = volumetric humidity, 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. Modeling 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 absorption

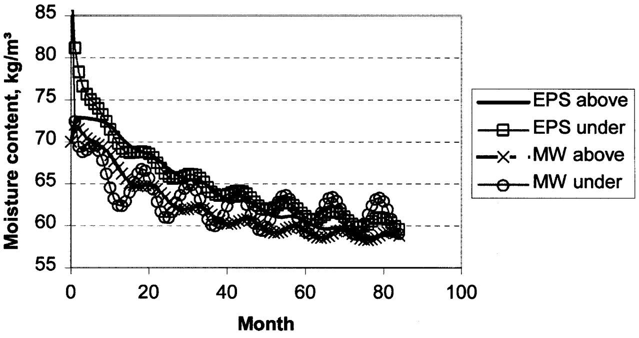

Figure 5 *The moisture content in the concrete slab during the drying-out phase. The diagram shows the moisture content above and below the heating coil for both mineral wool insulation (MW) and expanded polystyrene (EPS). The insulation thickness is 100 mm.*

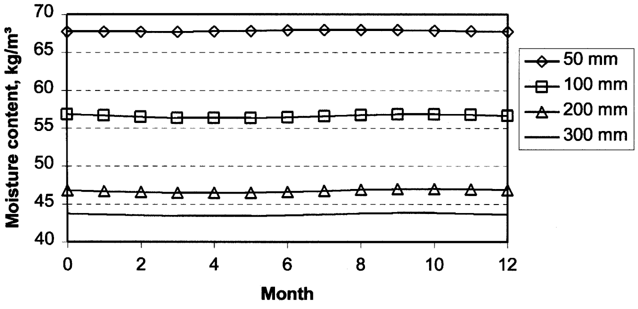

Figure 6 *The moisture content above the heating coil when using expanded polystyrene insulation.*

curves of the material have also been simplified to straight lines—material data used for the calculations are shown in Appendix B.

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

Case Studies

The steady-state moisture conditions in the slab depend on the thickness and properties of the thermal insulation and on the temperature conditions above and below the slab. The following parameters have been varied in the parameter study:

- The thickness of the thermal insulation: 50 to 300 mm
- The vapor permeability of the thermal insulation: mineral wool (24 higher vapor permeability than expanded polystyrene) and expanded polystyrene.

Theoretical Simulation, Results, Discussion

Figure 5 shows that 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.

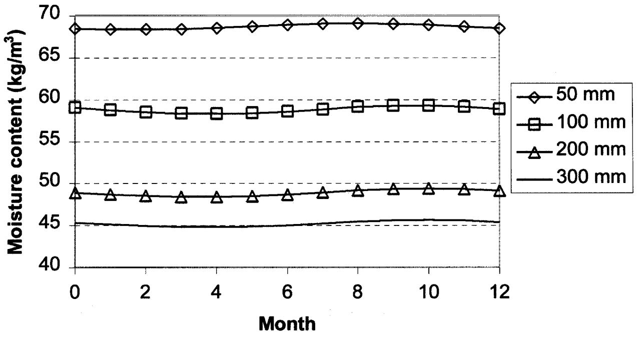

Figure 7 *The moisture content above the heating coil when using mineral wool insulation.*

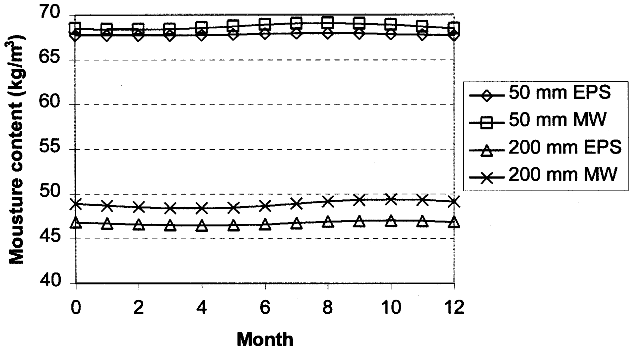

Figure 8 *The moisture content in the concrete above the heating coil for different thicknesses and types of insulation (MW = mineral wool, EPS = expanded polystyrene).*

In all cases, the equilibrium condition of the moisture content in the concrete above the heating coil is less than 70 kg/m^3, both for mineral wool and for expanded polystyrene, as can be seen in Figures 6 and 7. It can also be seen that, as the absorption curve of the concrete has been assumed to be linear between 0 and 100 kg/m^3, a moisture content of 70 kg/m^3 corresponds to a relative humidity in the concrete of 70%. Figure 8 shows that there is little difference in the moisture content of the concrete, whether mineral wool or expanded polystyrene insulation is used. As expected, the moisture content of the concrete is very low in well-insulated designs. It can be seen that 50 mm of insulation gives a moisture content of 70 kg/m^3, which probably does not result in any risk of moisture damage occurring underneath a plastic floor covering.

The moisture content in the concrete below the heating coil is more sensitive to the type of insulation. With mineral wool insulation, the moisture content varies more over the

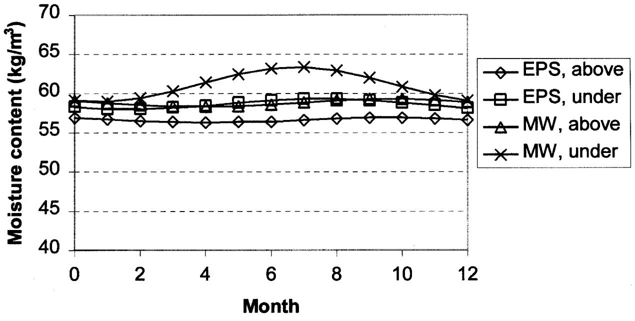

Figure 9 *The moisture content in the concrete slab above and below the coil, for both mineral wool (MW) and expanded polystyrene insulation (EPS). The insulation thickness is 100 mm.*

year, as can be seen in Figure 9. It can also be seen that the moisture content in the concrete above the heating coil is almost independent of the choice of insulating material.

Figure 10 shows how the temperature difference across the insulation varied in thickness. It can be seen that the difference decreases with increasing insulation thickness, and that the temperature difference between 100 mm and 200 mm of insulation is greater than that between 200 mm and 300 mm thickness. This was expected, as there is a greater reduction in heat flow between 100 mm and 200 mm than between 200 mm and 300 mm—in other words, the law of diminishing returns applies.

Figure 11 shows the vapor concentration gradient (i.e., the driving force for diffusion) at the underside of the 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 vapor resistance between the two types of insulation. (The calculations have assumed a factor of 24 in the difference.) It can also be seen that the vapor 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.

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 vapor-tight plastic sheet. The mean value of the moisture content gradient over the year is negative for both materials, which therefore means that there is a net moisture transport to the indoor air.

All the simulations have been made for a given temperature in the heating coil. In practice, the coil temperature varies with the heat demand of the house and the desired indoor temperature. Calculations with different coil temperatures have shown that the relative humidity in the concrete above the coil changes at about five percentage points per °C (i.e., if the coil temperature is reduced by 1°C, the relative humidity

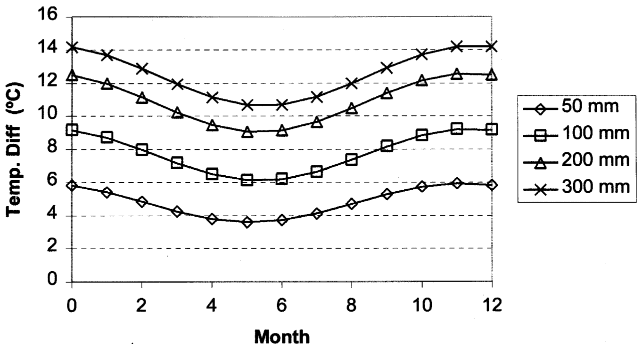

Figure 10 *Temperature differences across the insulation with varied thicknesses.*

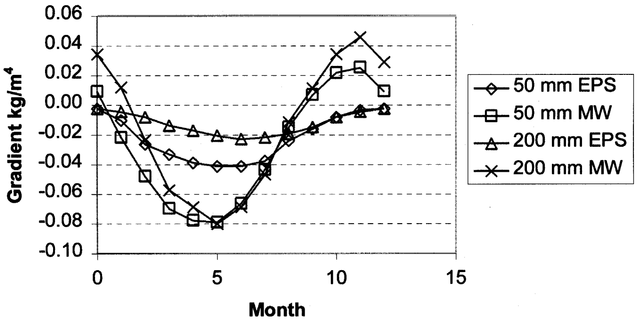

Figure 11 *The vapor concentration gradient at the underside of the slab for different types and thicknesses of insulation.*

of the upper surface of the concrete under the floor covering will increase by five percentage points).

In summarizing, 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 on 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 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—for example, if the coil temperature is reduced—the relative humidity at the upper side of the concrete increased by about five percentage points per degree Celsius.

CONCLUSIONS

Measurements and analysis of the results from the house in Bromölla have shown that there is no risk of moisture damage in a slab-on-grade foundation. It can also be seen that it is not only the conditions at the center of the slab (which are normally regarded as the design conditions) that must be considered, but also those around the edge of the slab, under the grade beam. This is because the type of insulation and the insulation thickness in this area differ from conditions under the rest of the slab.

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 with respect to 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.

ACKNOWLEDGMENTS

This paper is a result of the project on “Heat loss to the ground from a slab-on-grade foundation with floor heating” (Värmeförluster från en grund som utföres med golvvärme). The project has been financed by the Swedish Foundation for Knowledge and Competence Development, by the Plastic- and Chemicals Federation, and by the Swedish Council for Building Research.

REFERENCES

Blomberg, T. 1991. *Manual for Heat2*. Lund: Department of Building Physics. TVBH-7122.

Elmarsson, B. 1992. *Building aspect of floor heating (in Swedish).* LUTVDG/(TVBH-7134)1-98/(1992). Lund.

Hedenblad, G., et al. 1998. Torkas PC program. Lund: Institute of Building Technology, Lund Institute of Technology.

Nilsson, L.O., and A.C. Andersson. 1981. *Floor heating in a slab, analyses of moisture content and temperature calculations* (in Swedish) (Golvvärme i betonggolv, temperaturberäkningar, analys av fuktbalansen). Lund: Department of Building Materials, Lund Institute of Technology. LUTVDG/(TVBM –7002), ISSN 0348-7911.

Johansson, A. 2000. F*loor heating in a concrete slab on the grade* (in Swedish). Report R-00:7. Gothenburg: Institute of Building Physics, Chalmers University of Technology.

APPENDIX A

MEASURED TEMPERATURES

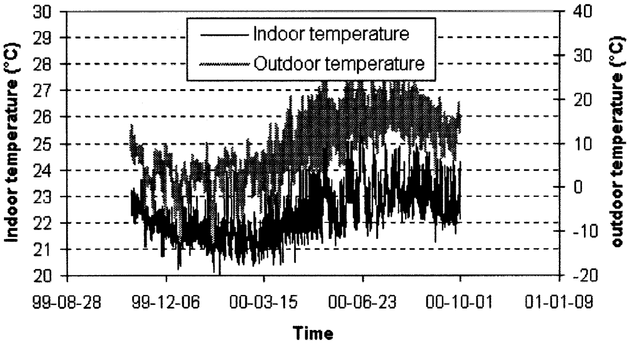

Figure A1 *Measured indoor and outdoor temperatures in the Bromölla house.*

APPENDIX B

MATERIAL DATA

The properties of the materials in the investigation are shown in the table below. Most of them are given in CEN 12524 and ISO 10456. The sorption isotherm is assumed to be linear.

Table B1

Material	Thermal conductivity, W(mK)	Thermal capacity, Ws/(m^{3}K)	Vapor permeability, m^2/s	Relative humidity
Concrete	$2,0 \cdot e^{0,004 \cdot w}$	$(2000 + 4,2 \cdot w) \cdot 10^3$	$RH < 0,9$ $\delta_v = \frac{0,5}{0,9} \cdot RH \cdot 10^{-6}$ $RH > 0,9$ $\delta_v = \left(0,5 + \frac{9,5}{0,1} \cdot (RH - (0,9))\right) \cdot 10^{-6}$	$w < 100\colon RH = \frac{w}{100}$ $w > 100\colon RH = 1,0$
Expanded polystyrene	$0,039 \cdot e^{0,004 \cdot w}$	$(56 + 4,2 \cdot w) \cdot 10^3$	$0,5 \cdot 10^{-6}$	$w < 1\colon RH = \frac{w}{1}$ $w > 1\colon RH = 1,0$

Table B1 (Continued)

Mineral wool	$0,039 \cdot e^{0,004 \cdot w}$	$(56 + 4,2 \cdot w) \cdot 10^{3}$	$12 \cdot 10^{-6}$	$w < 1: RH = \frac{w}{1}$ $w > 1: RH = 1,0$
Drainage	2,0	$2000 \cdot 10^{3}$	$10 \cdot 10^{-6}$	$w < 10: RH = \frac{w}{10}$ $w > 10: RH = 1,0$
Soil	1,5	$3000 \cdot 10^{3}$	$2 \cdot 10^{-6}$	$w > 0: RH = 1,0$