Heat Loss Due to Thermal Bridges in a Foundation with Floor Heating

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ABSTRACT

This paper provides an overview of the heat losses through the thermal bridge in the junction between a wall and a slab on grade at the perimeter of the foundation. First, the paper discusses the heat losses through the thermal bridge. In particular, the additional heat loss through the thermal bridge due to floor heating. In addition, the paper provides a thorough description of the total heat loss through the thermal bridge in the junction slab on grade and the wall. The result may be used in order to calculate the heat loss through the building envelope of a building.

INTRODUCTION

In order to minimize the heat loss at the perimeter of a foundation of the type slab on grade, the heat loss through thermal bridges must be taken into account. In international heat loss calculation standards the thermal bridge effect is taken into account.

Several authors have looked into the heat losses to the ground and the effect of perimeter insulation for the case of regular slab-on-grade foundations without floor heating, such as; (Hagentoft 1988,1991,2002) (Claesson et. al. 1991), (Anderson 1991,1993), (Krarti et al, 1993) (Meng, 1995)and (Thomas et al 1996). Heat losses from floor heated slabs has recently been studied by (Weitzman, 2004) and (Rantala, 2005). However, very little has been done in the analysis of the combination of floor heating and thermal bridges.

In calculation of the perimeter heat loss, the thermal interaction between the foundation and the wall is very often neglected. The assumption of a fictitious adiabatic surface at the interface is often made. This assumption will underestimate the heat loss for a regular foundation without floor heating. For a slab with floor heating installed, this simplification will probably be even more severe.

This paper presents an analysis for how to estimate these additional heat losses. As a starting point the procedure in the ISO 13370 standard is used.

HEAT LOSS THROUGH THE SLAB

Heat loss through the thermal bridge at the edge beam of a slab on grade can be calculated using the theoretical model presented in the ISO-13770 standard. However, the standard does not account for floor heating. The first base U-value is calculated assuming a simplified foundation design with no thermal interaction between the wall and the slab. Basically the foundation design, for the base case, is thermally restricted to a surface resistance on a semi-infinite ground. With an additional calculation, in some cases by using formulas but normally from numerical analysis, the perimeter heat loss due to the actual edge beam design can be accounted for by a linear thermal transmittance factor, the so called ψ_g-value. This factor may as well account for the interaction between the foundation and the wall. However, in this paper it does not.

In the analysis, the characteristic dimension of the floor, B', is used. This allow for the three-dimensional nature of heat flow to the ground. This width is defined as the area of the floor divided by half the perimeter length:

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$$B' = \frac{A}{P/2} \tag{1}$$

where

U_0 = U-value of the floor construction with no heat loss at the edge beam

B' = Characteristic length

P = Perimeter of the slab

For an infinitely long floor *B'* is the same as the width of the floor. In the figures and in the elementary cases below, a cross-section of an infinitely long floor with half the characteristic dimension is presented. This will cover the floor construction from the edge beam to the symmetry plane in the middle of the building.

The principle of superposition will be used in order to abstract the extra perimeter steady-state heat loss. The thermal process in the foundation is divided into two cases as illustrated in Figure 1. In Case I the heating power to the pipes is zero, corresponding to a slab without floor heating. This case is also accounting for the temperature difference between the interior and the exterior. The heat loss is denoted Q_g.

For Case II the boundary temperatures are set to zero and the heating power to the heat pipe is Q_{pipe}. The heat loss, $Q_{g,fh}$, accounts for the floor heating losses.

In Roots, 1998, the global performance factor, η_g, is introduced. It gives the relation between released heat to the interior air in relation to the total heating power:

$$Q_{g,fh} = (1 - \eta_g) \cdot Q_{pipe} \tag{2}$$

where

η_g = Global performance factor

$Q_{g,fh}$ = The heat loss from the floor heating system

Q_{pipe} = The heating power

The total heat loss, Q_g, tot, reads:

$$Q_{g,tot} = Q_g + Q_{g,fh} = Q_g + (1 - \eta_g) \cdot Q_{pipe} \tag{3}$$

where

Q_g = The heat loss from a slab without floor heating

The thermal transmittance for a slab on grade, without floor heating, is obtained from the ISO- 13770 standard:

$$U = U_0 + \frac{2 \cdot \psi_g}{B'} \tag{4}$$

where

U_0 = U-value of the floor construction with no heat loss at the edge beam

B' = Characteristic length

ψ_g = Line heat loss at the edge beam

The heat loss, Q_g, for the case without floor heating, accounting for the actual beam design becomes:

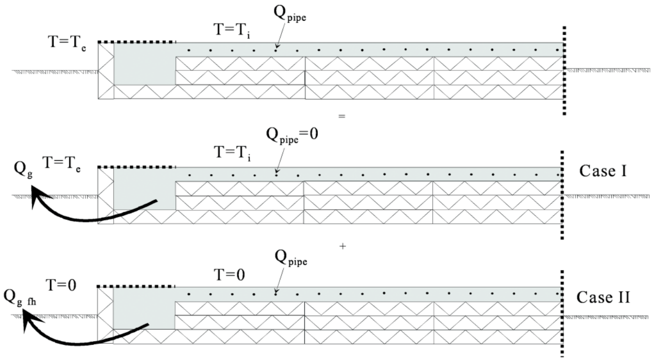

Figure 1 *Superposition of a slab on grade with and without floor heating. The dashed lines at the perimeter denote adiabatic surfaces, i.e. no heat flow passes these surfaces.*

$$Q_g = \left(U_0 + \frac{2 \cdot \psi_g}{B'}\right) \cdot A \cdot (T_i - T_e \tag{5}$$

where

A = Inner area of slab

T_i = Interior air temperature

T_e = Exterior air temperature

Additional Heat Loss Due to Floor Heating — Influence of Wall Neglected

In the analysis of case II, we will first abstract the extra heat loss due to the general warming-up of the whole slab due to the heating, neglecting effect of the edge beam design. The case II,0, see Figure 2, corresponds to the base case (denoted with a 0-indices) in the ISO-standard. The heat loss is denoted by $Q_{0,fh}$.

Introducing a dimensionless performance factor ${}_0$, that gives the released heat to the interior air, we get:

$$Q_{0,fh} = (1 - \eta_0) \cdot Q_{pipe} \tag{6}$$

where

η_0 = Global performance factor in the case with adiabatic surfaces at the edge beam

The total heat loss $Q_{g,fh}$, due to the floor heating is obtained from the sum of the heat loss from the basic case (Case II,0) and an additional one:

$$Q_{g,fh} = Q_{0,fh} + \Delta Q_{g,fh} \tag{7}$$

where

$Q_{0,fh}$ = Heat loss in the case of adiabatic surfaces at the edge beam

$\Delta Q_{g,fh}$ = Additional heat loss through the edge beam in the case of floor heating

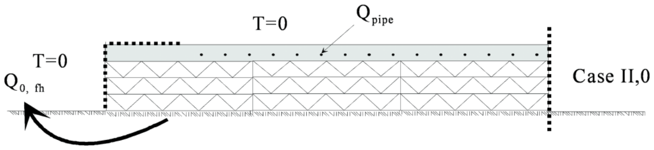

Figure 2 *The first estimate of heat loss, $Q_{0,fh}$, due to the floor heating, neglecting the actual edge beam design.The dashed lines at the perimeter denote adiabatic surfaces, i.e. no heat flow passes these surfaces.*

The first term on the right hand side represents the heat loss for the case without heat loss through the edge beam. The second term represents the heat loss though the edge beam. We define a correction term, $\Delta\eta_g$, for the performance factor. The extra heat loss from the floor heating system reads:

$$\Delta Q_{g,fh} = \Delta\eta_g \cdot Q_{pipe} \qquad (8)$$

where

$\Delta\eta_g$ = Correction term due to heat loss through the edge beam in the case of floor heating

The total extra heat loss due to the floor heating is the sum of the heat loss from the base case and the heat loss at the edge beam:

$$Q_{g,fh} = ((1-\eta_0)+\Delta\eta_g) \cdot Q_{pipe} \qquad (9)$$

or

$$Q_{g,fh} = (1-\eta_g) \cdot Q_{pipe} \qquad (10)$$

where

$$\eta_g = \eta_0 - \Delta\eta_g \qquad (11)$$

The total heat loss to the ground below the slab can then be written as:

$$\begin{aligned} Q_{g,tot} &= \left(U_0 + \frac{2 \cdot \psi_g}{B'}\right) \cdot A \cdot (T_i - T_e) \\ &+ ((1-\eta_0)+\Delta\eta_g) \cdot Q_{pipe} \end{aligned} \qquad (12)$$

For the floor heating system, the global performance factor, η_0, is very important when estimating the heat loss. It can be calculated by using following approximation, Roots, 1998:

$$\eta_0 = 1 - U_0 \cdot R_{in} \qquad (13)$$

where R_{in} is the thermal resistance between the centre of the pipe and the interior air.

Additional Total Heat Loss

For a real construction, heat will flow up into the wall as well. Part of the heat will flow back into the building and part of it will represent losses. Figure 3 illustrates the thermal process and it will have an influence on the performance factor.

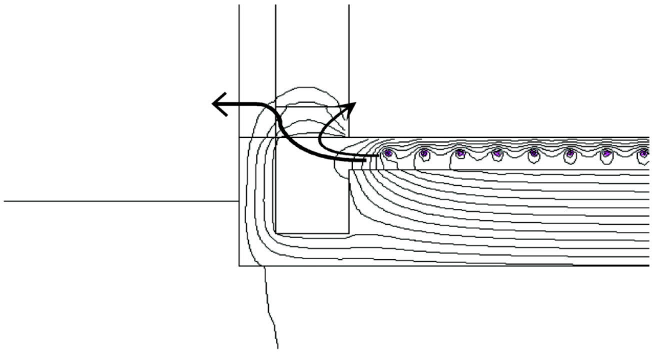

Figure 3 *Simulated (Blomberg, 1991) isotherms in a slab on grade with floor heating. Heat is transferred both back to the building and out through the wall.*

A similar analysis as in the previous section can be done in order to estimate the joint influence of the heat flow up to the wall and the real edge beam design.

The total extra heat loss due to the floor heating then becomes:

$$Q_{g,fh} = ((1-\eta_0)+\Delta\eta) \cdot Q_{pipe} \qquad (14)$$

The corrections term, $\Delta\eta_g$, is the sum for the heat loss through the edge beam, $\Delta\eta_g$, and the wall, $\Delta\eta_w$:

$$\Delta\eta = \Delta\eta_g + \Delta\eta_w \qquad (15)$$

where

$\Delta\eta_w$ = Correction term due to heat loss through the wall in the case with floor heating.

The $\Delta\eta$ factor is calculated as the difference between the heat loss for Case II, in Figure 1, and the Case II,0 in Figure 2. Both the real wall and edge beam design is accounted for. The total heat loss becomes:

$$\begin{aligned} Q_{g,tot} &= \left(U_0 + \frac{2 \cdot \psi_g}{B'}\right) \cdot A \cdot (T_i - T_e) \\ &+ ((1-\eta_0)+\Delta\eta) \cdot Q_{pipe} \end{aligned} \qquad (16)$$

CASE STUDIES AND DISCUSSION

A modern Swedish slab on the grade with floor heating will be used in these case studies. The reference slab, the base case, is presented in Figure 4.

Data used in the simulations:

- The insulation thickness, d_{iso}, is varying between 0.1 - 0.3m.
- The space between the heat pipes, c, is varying between 0.1 - 0.3m.
- The thermal conductivity of the soil = 2.0 W/mK.

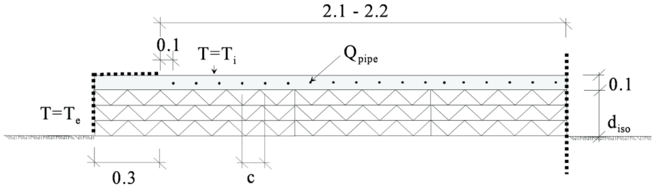

Figure 4 *The slab on grade with adiabatic surfaces. The insulation thickness below the slab is denoted d_{iso} and the space between the heat pipes is denoted c. The inner width is varying between 2.1-2.2m. In the case with the space between the pipes equal to 0.3m the inner width is 2.2m. In all other cases it is 2.1m. The dashed lines at the perimeter denote adiabatic surfaces, i.e. no heat flow passes these surfaces.*

- The thermal conductivity of the concrete = 1.7 W/mK.
- The thermal conductivity of wood = 0.14 W/mK.
- The thermal conductivity of the thermal insulation = 0.04 W/mK.
- The thermal resistance at the inside surface = $0.13 m^2 K/W$
- The thermal resistance at the outside surface = $0.04 m^2 K/W$
- Diameter of heat pipe = 0.012m.

Accounting for the Edge Beam Design — Neglecting the Influence of the Wall

The considered slab is illustrated in Figure 5. The inner width is about 2m. The variation depends on the space between the heat pipes, which are mounted in the centre of the concrete slab.

The performance factor $\Delta\eta_g$. represents the influence of the floor heating and edge beam interaction. It has a small influence on the heat loss when the insulation thickness is varying as shown in Figure 6. The heat loss through the edge beam is less than 1% of the total heat power to the heat pipes.

When the insulation thickness increases, the heat loss from the central part downwards will decrease and the slab will be warmer. Since the edge beam insulation is constant in the simulations, and at the same time the slab becomes in general warmer, the heat loss through the edge beam will increase with insulation thickness d_{iso}.

With increasing space between the heat pipes, the edge loss will increase as shown in Figure 7. The heating power is evenly distributed to the pipes in the simulations. With larger space between the pipes, a relative larger part of the heating power is released from the pipe closest to the edge beam, which has a constant distance of 0.1m to the exterior wall. Hence, the edge beam heat loss will increase with increasing distance between the heating pipes.

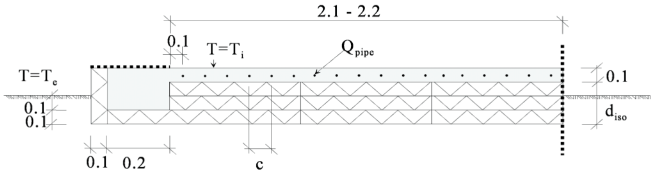

Figure 5 *Considered slab construction, neglecting the wall. The insulation thickness below the slab is denoted d_{iso}. The space between the heat pipes is denoted c. The inner width, $B'/2$ to the symmetry line is varying between 2.1-2.2m. In the case with the space between the pipes equal to 0.3m the inner width is 2.2m. In all other cases it is 2.1m. The dashed lines at the perimeter denote adiabatic surfaces, i.e. no heat flow passes these surfaces.*

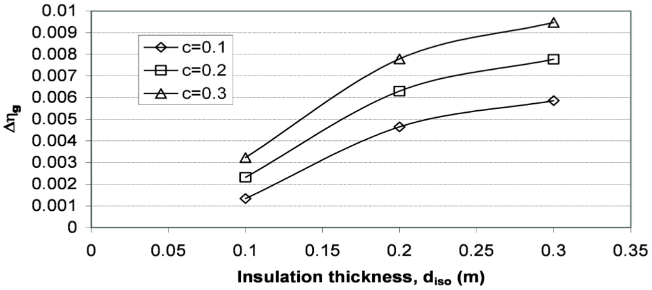

Figure 6 *Variation of the performance factor, $\Delta\eta_g$, as a function of the insulation thickness.*

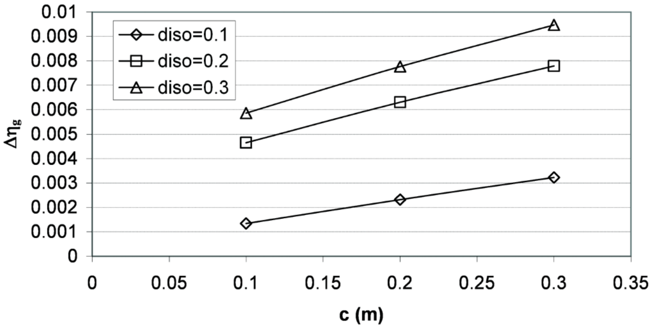

Figure 7 *Variation of the performance factor, $\Delta\eta_g$, as a function of the space, c, between the heat pipes.*

The heat loss through the edge beam is a function of several parameters and one of them is the insulation thickness. When the insulation thickness increases the heat loss through the edge beam will become a larger part of the total heat loss, which can be seen in Figure 8.

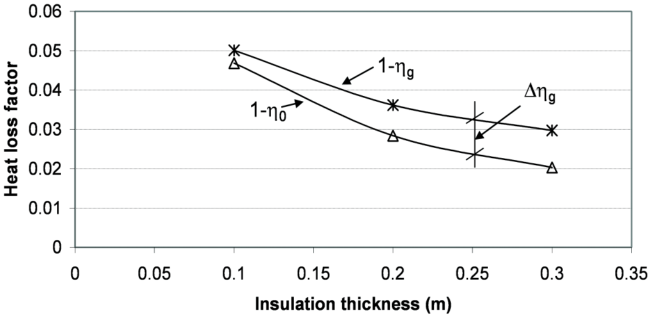

Figure 8 *Variation of the heat loss factors as a function of the insulation thickness. The space, c, between the heat pipes is 0.3m.*

The results indicate that the insulation thickness below the slab and the space between the pipes has a minor influence on the heat loss through the edge beam.

Accounting for Both the Wall and the Edge Beam Design

In this section the thermal interaction with an exterior wall is investigated. The studied design is illustrated in Figure 9 with a sill mounted at the bottom of the wall

The increase in heat loss, due to the wall and the edge beam, caused by the floor heating system, is given by the factor $\Delta\eta$. The simulation results show that the heat loss is less than 2%, see Figure 10.

Figure 11 shows the variation of the $\Delta\eta$ factor as a function of the space, c, between the heat pipes.

The difference between the $\Delta\eta$ -factor and the $\Delta\eta_g$ -factor gives the influence of the wall interaction, i.e. the $\Delta\eta_w$ –factor, see (15). By combining the previous results it can be shown that the wall will increase the heat loss with less than an extra 0.6% as shown in Figure 12.

Figure 13 shows the performance factors (1-) representing the heat losses from the floor heating both accounting for and neglecting the edge beam and wall design. The interaction with the wall seems to have a rather constant influence on the heat loss, while increase in the edge beam losses increases with insulation thickness of the slab.

In all considered cases, the heat loss through the edge beam is rather low, less than 1.5% of the total heat power to the floor heating system. However, it is important to reduce the energy loss. New designs of slab can reduce the heat loss through the edge beam and the wall.

It should be noted that the presented results do not cover all types of slab on grade. The results are only valid for a modern Swedish slab on grade. Other results may be achieved for another design of the foundation and small changes may lead to another result. The thermal resistance of the floor covering is for instance an important parameter. The heat loss from the pipes, and through the edge beam, will increase with increasing thermal resistance of the floor covering.

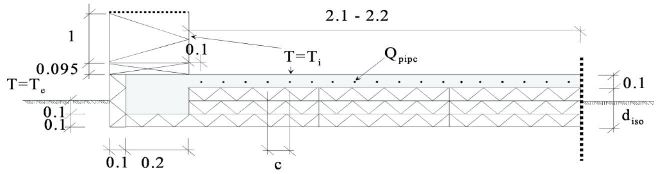

Figure 9 *The slab used in the simulation of the heat loss through the edge beam in the case with a wall.*

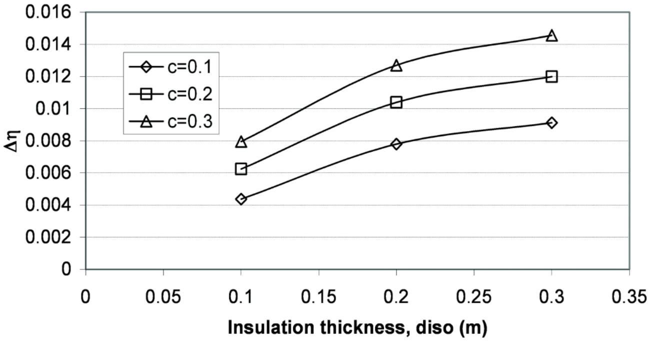

Figure 10 *Variation of the* $\Delta\eta$ *factor as a function of the space, c, between the heat pipes.*

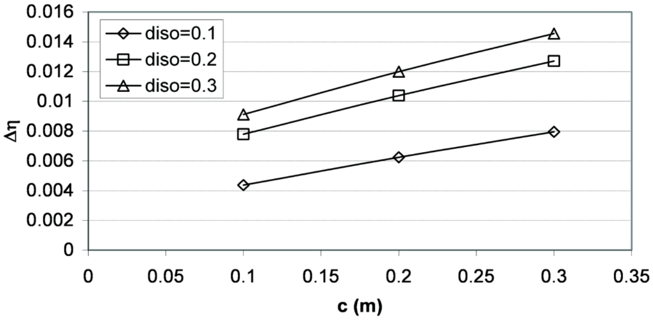

Figure 11 *Variation of the* $\Delta\eta$ *factor as a function of the space, c, between the heat pipes.*

CONCLUSION

When calculating the heat loss from a slab on grade to the ground, according to ISO-standard, the extra heat loss due to a floor heating system is not included. A theoretical model has been developed in order to determine this extra heat loss.

The results show that the heat pipes have an influence on the heat loss. The magnitude of the influence depends strongly on the design of the foundations. The heat loss through the junction between the wall and the slab has a minor influence for the studied cases.

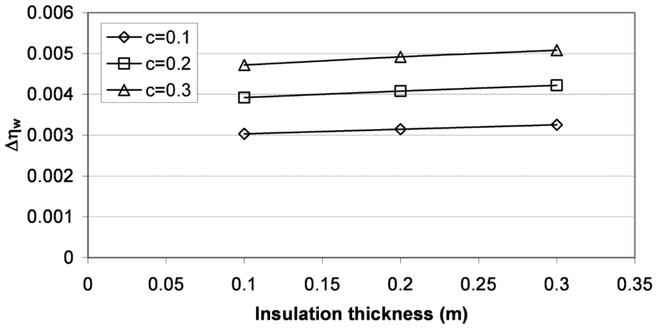

Figure 12 The $\Delta\eta_w$-factor as a function of the insulation thickness.

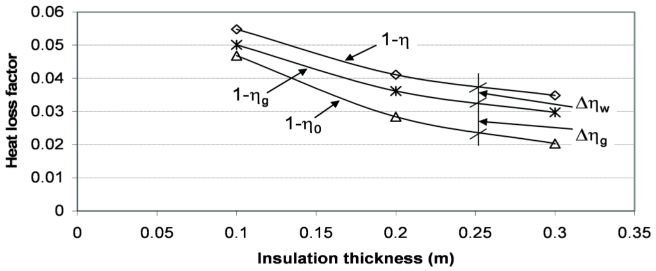

Figure 13 The heat loss factors as a function of the insulation thickness.The space between the pipes is 0.3m.

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