Effectiveness of Beaver Plastics' INSULWORKS insulation system used below radiant floor slabs

For:
Beaver Plastics
Edmonton, Alberta, Canada

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April 2000

Introduction

Beaver Plastics produces an expanded polystyrene (EPS) foam insulation board, named INSULWORKS, for use below concrete slabs with radiant hydronic heating systems. The foam is preformed in such a way as to allow easy fixing of the hydronic tubing.

Beaver Plastics has noted market resistance to the use of insulation below concrete slabs because the existing research suggests that little or no insulation is required in this location for energy savings. However, there is no existing research into floor slabs that contain a heat source, such as radiant floor heating. Also, in many cases slabs are placed over wet soils (i.e., highly conductive) or even over high water tables (very high capacity heat sinks).

Despite the perceived benefits of underslab insulation in hydronic heating applications, the potential benefits have not been studied or documented. Beaver Plastics requested that John Straube Building Envelope Engineering conduct a series of computer simulations to document the size of the energy savings from using below slab insulation in hydronically heated slabs.

Objectives and Scope

The objective of the proposed work is to estimate and demonstrate the magnitude of the energy savings from using insulation below concrete slabs on grade with radiant heating.

There are hundreds of possible combinations of insulation, soil type, and building configuration. To provide a reasonable scope, the number of situations has been restricted to the most practical and likely combinations.

The study used the two-dimensional dynamic heat flow simulation software package Heat2D. This simulation program allows one to model the heat delivered to the slab by the individual radiant floor tubes. It also accounts for the ability of the soil and foundation materials to store heat (termed thermal mass or heat capacity). Different floor finishes (e.g., carpet or wood flooring) can also be accurately modelled. These features of the dynamic simulation program allow for accurate and realistic results.

Program Outline

A series of simulations were conducted which modeled the two most common foundation/basement situations, a range of insulation values, and a range of soil properties.

Each model considered a house 8 meters wide and infinitely long. Narrower basements will have slightly higher heat loss, and wider basements will have slightly less heat loss. Three-dimensional effects at corners also tend to increase heat loss somewhat. These additional losses can be easily quantified but were not included in the limited scope of this work.

The two basement foundation systems considered are shown in Figure 1 as a function of the location of the heated slab. Additional important construction variables include the amount of sub-slab insulation (either 2” of INSULWORKS or none) and the amount of insulation on the wall (2” of exterior EPS (R8) or R12 interior stud wall with batt insulation.

Typical finishes over radiantly heated concrete floor slabs range from ceramic tiles (practically no thermal resistance) to deep pile carpet (high thermal resistance). The more thermally insulating the floor finish, the higher temperature that the slab must be heated to deliver sufficient heat into the house. The hotter the slab is operated, the more heat lost to the soil. The thermal resistance of a ¾” wood floor (approximately RSI0.18) as the slab floor covering was used for all simulations. Wood flooring is both a common finish over radiant slabs and its thermal resistance falls in the middle of the range of values for finishes. An interior basement wall finish of ½” drywall was assumed for all basement cases.

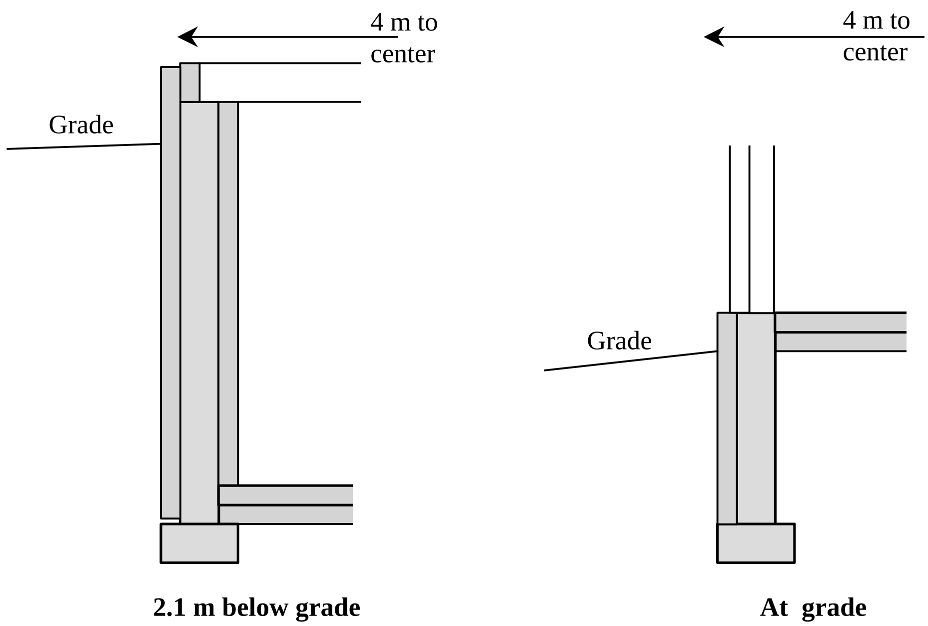

Figure 1: Slab Locations Considered

Three different soil types have been considered and are listed in Table 1. The thermal conductivity and volumetric heat capacity for each type of soil has also been adjusted to account for the different densities and moisture contents.

Soil Description	**Conductivity (W/mK)**	**Heat Capacity (MJ/m3 K)**
Dry Sandy Loam	0.70	1.50
Moist Clay	1.50	1.65
Wet Sand	2.30	1.80

Table 1: Soil Properties

The outdoor temperature has been assumed to vary in a manner representative of a moderately cold climate. The peak summer temperature was fixed at 20 °C and the minimum winter average at –10 °C. The monthly average temperatures of Toronto and Calgary have been plotted alongside the simulated climate in Figure 2. The interior temperature also was assumed to vary sinusoidally, from a minimum of 20 °C on January 21st to a maximum of 24 °C on July 21st. Note that these values are averages for periods of about a week. Short-term variations will have little effect on the results since these variations are damped by the very high thermal storage capacity of the soil.

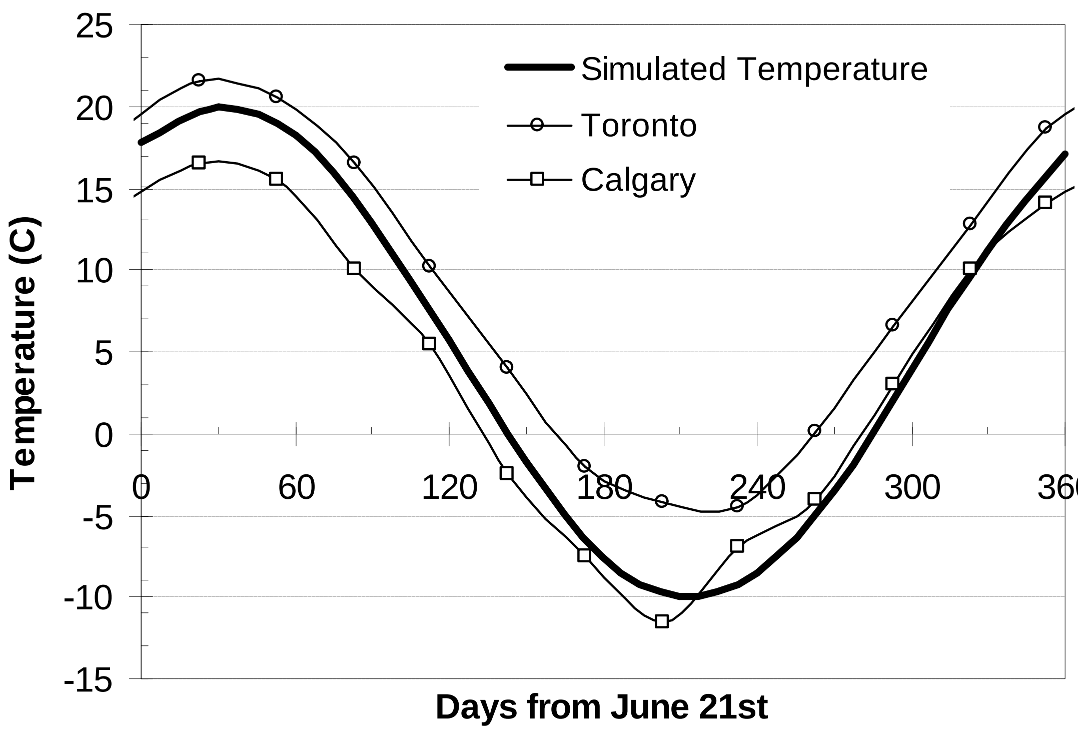

Figure 2: Interior and Exterior Temperature Conditions Assumed

It has been assumed that the slab will be heated from late October through to late March with a heat source strong enough to maintain a well-insulated house at proper temperatures. A peak heat flux of 40 W/m^2 on January 21 was chosen, and the flux decreased sinusoidally (much like the exterior temperature) during other times (Figure 3). The total annual amount of heat energy delivered to the house interior was maintained at about 130 kWh/m^2. Houses with poor insulation or excessive air leakage would require a higher heat flux and thus higher slab temperature to maintain interior temperatures, and hence heat losses to the soil would also be higher.

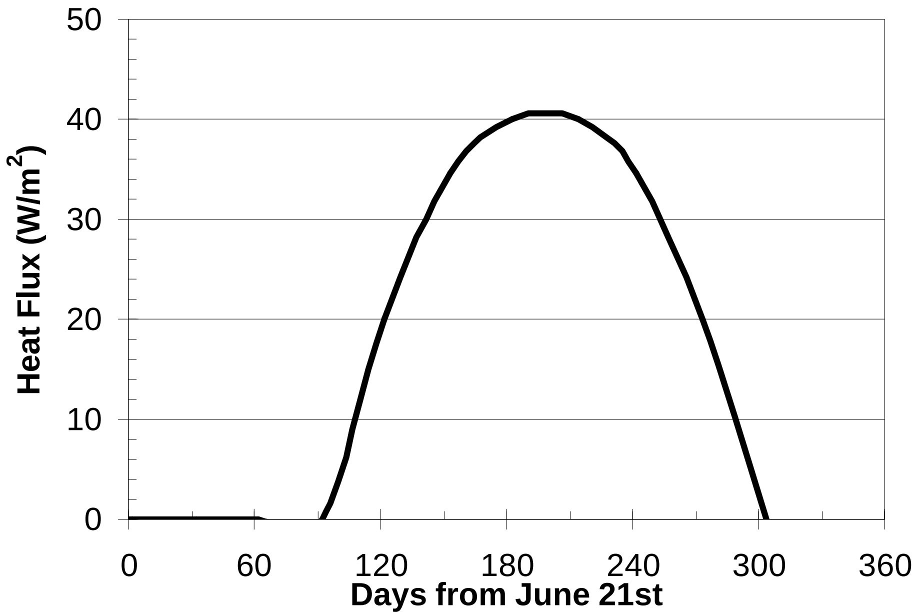

Figure 3: Assumed Radiant Slab Heat Flux

The table below summarizes the range of variables considered in the research program. These variables result in a total of 24 possible simulations.

Sub-slab Insulation	None and 2” INSULWORKS
Slab location	At Grade and 2.1 m below
Soil Conductivity, k	0.7, 1.5, 2.3 W/m•K
Foundation Wall Insulation	2” EPS exterior and interior RSI 2.1 batt

Table 2: Summary of Simulation Variables

As has been found by others, the heat flow situation below grade requires approximately 3 to 5 years to stabilize from a uniform temperature start. Based on our preliminary simulation runs, the fifth heating season was chosen as the comparison period. All simulations began with a uniform temperature of 5 °C on April 21st.

The simulation was conducted over a domain 20 m below grade, 0.3 m above grade and a total of 24 m width. Because symmetry was assumed only half of the basement (e.g., from the center-line of the house) was modeled. Therefore the results are valid for an 8 m wide basement with 20 m (24 m less the 4 m basement width) of soil on each side.

Results

Figures 4 through 7 provide snap shots of part of the result of the computer model (about 10 m wide and 6 m deep) at a specific time of the year, either Feb 21 or Aug 21. The black isotherm lines provide a map of the temperatures, as do the colours (see the colour legend next to the figures). The arrows show the direction and relative magnitude of the heat flow. The model is of exactly half of a basement, meaning that the mirror image could be attached to the right side of the diagram to make a whole basement. The examples are all of a full basement situation, a moderately well insulated house, and a conductive soil type (i.e., wet sand). Hence, these graphical representations demonstrate the greatest heat loss of all the full basement simulations conducted.

Figure 4 presents the temperatures and heat flux during August around a basement with 2” of EPS foam below the slab. The warm air temperatures and warm house temperatures at this time of year are heating the soil. Note that there is heat loss to the ground all year long (i.e. the soil temperatures never reach the indoor air temperature).

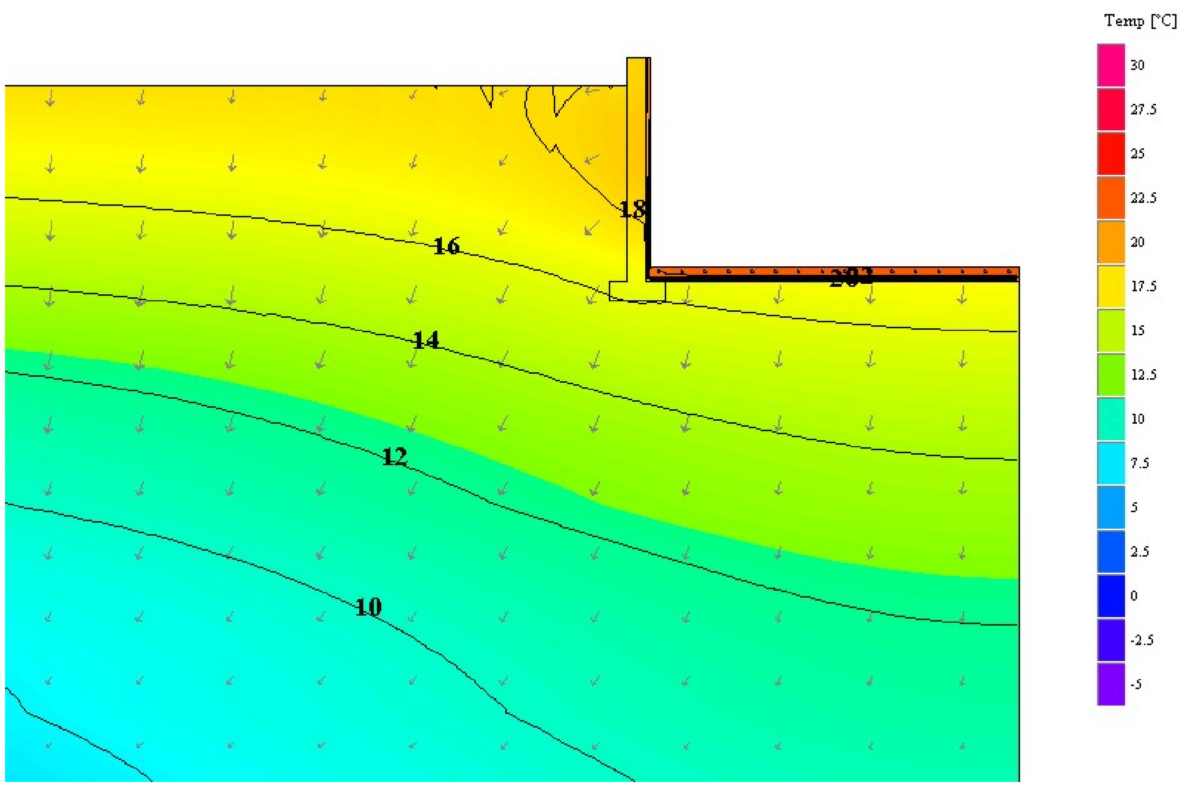

Figure 4: Insulated Slab in August

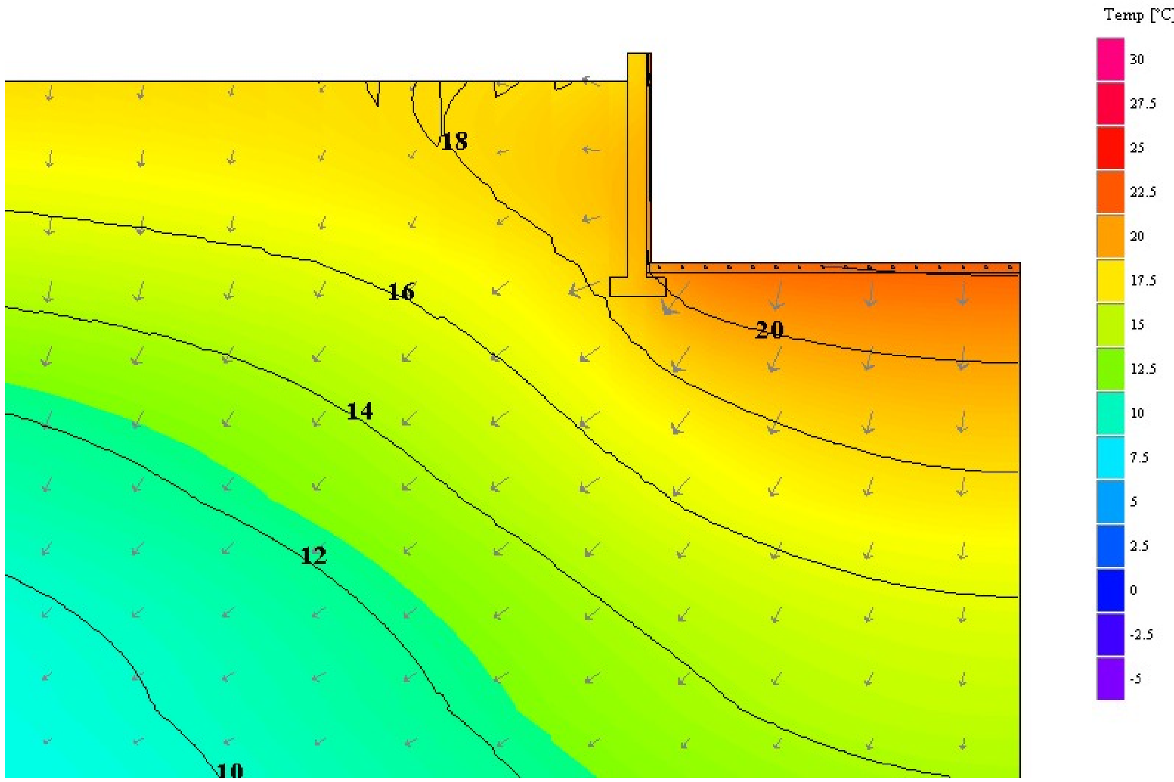

Figure 5: Uninsulated Slab in August

For comparison the same model has been run without insulation below the slab. The summer condition (Figures 5) shows that the soil temperatures below the slab are much warmer than in the case with sub-slab insulation. Heat is flowing at a much greater rate from the house into the soil. The winter condition (Figures 6 and 7) shows the largest difference however. The soil is much warmer below the slab, and the heat flow arrows are longer, indicating larger flows. The difference in heat flow is very significant.

Figure 7 is a plot of the uninsulated basement in February. The slab is very hot (over 30 °C) at this time of year since a significant amount of heating is required. What is striking is the classic circular heat flow pattern – heat from the middle of the slab (the right edge of the diagram) flows in a circular arc towards the outdoors. (The heat flow through the basement wall also adds to the heat loss from the house). It can also be seen that the soil is frozen to a depth of 2 m far from the house (the left side) but only 1.2 m at the foundation wall. The large arrow at the footing indicates that a significant amount of heat is flowing out of the house at this location.

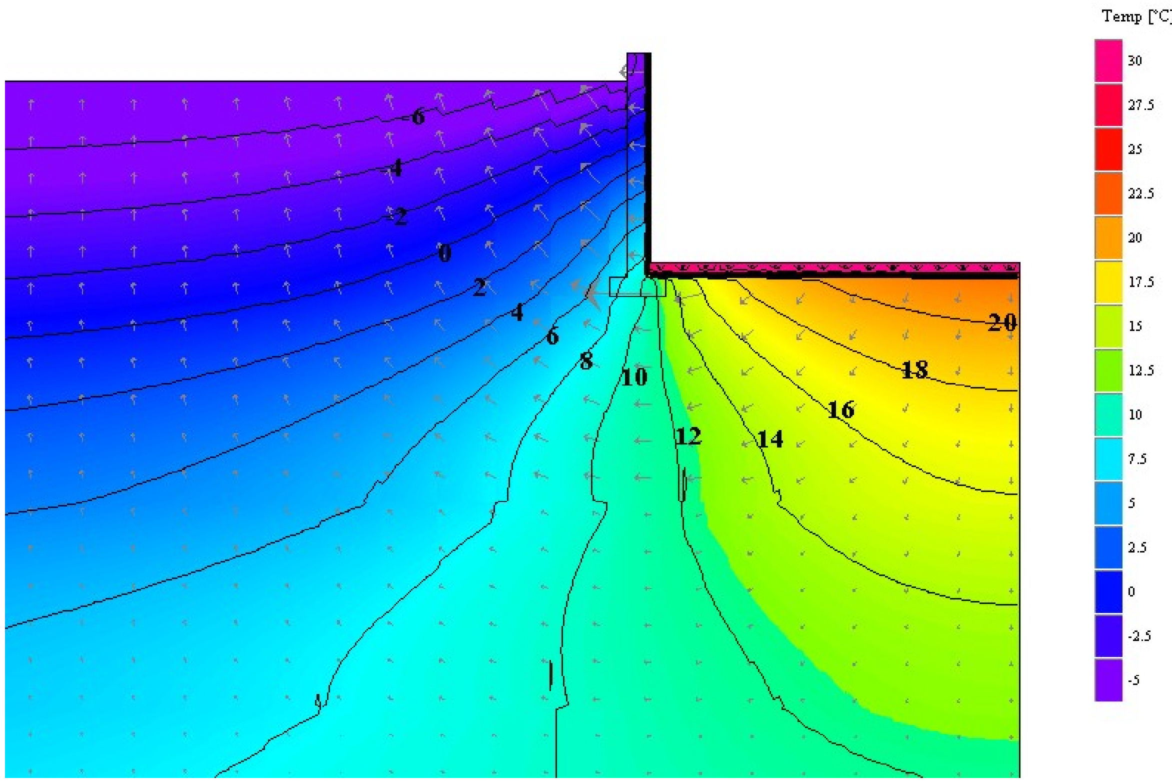

Figure 6: Insulated Slab in February

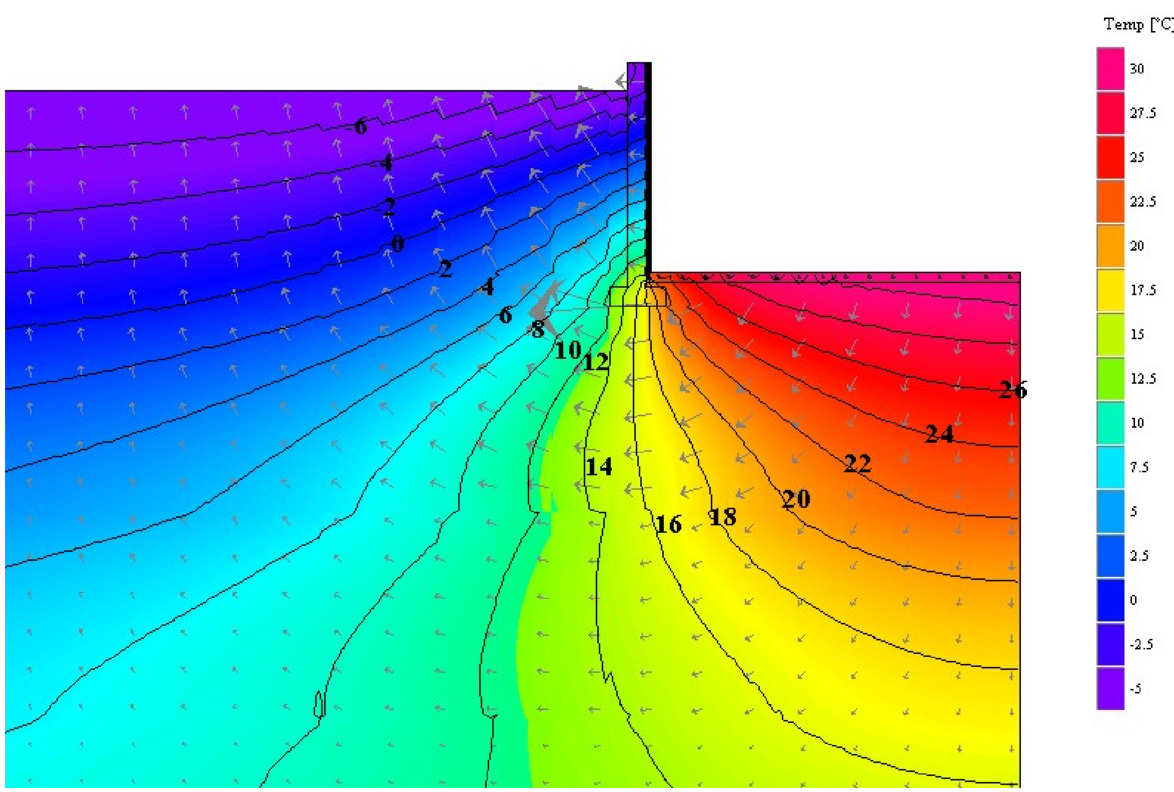

Figure 7: Uninsulated Slab in February

Figure 8 plots the average heat loss through the insulation into the soil over a typical year (centered about January, since this is the time when the slab is heated the most). The difference in heating energy that would have to be purchased for the case of 2" of EPS below the slab and the case of the uninsulated slab is the difference between the two lines. The difference over the heating season is approximately 28 kWh/m^2. Considering an energy cost of 10 cents per kWh, the annual cost savings would be about \$2.80/m^2/yr.

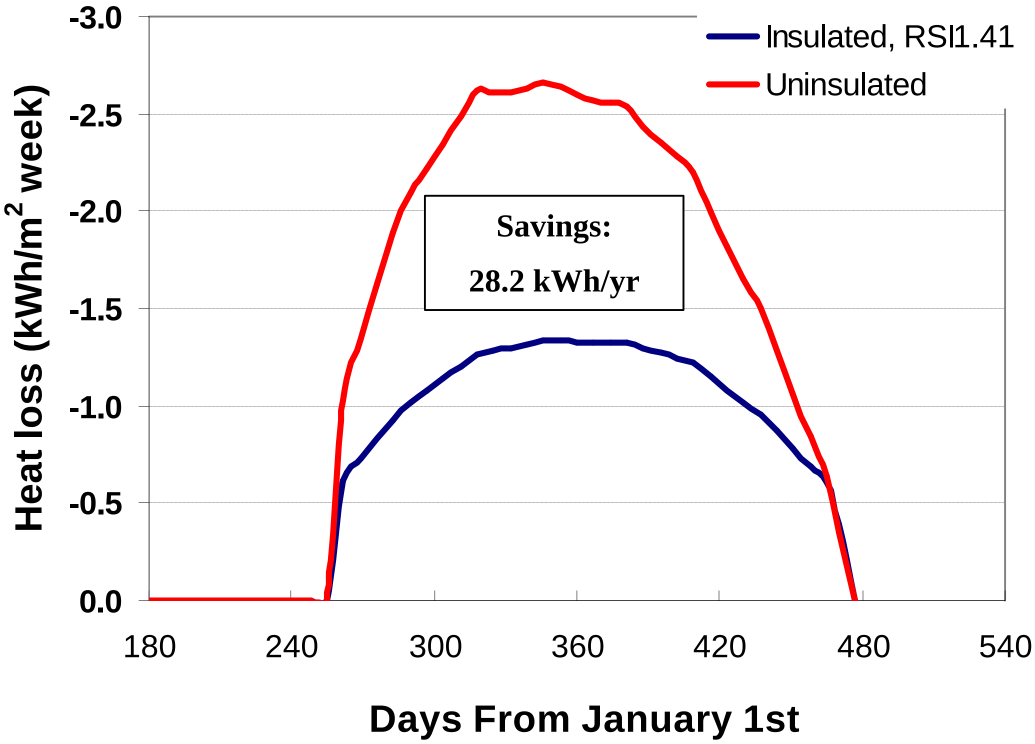

Figure 8: Heat Loss Compared for Insulated and Uninsulated Radiantly Heated Basement Slab (soil conductivity k=2.3 W/m•K)

The results in Figure 8 apply to a basement with the slab installed on moist, conductive soil. Table 3 and 4 summarize the results for 23 other combinations. In all cases, the use of insulation below the slab results in large reductions in heat flow. In fact, in the case of an uninsulated heated slab, almost half of the purchased energy is lost to the soil. The more insulating the soil, the less the effect. The effect of a water table at a reasonable distance below the slab (not an unlikely scenario) would likely cause an even higher heat loss than shown for the high soil conductivity case.

Most existing recommendations for sub-slab insulation are based on unheated slabs. Two simulations for an average soil case (i.e., moist clay soil, k=1.5, c_p=1.65) were conducted. The results of these simulations are listed in Table 5. They show that the heat loss through both an uninsulated and insulated radiantly heated slab were over twice that of uninsulated and insulated unheated slabs. Since heat loss through radiantly heated floors is so much higher than through unheated slabs, the normal rules and practice for insulating unheated slabs clearly do not apply to radiantly heated slabs – more insulation is required for heated slabs.

Soil Properties		Insulation Strategy		Energy Use	
Thermal Conductivity, k (W/mK)	Thermal Heat Capacity, c_p (kJ/kg K)	Wall (m^2•K/W)	***Slab*** (m^2•K/W)	Annual Heat Loss (kWh/m^2)	Annual Savings (kWh/m^2)
2.3	1.8	1.41	**1.41**	-33.2	-28.2
2.3	1.8	1.41	0.00	-61.5	
2.3	1.8	2.11	**1.41**	-35.9	-27.8
2.3	1.8	2.11	0.00	-63.7	
1.5	1.65	1.41	**1.41**	-26.1	-16.6
1.5	1.65	1.41	0.00	-42.7	
1.5	1.65	2.11	**1.41**	-28.9	-15.9
1.5	1.65	2.11	0.00	-44.8	
0.7	1.5	1.41	**1.41**	-16.0	-6.8
0.7	1.5	1.41	0.00	-22.7	
0.7	1.5	2.11	**1.41**	-18.3	-6.8
0.7	1.5	2.11	0.00	-25.1	

Table 3: Full Basement Heat Loss Simulation Results

Soil Properties		Insulation Strategy		Energy Use	
Thermal Conductivity, k (W/mK)	Thermal Heat Capacity, c_p (kJ/kg K)	Wall (m^2•K/W)	***Slab*** (m^2•K/W)	Annual Heat Loss (kWh/m^2)	Annual Savings (kWh/m^2)
2.3	1.8	1.41	**1.41**	-38.1	-31.2
2.3	1.8	1.41	0.00	-69.3	
2.3	1.8	0.70	**1.41**	-39.8	-34.6
2.3	1.8	0.70	0.00	-74.4	
1.5	1.65	1.41	**1.41**	-30.9	-18.6
1.5	1.65	1.41	0.00	-49.5	
1.5	1.65	0.70	**1.41**	-32.6	-20.7
1.5	1.65	0.70	0.00	-53.3	
0.7	1.5	1.41	**1.41**	-20.1	-7.0
0.7	1.5	1.41	0.00	-27.0	
0.7	1.5	0.70	**1.41**	-21.4	-8.1
0.7	1.5	0.70	0.00	-29.5	

Table 4: Slab at Grade Heat Loss Simulation Results

Soil Properties		Insulation Strategy		Energy Use	
Thermal Conductivity, k (W/mK)	Thermal Heat Capacity, c_p (kJ/kg K)	Wall (m^2•K/W)	Slab (m^2•K/W)	Annual Heat Loss (kWh/m^2)	Percentage of Radiantly Heated Slab
1.5	1.65	1.41	1.41	-13.8	45%
1.5	1.65	1.41	0.00	-20.8	42%

Table 5: Full Basement Heat Loss Simulation Results for *Unheated* Slabs

Another issue is the importance of slab edge insulation for local heat loss. As we have found in other studies, a piece of 4” high and ¾” thick EPS between the slab and the wall is likely the most cost effective piece of insulation in the entire house. If possible, this insulation between the heated slab and the unheated wall should be at least 1” thick.

Conclusions

Detailed two-dimensional dynamic computer simulations of radiantly-heated slabs has shown that under-slab insulation can significantly reduce heat loss. The size of the energy savings will depend on many variables such as climate, house design, and soil properties. Only the effect of soil properties was investigated in this study, and found to be significant in the cold climate conditions simulated.

Heat loss for a slab on grade averaged only about 15% greater than heat loss through a slab in a full basement. Placing the slab about 2 m (6 feet) lower in the ground therefore does not reduce energy loss to any great extent. It can be concluded that the additional 2 m (6 feet) of soil is not an effective insulator.

It was found that the heat loss through an uninsulated radiantly heated slab can be reduced by as much as 46% if insulated with 50 mm (2" or R8) of EPS. Therefore, 75 mm (3" or R12) could be expected to reduce sub-slab heat loss by more than 50% in many situations.

Heat losses through radiantly heated slabs were found to be over twice that of otherwise similar unheated slabs for the conditions considered. Since heat loss through radiantly heated floors can be so much higher than heat losses through unheated slabs, it can be concluded that the normal rules and practices for insulating unheated slabs clearly do not apply to radiantly heated slabs.

Sincerely,

John Straube, Ph.D. Chris Schumacher, B.Tech (Arch), B.A.Sc.

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