Heat Loss Comparison for Various In-floor Heating and Slab Insulation Configurations

A common home renovation is to convert a previously un-occupied basement into living space. This frequently includes installing tile flooring and electric in-floor heat onto an existing concrete slab. There are a lot of opinions concerning the need for and thickness of slab insulation for such applications. This study looks at a typical basement slab configuration and evaluates the thermal efficiencies of several heating and insulation strategies to determine the value of proposed modifications, using standard, recognized engineering formulae and published physical material properties. This study does not take into account the "feel" of the floor, but only the performance of in-floor heating and insulation to maintain a given temperature. Other considerations such as available head room or the need to maintain floor elevations are not included.

The basement slab configuration under consideration is a simple 3.5 inch slab on grade (SOG). The desired room temperature is approximately 70 degrees F, and the year-round ground temperature is assumed to be 55 degrees F. Without any modification to the slab, the room looses heat to the ground through the floor slab based on the following equation:

$$q = (A\ \Delta T)/(L/k) \qquad \textbf{(Equation 1)}$$

Where:

q	=	heat loss, BTU/hr
A	=	Area of floor, ft^2, (assumed 1 ft^2)
ΔT	=	Room temp - ground temp, deg. F (deg. R)
	=	70 – 55 = 15
L	=	thickness of material, ft
k	=	Thermal conductivity, BTU-ft/hr-ft^2-deg R

Considering only 1 square foot of floor area, we can calculate heat losses on a square foot basis. The thermal conductivity of concrete is ranges from 0.5 to 0.7 depending on water content. Because this study is evaluating a potential conversion of basement space to living space, the concrete can be assumed fully cured and dry. Thus, the heat loss through the slab is approximately 25.7 BTU/hr/ft^2. This is the baseline heat loss for the slab.

Note: no consideration is taken for the effects of the thermal conductivity of the soil. Soil thermal conductivity can range from 0.20 to 1.5 BTU-ft/hr-ft^2-deg R, depending on water content. The soil can become thermally "saturated" in the area immediately adjacent to the slab and extend into the soil for several inches before reaching heat sink temperature. This "saturation zone" has the effect of more insulation, but for this analysis, this effect is ignored. Further, no evaluations of slab edge effects or heat losses into the room are performed. This simplified analysis is considered acceptable for preliminary design purposes.

If the homeowner wanted in-floor heat to raise the floor temperature to, say, 80 deg. F, (ΔT = 80 - 55 = 25 deg F) the floor heat loss becomes 41.38 BTU/hr/ft^2. The increase is due to the difference in temperature and is offset slightly by the increase in slab thickness due to the setting materials.

To offset the heat losses, the homeowner may elect to install an insulation membrane between the heating system and the slab. He may select a number of insulation options. The most common ones include 1/8” or ¼”cork and ¼”, ½” or 1” foam. There are other sheet membranes available, but for the purposes of this study, these are not under consideration.

The thermal conductivity of foam and cork (0.020 and 0.025 BTU-ft/hr-ft^2-deg R, respectively) are similar enough that this study will not address foam in less than ½” thickness. This study does not address cork in thickness greater than ¼” due to availability.

To calculate the effects of adding insulating to the slab, Equation 1 becomes:

$$q = (A \Delta T)/[(Lc/kc)+ (Li/ki)] \quad \textbf{(Equation 2)}$$

Where:
- Lc = thickness of concrete, ft
- kc = Thermal conductivity of conc., BTU-ft/hr-ft^2-deg R
- Li = thickness of insulator, ft
- ki = Thermal conductivity of ins., BTU-ft/hr-ft^2-deg R

Note: it is not important where the insulation is located in the floor slab for the purposes of heat loss calculations, except that the insulation is between the heat source and the ultimate heat sink (soil). Under slab insulation is equally effective as surface applied or mid slab insulation. The only difference comes when slab heat-up rates are being calculated, or when internal temperature measurement is important; both are beyond the scope of this evaluation.

Equation 2 yields the following:

Table 1

Insulation	**Heat loss, BTU/hr/ft^2**
Baseline	25.7
None	41.4
1/8” cork	24.5
¼” cork	17.4
½” foam	9.3
1” foam	5.2

To calculate the costs, the heat loss is converted to watts and multiplied by national average cost. The cost of electricity varies across the nation from high of 17.27 cents/kW-hr in the New England region, to a low of 9.12 cents/kW-hr in the southeast region. For the purposes of this analysis, the national average of 11.76 cents/kW-hr is used (Source: www.eia.doe.gov). Table 1 becomes:

Table 2

Insulation	**Cost, cents/ft^2/day**
Baseline	1.83
None	3.42
1/8” cork	1.74
¼” cork	1.24
½” foam	0.66
1” foam	0.37

It is important to note that a change in the heat loss mechanism occurs when the in-floor heat is utilized. The heat lost through the slab comes from the in-floor heating system instead of from the room environment, and thus the house heating system. Thus, the total heat loss from the slab is offset by the decrease in heat loss from the room. Table 2 becomes:

Table 3

Insulation	**Cost, cents/ft^2/day**
None	1.59
1/8” cork	-0.09
¼” cork	-0.59
½” foam	-1.17
1” foam	-1.46

Electric in-floor heating products come in 2 basic forms: wires and mats. The mats are basically wires embedded in a mesh to make installation easier. In both cases, the wire size and spacing are designed to provide a watt density (watts per square foot) sufficient to bring the floor up to approximately 80 degrees. Based on the Table 1, a watt density of about 12 watts per square foot, or about 47.6 BTU/hr, (a common capacity of electric heating mats) is sufficient to heat an un-insulated slab. Insulation added under the heat mats reduces the required watt density to maintain floor temperature.

The monthly costs for heating the floor of a typical 5x7 basement bathroom would average about $16.69, if the slab was not insulated. *Note: the typical in-floor heat arrangement would not include heat wires under the vanity, tub or toilet. This reduces the heat consumption proportionately. Potentially, only half the floor area would be heated.* Compare this to the average monthly electric bill of approximately $110.00 (average home using 936kW/month at 1.764 cents/kW {Source: www.eia.doe.gov}. This does not include heating costs, which are assumed almost equal with non-heating electrical costs), the floor heat would be about 7% to 15% of total electrical costs, but a small percentage of all energy costs for the average house. <u>Adding 1/8” of cork under the heat mat offsets this cost entirely.</u>

Conclusions:

More insulation is better than less; a little insulation is better than none; heat mats with no slab insulation will still work:

From Table 1, one can see that increasing the floor temperature by adding an in-floor heating system almost doubles the heat loss through an un-insulated slab. Also, by adding increasingly thicker layers of insulation between the heat source and the floor slab (or under the slab), the heat losses can be reduced. Further cost analysis is needed to determine how much insulation can be installed such that the installation and material costs are paid back in the typical 5-year pay-back period. However, it is clear that a small amount of insulation can significantly reduce energy losses.

Table 2 associates heat loss with cost. Table 3 illustrates the net energy cost of the insulation and in-floor heat due to offsets in the loss of room heat to the floor. Note that 1/8" of cork completely offsets the cost of the electricity that the in-floor heat provides. Thicker insulation appears to allow the in-floor heating system to provide space heat for the area, but to determine the extent that the in-floor heat could replace space heating requires an analysis that is a bit more involved and is not part of this evaluation. Another conclusion that can be inferred from Table 3 is that bigger rooms cost more to heat. A 16 square foot shower stall with no slab insulation, for example, would require only 25 cents a day to heat, if the heat remained on continuously.

Typical in-floor heating mats have sufficient heating capacity (watt density) to raise the floor temperature without insulation. Heat-up times are affected, though.

The available space, headroom, adjacent floor heights, budget and homeowner's planned use for the space are considerations for selecting in-floor heat and insulation products that may override thermal efficiency requirements. No all-encompassing design would be acceptable in all applications.

Disclaimer: Many of the variables that went into this analysis are subject to local conditions, pricing and building practices. For example, the ground temperature can greatly affect the total heat losses, but it also affects the baseline analysis equally. The resulting numbers may change, but the conclusions will not be impacted. Average house size and electrical usage are used only as a comparison. Obviously, if the home in question is significantly larger or smaller than the "average" house, the comparison becomes skewed, but it still remains valid for talking purposes. The homeowner is encouraged to seek the advice of a local professional engineer when undertaking a large project so that local conditions, project requirements, budget, and homeowner expectations are merged successfully.