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Reducing Crawl Space Heat Loss

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ABSTRACT

The objective of this work is to compare alternative methods of reducing heat loss rates from floors to crawl spaces. The heat loss rate to the crawl space of a building is calculated without any insulation, with a radiation barrier, with glass fiber insulation, and with foil-faced glass fiber insulation. Radiant barriers prove to be an effective means of reducing heat losses to crawl spaces.

INTRODUCTION

In 1984 the United States used nearly 74 quads or 74×10^{24} Btu (7.8×10^{28} J) of primary energy, of which 59 quads (6.2×10^{27} J) was used to heat residential buildings (U.S. DOE 1987). About 15% of a residential building's heat loss is through the floor. According to the Energy Information Administration's *Housing Characteristics, 1984* (U.S. DOE 1986), 41.8% of single-family housing units (or 24 million houses) have crawl spaces or basements that are not insulated. This results in approximately 0.4 quads (3.9×10^{26} J) of energy being lost through uninsulated crawl spaces and basements. The Energy Information Administration's *Characteristics of Commercial Buildings, 1983* (U.S. DOE 1985), does not list insulating crawl spaces or basements as energy conservation alternatives.

Crawl spaces are frequently uninsulated. In fact, the *1977 ASHRAE Fundamentals* did not provide a means for calculating the heat loss rate in a crawl space (ASHRAE 1977). The *1985 ASHRAE Fundamentals* discusses reducing heat loss from crawl spaces by insulating the floor above (with conventional insulating material) or insulating either the outside or inside of the foundation walls (ASHRAE 1985, p. 25.3). Guidelines on whether to keep crawl space vents open or closed during the heating season are also discussed.

The typical means to reduce crawl space heat loss is to insulate the floors or the crawl space walls. Although radiation barriers have been studied for the purpose of reducing both heat gain (for cooling purposes) and heat loss in attics (Oak Ridge National Laboratory 1985), they have not been studied in depth for use in insulating crawl spaces.

Heat transfer between two surfaces generally occurs by conduction, convection, or radiation. Heat loss rate from a warm floor to a cool crawl space is primarily by radiation heat transfer. The temperature gradient between the soil and the floor is stable. That is, the warmer air is on top. Therefore, there is no buoyancy force to cause air circulation and the convective heat transfer coefficient is identically zero (Incropera and deWitt 1985, p. 419). Conduction through air is small. In fact, the heat transfer rate through 3 ft (1 m) of air at a 9°F (5°C) temperature difference is only .041 Btu/h · ft² (0.13 W/m²). Although the temperature difference between the floor and ground is small, the heat loss rate by radiation is not negligible since it is proportional to the fourth power of the temperatures. For a floor at 59°F or 519°R (15°C or 288K) and ground temperature of 50°F or 510°R (10°C or 283K), each with an emissivity of 0.9, the heat transfer rate (ignoring walls) is 6.85 Btu/h · ft² (21.6 W/m²), or more than 150 times greater than the conductive heat transfer rate.

The existence of radiative heat transfer in crawl spaces is tacitly assumed. Since convective heat transfer does not exist, there is an attempt to reduce the surface temperature of the floor by insulating it. In this way, the surface of the insulation transfers heat to the ground at a much smaller temperature difference than if it were a bare floor. If only conductive heat transfer existed, then it would be better not to insulate the floor, since stagnant air is a better insulator than glass fiber insulation.

NUMERICAL MODEL

An analytical model was developed to determine the heat loss rate from a floor to a crawl space for four scenarios: an uninsulated floor, with a radiation barrier, with glass fiber insulation, and with foil-faced glass fiber insulation. The radiant heat transfer characteristics of the floor, soil, walls, and insulating materials were assumed to be opaque, diffuse, and independent of wavelength (i.e., graybody assumption). The soil was assumed to be a constant temperature heat sink, even though actual soil temperatures vary widely by location and depth. Seasonal variations in soil temperature can propagate to more than 30 ft (10 m) in depth, depending on the location (ASHRAE 1977, p. 12.5).

Since heat transfer was assumed to be primarily by radiation, the air temperature in the crawl space was assumed to be insignificant, providing that it was less than the floor temperature. This assumption would affect the heat transfer rates for all of the cases. Low air temperatures would cool the soil temperature and therefore increase the

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heat loss rates, which might be the case of well-vented crawl spaces. This would not be a problem if the vents were closed during the heating season. However, closing the vents may not be a suitable option where condensation in the crawl space is a problem. Heat sources, such as uninsulated (or poorly insulated) ducts, were not included in this analysis since this is only a simplified analysis. They would reduce the heat loss rate for all four scenarios.

The crawl space was modeled as a square building with a 3.3 ft (1 m) high crawl space. The floor was modeled as 39.4 ft x 39.4 ft (12 m x 12 m), resulting in a 1550 ft^2 (144 m^2) building. The baseline conditions were:

Floor: T_f = 518°R (288 K) and eps_f = 0.9
Ground: T_g = 509°R (283 K) and eps_g = 0.9
Walls: T_w = 500°R (278 K) and eps_w = 0.9

Radiation Barrier, Top:	eps_{rbt} = 0.07
Radiation Barrier, Bottom:	eps_{rbb} = 0.07
Insulation, Paper-Faced:	eps_{ins} = 0.90
Insulation, Foil-Faced:	eps_{ins} = 0.07
Insulation, Conductivity:	k = .28 Btu · in/h · ft^2 · °F (0.04 W/m · K)

where "eps" refers to the emissivity. The wall was assumed to be concrete, the floor wooden, and the ground sandy; all of which have an emissivity of about 0.9. The emissivities of the top and bottom of the radiation barrier were allowed to differ. The temperatures of the wall, floor, and ground were assumed to be constant.

The view factors (Incropera and deWitt 1985, p. 626) were calculated to be:

$F_{f,g} = F_{g,f} = 0.90$
$F_{f,w} = F_{g,w} = 0.025$
$F_{w,f} = F_{w,g} = 0.44$

where the subscripts are:

f = floor
g = ground
w = wall

and $F_{i,j}$ refers to the view factor from i to j.

The view factors from the radiation barrier and insulation surface were the same as from the floor. Although the radiation barrier and insulation surface were considered to be installed along the joists so that they were 6 in (150 mm) below the floor, there was no effect on the view factors. Since the floor is only 6 in (150 mm) from the radiation barrier [compared with a length of 39.4 ft (12 m)], the view factor was essentially 1.0.

The joists provide a significant complication in the analysis. However, since the conductivity of wood, 0.7 Btu · in/h · ft^2 · °F (0.1 W/m · K), is low and the view factor of the face of the joists to the ground or walls is low, the crawl space was modeled without joists.

Infiltration through the crawl space was not included and crawl space vents were not considered. Often they can be closed during the heating season. However, venting may be necessary. Venting would decrease the soil temperature, but the air velocity would be so low that convective heat transfer could still be neglected.

The heat loss rate from the floor to the crawl space was determined by a system of three equations consisting of energy balances (Incropera and deWitt 1985, p. 638) on each surface (floor, walls, and ground):

$$(A_i \times eps_i) \times (E_b - J_i) / (1 - eps_i) = A_i F_{ij} (J_i - J_j) \quad (1)$$

where,

A_i = surface area of surface i (wall, floor, ground, radiant barrier)
eps_i = emissivity of surface i
E_b = $C_1 \times T_i^4$, the blackbody radiation at T_i
J_i = radiosity of surface i (emitted and reflected energy)
F_{ij} = view factor from i to j
C_1 = .171 x 10^{-8} Btu/h · ft^2 · °R^4 (5.67 x 10^{-8} W/m^{2}K^4), the Stefan-Boltzmann constant.

When a radiation barrier was included, the radiation barrier temperature was eliminated by using the heat transfer rate from the floor to the radiation barrier:

$$q_{f,rbt} = C_1 \times A_f \times (T_f^4 - T_{rb}^4) / (C_2 + C_3 - 1) \quad (2)$$

where,

C_1 = Stefan-Boltzmann constant from Equation 1
C_2 = $(1/eps_f)$
C_3 = $(1/eps_{rbt})$.

When insulation was included, the solution was determined iteratively using the heat transfer from the floor through the insulation as:

$$q_f = A_f \times k \times (T_f - T_{ins}) / t \quad (3)$$

where,

t = insulation thickness
T_{ins} = surface temperature of the insulation.

Only one thickness of insulation, 6 in (150 mm), was considered, since in practice the insulation is placed between the 6 in (150 mm) high joists.

DISCUSSION

It is difficult to determine the actual temperature of the ground, or even the average temperature over the winter, without actually measuring it. Soil composition and conductivity, foundation materials and depth, weather conditions, and other factors make it difficult to predict heat transfer in the ground. Therefore, the sensitivity of the results to ground temperature was examined. This analysis restricted the ground temperature to above freezing compared with examples in *ASHRAE Fundamentals* (ASHRAE 1985, p. 25.4) that used 10°F (-12°C) for a vented crawl space and 51°F (11°C) for an unvented crawl space.

Figures 1A and 1B show the effect of soil temperature on the heat transfer rate. Soil temperature strongly affected the heat loss rate from the bare floor, but it had a much smaller effect if a radiation barrier (foil) or insulation was used. Figure 1A clearly shows the advantage of using any of the three methods to reduce the heat loss rate from the floor. The actual heat loss rate from the bare floor may be less than that calculated because the floor might heat the surface of the soil and reduce the radiation heat transfer. However, an example in the *ASHRAE Fundamentals* (ASHRAE 1985, p. 25.4) has a heat loss of 18,020 Btu/h (5280 W) from a 1200 ft^2 (111.5 m^2) uninsulated floor to a vented crawl space at 10°F (−12°C).

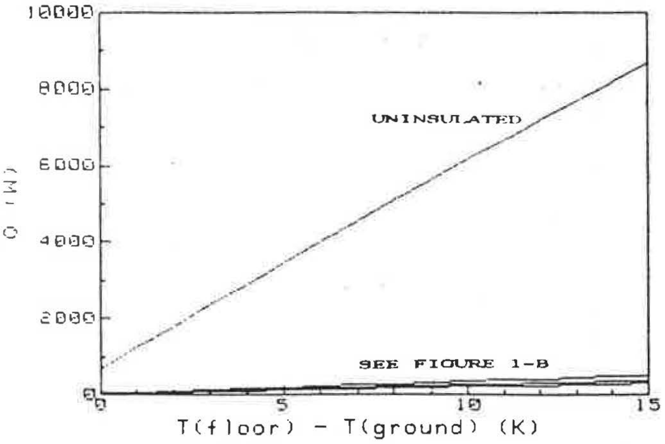

Figure 1A *Ground temperature variation, all cases*

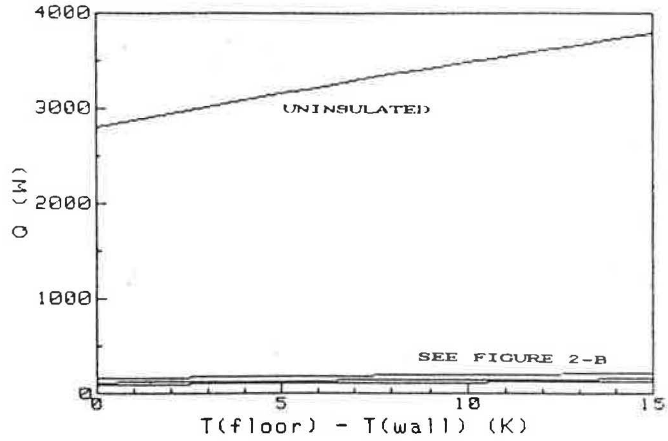

Figure 2A *Wall temperature variation, all cases*

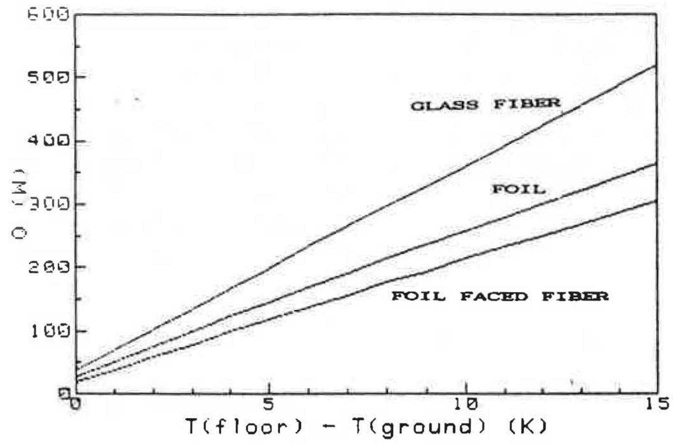

Figure 1B *Ground temperature variation, insulated cases*

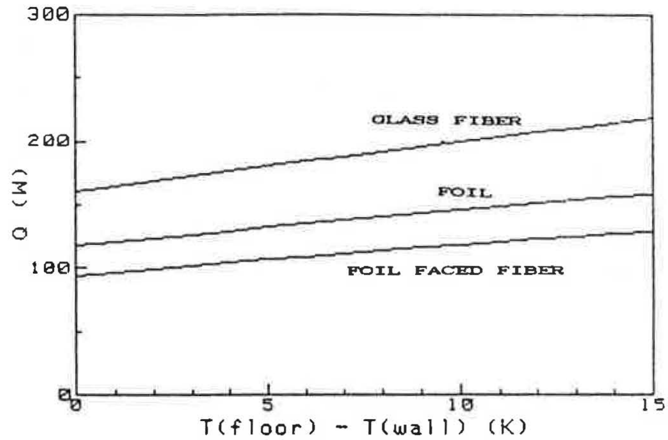

Figure 2B *Wall temperature variation, insulated cases*

Figure 1B shows the relative effectiveness between the three methods used to reduce the heat loss rate: a radiation barrier, glass fiber insulation, and foil-faced glass fiber insulation.

Perhaps the most significant result from Figure 1 is that the foil radiation barrier was more effective in reducing the heat loss rate than the glass fiber insulation. A suitable radiation barrier would be ordinary aluminum foil used for cooking, which has very low emissivities, costs only a fraction of that of glass fiber insulation, and would be much easier and faster to install than glass fiber insulation. A foil barrier would cost less to buy, cost less to install, and save more energy. It is, in effect, a low-cost energy conservation item.

The foil-faced insulation combines the advantages of both the glass fiber insulation and the radiation barrier. However, it only slightly reduces the heat loss rate from the floor over the foil barrier. The reason it has some advantage over the use of only a radiation barrier, is that the temperature of the radiation barrier (attached to the outside of the insulation) is lower due to the insulation rather than heating the radiation barrier directly by radiation from the floor. The additional initial and installation costs of the foil-faced insulation would be difficult to justify compared with using only a radiation barrier.

The relative ranking of these options remained the same for all ground temperatures (Figure 1), wall temperatures (Figure 2), wall emissivities (Figure 5), and ground emissivities (Figure 6).

The magnitude of the heat loss rate from the floor to the crawl space walls can be inferred from Figure 1A. As the ground temperature approached the floor temperature, the heat loss rate went to some nonzero value, representing the heat loss rate to the crawl space walls. This value was very small if the floor had a foil barrier or was insulated (Figure 1B).

The effect of the wall temperature can be seen in Figure 2 and was negligible for the floor with foil or insulation. Note that the case of zero temperature difference does not represent the heat transfer rate between the floor and ground only. If the wall temperature is equal to the floor temperature, then the reflected energy from the floor is not lost to the walls, as in the other cases. To ignore the walls, either an analysis between infinite plates could be used or the walls could be treated as reradiating walls (that is, they are heavily insulated and their temperature is not specified).

A potential problem with a radiation barrier is degradation of the emissivity. Since the barrier would not be subjected to weathering (in particular, ultraviolet radiation), the

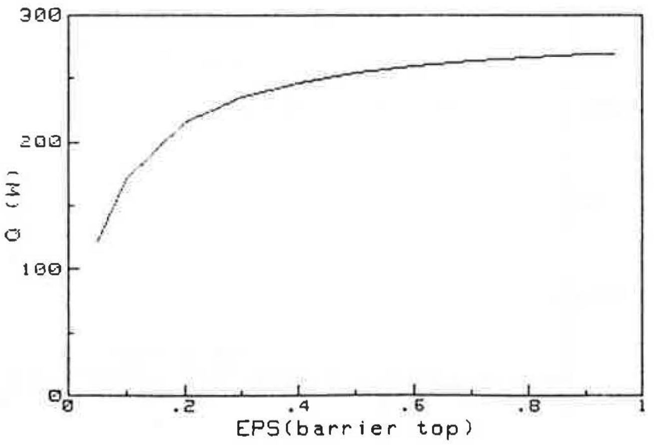

Figure 3A *Emissivity variation of radiant barrier top*

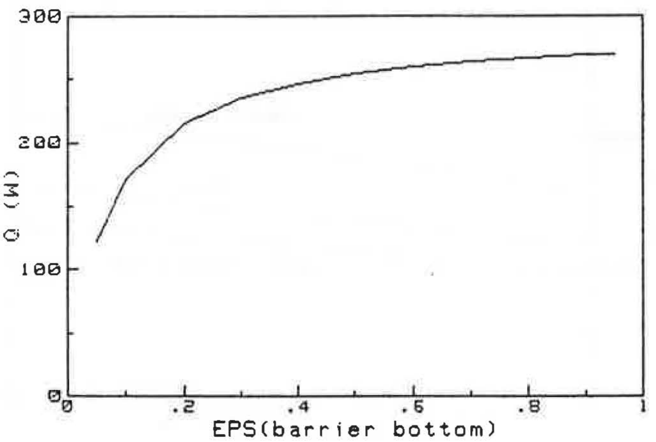

Figure 3B *Emissivity variation of radiant barrier bottom*

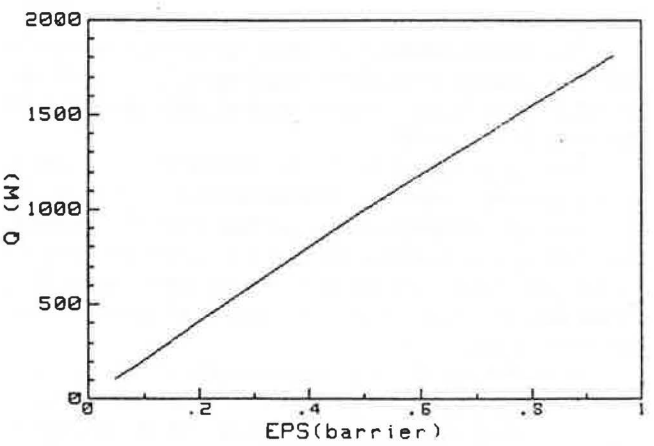

Figure 3C *Emissivity variation of radiant barrier, both sides*

only significant degradation mechanism would be from dust settling on the top surface of the radiation barrier. (Perhaps dust accumulation can occur on both sides in humid areas. The effect of changing the emissivity of both sides of the radiation barrier is discussed later.) The effect of decreasing the emissivity of the top of the radiation barrier is shown in Figure 3A. Going from a very low emissivity to a very high emissivity approximately doubled the

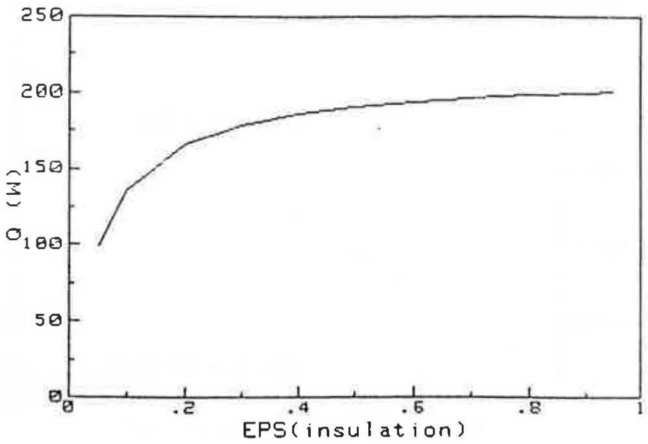

Figure 4 *Glass fiber insulation emissivity variation*

heat loss rate from the floor. If the emissivity increased to greater than 0.15, then the paper-faced insulation was more effective in reducing the heat loss rate. However, the difference was small and the radiation barrier remains the more cost-effective option. Figure 3B shows that the effect of changing the emissivity of the bottom of the radiation barrier was very similar to that of the top.

Heat transfer between two parallel surfaces with a radiation barrier in between can be approximated as (Incropera and deWitt 1985, p. 647):

$$q_{f,g} = C_1 \times A_f \times (T_f^4 - T_g^4) / C_4 \quad (4)$$

where,

C_1 = Stefan-Boltzmann constant in Equation 1

$C_4 = (1/eps_f) + (1/eps_g) + ((1 - eps_{rbt}) / eps_{rbt}) + ((1 - eps_{rbb}) / eps_{rbb})$

Changing either eps_{rbt} or eps_{rbb} has the same effect in the approximate model. In the model, the bottom of the radiation barrier interacted with the walls as well as with the ground and the difference between changes in the emissivity of the top and bottom of the foil was approximately the same. If the foil had different emissivities initially, it would make little difference which way it was installed. However, since the emissivity of the top of the foil is likely to degrade due to dust settling on it, it would be better to install the foil with the low emissivity toward the ground. It is not necessary to have foil with low emissivities on both sides, since the penalty is not large if only one side has a high emissivity.

Examination of the emissivities leads to the question of whether any type of intermediate material would be a suitable barrier. The answer is no. Figure 3 shows that any material will help some but not nearly as much as a material with at least one side having a low emissivity.

Glass fiber insulation can be obtained with either a paper facing or a foil facing (as well as without any facing). The effect of the emissivity of the insulation facing is shown in Figure 4. Unless the emissivity of the facing is less than 0.2 to 0.3, there is little advantage in reducing the emissivity of the facing.

The emissivity of the walls in the crawl space was also evaluated. If there is value in using a radiation barrier under the floor, then perhaps it would be worthwhile to consider

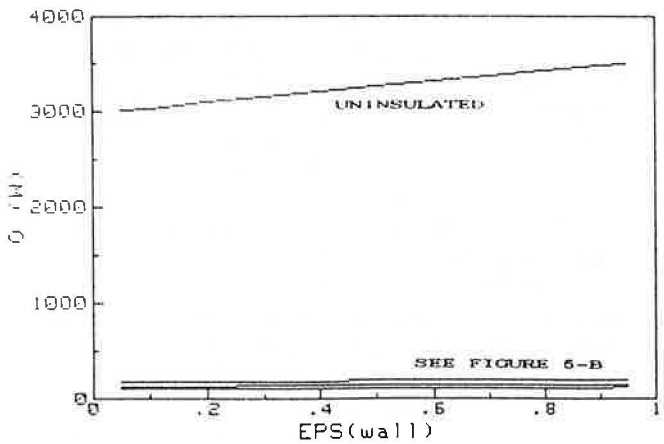

Figure 5A *Wall emissivity variation, all cases*

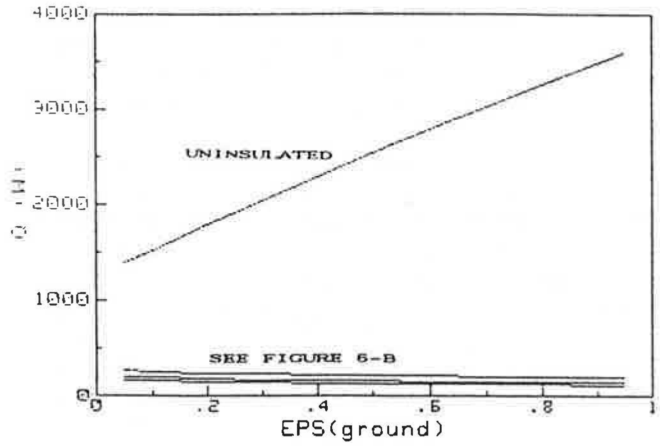

Figure 6A *Ground emissivity variation, all cases*

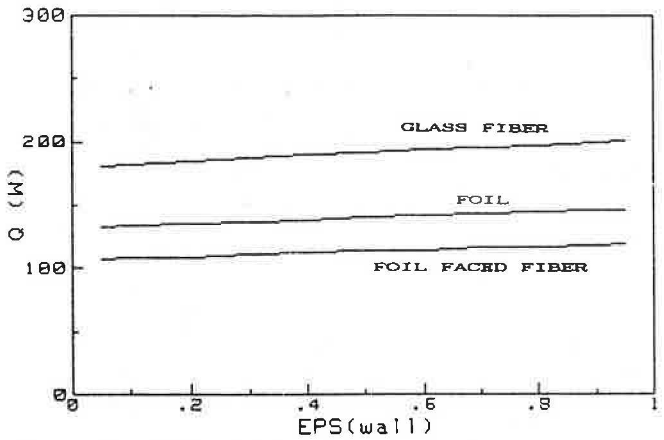

Figure 5B *Wall emissivity variation, insulated cases*

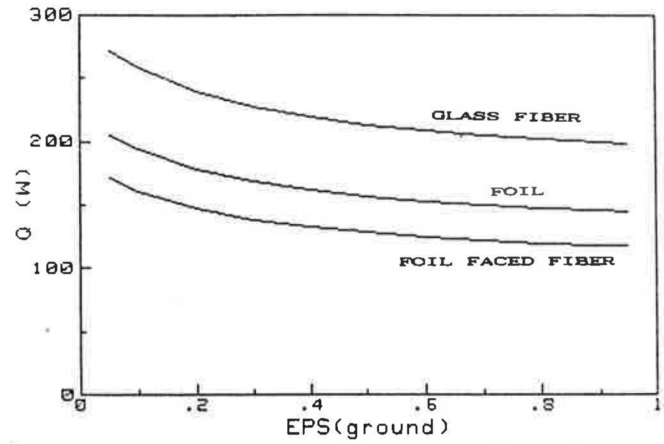

Figure 6B *Ground emissivity variation, insulated cases*

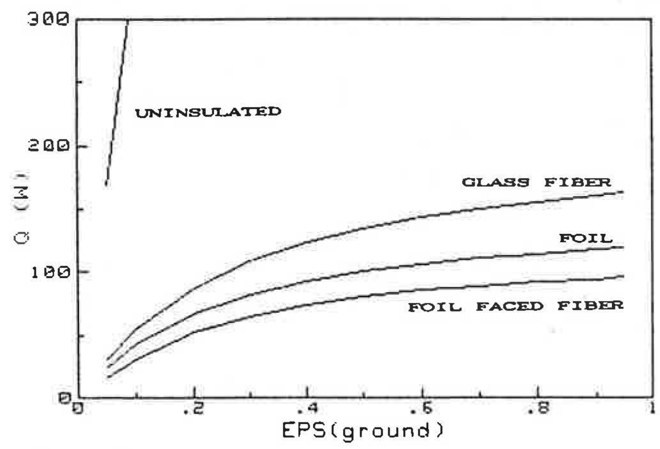

Figure 6C *Ground emissivity variation, wall temperature = floor temperature*

putting foil on the walls in an effort to reduce their emissivity (and absorption) as well. Although there was some benefit in doing this for the bare floor (Figure 5A), there was little benefit for the other cases (Figure 5B) when the floor was insulated or had a radiation barrier. Convective losses from the walls were assumed to be negligible.

The last major parameter varied was the emittance of the ground. The emittance of the ground can vary from 0.9 for sand to 0.93 to 0.96 for soil (Incropera and deWitt 1985). Another consideration would be to consider laying a radiation barrier directly on the soil rather than installing it underneath the floor. The results of this are shown in Figure 6. Reducing the emittance of the ground significantly affected the heat loss rate from the bare floor and had a small effect on the other three options. It is curious to notice that the heat loss rate increased for the three insulating options as the ground emittance decreased and that the bare floor heat loss rate approached a higher zero value (i.e., when the ground emittance and therefore absorptance is 0) than when the ground temperature equaled the floor temperature (Figure 1A). This would seem to oppose intuition and is certainly not predicted by the simple model (Equation 4). The phenomenon is caused by the fact that heat loss rate in a crawl space is that of an enclosure where all the surfaces interact with each other. As the emittance of the ground decreases, its reflectivity increases and radiation from the floor is partially reflected to the wall, which is at a lower temperature than the ground. Hence the heat loss rate from the floor will actually increase for the three options if the emissivity of the ground is decreased. This effect was checked by setting the temperature of the crawl space walls to that of the floor and therefore eliminating heat transfer from the floor to the walls. The results are shown in Figure 6C and are as expected. Since there was no heat loss from the floor to the wall, the heat loss rate approached zero as the emissivity of the ground decreased. If the walls were well insulated and the emittance of the ground very low, then the heat loss rate from the bare floor would decrease dramatically. However, this is not a practical solution since dust will settle on the ground, causing emittance to increase.

In an actual crawl space, where the wall temperature is not constant, the ground will heat the walls, reducing the heat loss rate from the floor to the walls. Reducing ground emissivity will reduce heat transfer from the ground to the walls and hence increase heat loss from the floor to the walls.

CONCLUSIONS

The model used in this analysis used several important assumptions including gray-body behavior, constant temperature surfaces, no infiltration (no effect from crawl space vents), no air movement from convective heat transfer from the crawl space walls, negligible joist effects, and no heat sources (ducts, pipes, etc.) in the crawl space. These assumptions need to be further investigated. In particular, does heat loss from the walls lead to substantial convective currents in the crawl space? Also in question is the long-term emissivity of the foil radiation barrier. Will it retain its original emissivity? The author installed such a barrier in his house in 1983 and, as of 1988, no degradation was visible.

The results from this analysis show that a radiation barrier is a very effective means of reducing the heat loss rate from floors to crawl spaces. For the base case considered, a bare floor had a heat loss rate of 11,770 Btu/h (3450 W) while the paper-faced glass fiber insulation lost heat at 680 Btu/h (200 W), the radiation barrier at 495 Btu/h (145 W), and the foil-faced glass fiber insulation at 410 Btu/h (120 W).

Depending on the emissivity of the top surface of the radiation barrier, the use of a radiation barrier ranged from more effective to slightly less effective than paper-faced glass fiber insulation. Foil-faced glass fiber insulation was always slightly more effective than the radiation barrier approach. However, a radiation barrier, which can be as simple as aluminum cooking foil stapled to floor joists, is far less expensive and much easier to install than glass fiber insulation. It would cost about $30 (using store-bought aluminum foil) for sufficient foil to insulate the crawl space of a 1550 ft^2 (144 m^2) building.

This analysis may overpredict the heat loss rate for the bare floor (Figure 1A). A heat loss rate of 11,770 Btu/h (3450 W) may be too high for a typical residence (although an ASHRAE example has a heat loss of 18,000 Btu/h [5280 W] for a smaller building [ASHRAE 1985, p. 25.4]). Radiation heat transfer from the floor to the ground may increase the temperature of the soil sufficiently to reduce the heat transfer rate. To characterize this effect, the conductivity of the soil would need to be known.

Other effects need to be considered in installing crawl space radiation barriers. Pipes that are below the barrier and heating ducts should be insulated. A radiation barrier is much easier to install around pipes and ducts than glass fiber insulation, which must be cut to fit and must also be cut around the cross-bracing of the joists. A radiation barrier should not affect moisture buildup in crawl spaces, although that may require further investigation in humid climates. A radiation barrier might also help prevent radon gas from entering buildings from crawl spaces.

Perhaps the most significant negative effect that any floor insulation might have is that the building is no longer closely coupled to the ground and any cooling effect in hot climates is lost.

Radiation barriers offer an inexpensive means of effectively reducing the rate of heat loss from floors to crawl spaces and should be considered as a means of reducing the heating load of a building.

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