

# Effects of Layered Soil on Basement Heat Transfer

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## ABSTRACT

*This paper presents a numerical model to investigate the foundation heat transfer from conditioned basements when the ground is composed of multilayered strata with different thermal properties. The model is used to determine the thermal performance of several basement insulation configurations under both steady-state and transient conditions. It is found that the nonhomogeneity of the soil significantly affects the heat transfer from uninsulated basement walls rather than the basement floor or insulated basement walls.*

## INTRODUCTION

The thermal properties of the ground are generally recognized to be the most important parameters that affect ground-coupled heat transfer. Unfortunately, data for soil thermal properties are often very difficult to obtain. Indeed, soil thermal properties are influenced by a myriad of factors such as soil type, soil density, soil moisture content, and even soil temperature and soil depth.

The majority of the existing ground-coupled methods can predict the heat flux variation along the ground-coupled surfaces providing that the soil is homogeneous with constant thermal properties. The main reason for this simplification is to avoid the mathematical complexity associated with modeling heat transfer in nonhomogeneous medium.

Very few methods exist that consider the spatial variation of soil thermal properties on ground-coupled heat transfer. The few methods that consider some spatial variation of soil thermal conductivity are based on numerical techniques. In particular, the Mitalas method considers an upper and lower layer of the ground medium with each layer characterized by a constant thermal conductivity (Mitalas 1987). Typically, the upper layer has higher thermal conductivity than the lower layer because of the effect of rainfall or frost (Sterling 1992). Mitalas investigated only three pairs of soil thermal conductivity values and neglected any lateral variation of soil physical properties. More recently, Gabbard and Krarti (1995) analyzed the soil layer effect on the steady-state heat

transfer of insulated slab-on-grade floors. In particular, they investigated the nonhomogeneous soil medium effect on the heat transfer from slab-on-grade floors with various insulation configurations. The study showed that when using an isotropic soil model, the total heat loss from a slab-on-grade floor can be underestimated or overestimated by as much as 35% depending on the conditions of the soil.

In this paper, the effect of inhomogeneous soil on ground-coupled heat transfer for insulated rectangular basements will be analyzed. First, the two-dimensional transient Fourier heat conduction equation will be solved in the Cartesian coordinate system using an implicit finite-difference technique for a rectangular basement. Then, the effect of nonisotropic soil on the steady-state and transient heat transfer of rectangular basements will be presented for various insulation configurations and soil thermal properties. For the transient analysis, only the spatial variation of soil thermal properties will be investigated. No reliable data are available to assess the temporal variation of soil thermal properties. Shen and Ramsey (1981) found that the moisture content of the soil adjacent to a foundation wall varied less with time than with depth.

## FORMULATION OF THE PROBLEM

The time-dependent heat conduction equation in a nonisotropic medium is given by the following equation:

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$$\frac{\partial}{\partial x} \left( k \frac{\partial T(r,t)}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T(r,t)}{\partial y} \right) = \rho c_p \frac{\partial T(r,t)}{\partial t} \quad (1)$$

where

- $r$  = vector space of  $x, y$ ,  
 $c_p$  = specific heat (W/kg·K [Btu/h·lbm·°F]),  
 $k$  = thermal conductivity (W/m·K [Btu/h·ft·°F]),  
 $\rho$  = density of material (kg/m<sup>3</sup> [lbm/ft<sup>3</sup>]),  
 $t$  = time (s [h]).

Under steady-state conditions, the temperature around the basement is subject to the following equation:

$$\frac{\partial}{\partial x} \left( k \frac{\partial T(r,t)}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T(r,t)}{\partial y} \right) = 0 \quad (2)$$

## FINITE DIFFERENCE FORMULATION

Equation 1 is solved by using a pure implicit finite-difference technique (Pantankar 1980). This pure implicit method was chosen as the best candidate for long-term analysis of a large two-dimensional finite-difference matrix because the implicit method has the important advantage of being unconditionally stable. That is, the solution remains stable for all space and time intervals. Therefore, there are no restrictions on the selection of  $\Delta X$ ,  $\Delta Y$ , and  $\Delta t$ .

The control volume and the associated nodal dimensions are shown in Figure 1. For a node P, E and W are its x-direction neighbors, while N and S are its y-direction neighbors. The control volume of node P is shown by the shaded area. Thus, the differential Equation 1 can be discretized as follows:

$$a_p T_p = a_E T_E + a_W T_W + a_N T_N + a_S T_S \quad (3)$$

where

$$\begin{aligned} \alpha_E &= k_E \Delta Y / (\sigma x)_E \\ \alpha_W &= k_W \Delta Y / (\sigma x)_W \\ \alpha_N &= k_N \Delta X / (\sigma y)_N \\ \alpha_S &= k_S \Delta X / (\sigma y)_S \\ \alpha_p^0 &= \rho c_p \Delta X \Delta Y / \Delta t \\ \alpha_p &= \alpha_E + \alpha_W + \alpha_N + \alpha_S = \alpha_p^0 \end{aligned}$$

and  $\sigma x$  and  $\sigma y$  refer to the size of the control volume around the node P and  $\Delta X$  and  $\Delta Y$  are the distance between node P and its neighbors, as illustrated in Figure 1. Note that the model of Equation 3 can handle variation in the soil thermal conductivity  $k$  as function of location. Typically, a nonuniform discretization scheme is used to solve the heat conduction equation, as will be discussed below. The time increment  $\Delta t$  is used in the transient analysis. In this paper, a time increment of one day was found to provide accurate results for the steady-periodic solution discussed below.

It should be mentioned that the steady-state heat conduction solution (i.e., solution of Equation 2) can be

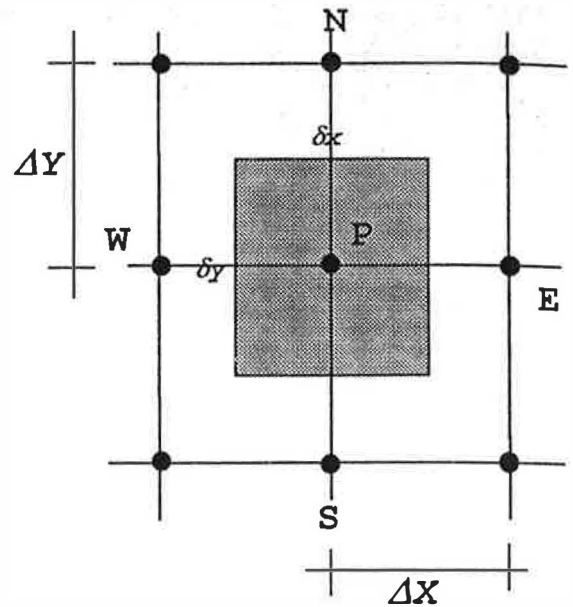


Figure 1 Control volume for the two-dimensional heat conduction problem.

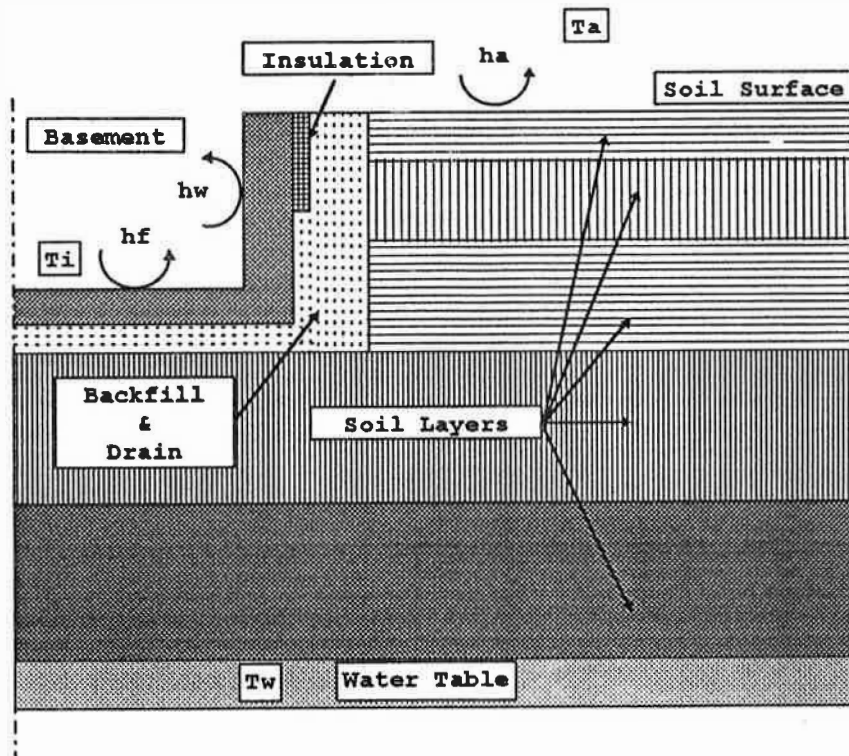
easily obtained by setting the specific heat ( $C_p$ ) to zero in Equation 3.

## FINITE DIFFERENCE SOLUTION

After the nodal network is set and an appropriate finite difference equation has been written for each node, the temperature distribution can be determined. This implies that a system of linear algebraic equations needs to be solved. Standard or general matrix solvers such as Gauss-Jordan and Gauss-Seidel methods are not suitable for this relatively large set of equations. For example, the system of linear equations for the rectangular basements requires about 10,000 unknown temperatures to be solved simultaneously. To solve this system of linear algebraic equations, a computer needs more than 700 MB of memory, which is not realistic for commonly available PCs and workstations. Therefore, a special matrix solver called LAPACK (Netlib 1993) is used in this paper to solve the set of linear systems. LAPACK is a library of FORTRAN 77 subroutines for solving the most commonly occurring problems in numerical linear algebra. It has a compact banded matrix storage method, which reduces the memory requirement to 24 MB, to solve the heat conduction problem of Equation 1.

## THE RECTANGULAR BASEMENT MODEL

Figure 2 shows half of a rectangular basement model used in the analysis presented in this paper. For building foundation heat transfer, the most influential zone is the zone adjacent to the building (i.e., the backfill-drain zone shown in Figure 2). Sterling (1992) provided a set of simple rules to determine the size of the zone of influence on building heat transfer. In addition, the climate of the build-



**Figure 2** The configuration of the rectangular basement with layered soil and backfill-drain.

ing site affects the soil temperature, soil moisture content, and soil frost line. In particular, soil moisture is influenced by the depth of the groundwater table, surface drainage, vegetation, and soil permeability. Soil far from the building can be modeled by a series of homogeneous layers of soil. This spatial zonation of the ground medium surrounding a building foundation is also recommended by Sterling (1992).

Throughout the analysis presented in this paper, it is assumed that the rectangular basement is 10 m (32.8 ft) wide and 3 m (9.8 ft) high. A water table is located at 14 m (46 ft) below the soil surface. The entire ground domain for the rectangular basement is 20 m (66 ft). Undisturbed boundary conditions are assumed at the edge of the domain.

The convection coefficients and building construction materials are obtained from *ASHRAE Fundamentals* (ASHRAE 1993). The basement wall is 0.2 m (8 in.) thick with high-density concrete block (thermal conductivity  $k = 1.038 \text{ W/m}\cdot\text{K}$  [0.548 Btu/h-ft $\cdot$ °F], density  $\rho = 977 \text{ kg/m}^3$  [61 lbm/ft $^3$ ], and specific heat  $C_p = 840 \text{ J/kg}\cdot\text{K}$  [0.20 Btu/lbm $\cdot$ °F]), while the basement floor is made up of 0.1 m (4 in.) thick high-density concrete with thermal conductivity  $k = 1.731 \text{ W/m}\cdot\text{K}$  (1.0 Btu/h-ft $\cdot$ °F), density  $\rho = 2243 \text{ kg/m}^3$  (140 lbm/ft $^3$ ), and specific heat  $C_p = 840 \text{ J/kg}\cdot\text{K}$  (0.20 Btu/lbm $\cdot$ °F).

The soil layer can be modeled as either a homogeneous medium or as a layered soil with up to five layers and with backfill and drain layer. The spatial dimensions

and thermal properties of soil layers and drain-backfill are listed in Table 1.

The insulation material is 0.1 m (4 in.) thick rigid insulation (thermal conductivity  $k = 0.058 \text{ W/m}\cdot\text{K}$  [0.033 Btu/h-ft $\cdot$ °F], density  $\rho = 91 \text{ kg/m}^3$  [5.7 lbm/ft $^3$ ]; and specific heat  $C_p = 840 \text{ J/kg}\cdot\text{K}$  [0.20 Btu/lbm $\cdot$ °F]) to model R-10 thermal insulation.

The annual convection coefficient for the soil surface is calculated with Equation 4 (McAdams 1959):

$$h_s = 5.7 + 3.8 u \quad (4)$$

where

$h_s$  = soil convection coefficient (W/m $^2$ ·°C) and  
 $u$  = wind speed (m/s).

For instance, if the average wind speed is 4 m/s, then the convection coefficient at the soil surface is

$$h_s = 5.7 + 3.8 u = 5.7 + 3.8 \times (4) = 21 \text{ W/m}^2\cdot\text{°C}.$$

The convection coefficients for the basement floor and basement wall are defined as 6.13 W/m $^2$ ·°C (1.08 Btu/h-ft $^2$ ·°F) and 8.29 W/m $^2$ ·°C (1.46 Btu/h-ft $^2$ ·°F), respectively.

It should be mentioned that the basement foundation model of Figure 2 can deal with the effect of snow cover at the soil surface. If such effect needs to be considered, the appropriate convection coefficient, thermal properties, and thickness should be selected for the first layer to represent soil cover. In this analysis, the effect of snow cover was not investigated.

**TABLE 1**  
**Spatial Dimensions and Thermal Properties**  
**of Soil Layers and Drain Backfill**

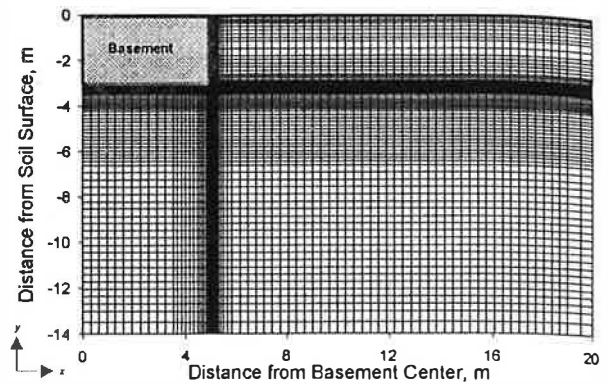
Dimensions	
<b>Backfill and drain</b>	
	at basement wall 0.5 m (1.6 ft)
	at basement floor 0.2 m (0.7 ft)
<b>Soil layers</b>	
1 layer case:	0.0-m ~ 14.0-m (2.5 W/m·K) 0.0-ft ~ 46-ft (1.45 Btu/hr.ft.°F)
2 layer case:	0.0 m ~ 0.5 m (2.5 W/m·K) 0.0 ft ~ 1.6 ft (1.45 Btu/h-ft.°F) 0.5 m ~ 14.0 m (1.0 W/m·K) 1.6 ft ~ 46 ft (0.58 Btu/h-ft.°F)
5 layer case:	0.0-m ~ 0.5-m (2.5 W/m·K) 0.0 ft ~ 1.6 ft (1.45 Btu/h-ft.°F) 0.5 m ~ 1.5 m (2.1 W/m·K) (1.6 ft ~ 4.9 ft (1.21 Btu/h-ft.°F) 1.5 m ~ 3.5 m (1.7 W/m·K) 4.9 ft ~ 11.5 ft (0.98 Btu/h-ft.°F) 3.5 m ~ 7.5 m (1.3 W/m·K) 11.5 ft ~ 24.6 ft (0.75 Btu/h-ft.°F) 7.5 m ~ 14.0 m (1.0 W/m·K) 24.6 ft ~ 46 ft (0.58 Btu/h-ft.°F)
<b>Thermal Properties</b>	
Backfill drain	
Thermal conductivity	$k = 2.0 \text{ W/m}\cdot\text{K}$ (1.16 Btu/h-ft.°F)
Density	$r = 2700.0 \text{ kg/m}^3$ (168 lbm/ft <sup>3</sup> )
Specific heat,)	$C_p = 800.0 \text{ J/kg}\cdot\text{K}$ (0.19 Btu/lbm.°F)
<b>Soil</b>	
Thermal conductivity	$k = 1.0 \text{ W/m}\cdot\text{K}$ (1.0 Btu/h-ft.°F)
Density,	$r = 2300.0 \text{ kg/m}^3$ (144 lbm/ft <sup>3</sup> )
Specific heat	$C_p = 840.0 \text{ J/kg}\cdot\text{K}$ (0.20 Btu/lbm.°F)

**Discretization Scheme for the Rectangular Basements**

Figure 3 shows the variable discretization scheme for the rectangular basement. A variable geometric discretization scheme is applied since it significantly reduces the computing time and the memory requirement. In general, the discretization grid is very fine near the wall and floor surfaces, 1 cm (0.4 in.) for the space increment  $\Delta X$  or  $\Delta Y$ , where the most interesting heat transfer occurs. The thick line around the rectangular basement represents the very fine discretization grid around the floor and wall. The nodal grids are gradually expanded in areas where relatively smaller temperature changes are expected.

The generation of the discretization grid starts with 1 cm (0.4 in.) and increases/decreases based on the relation shown below.

Discretization Scheme for Basement



**Figure 3** The variable discretization scheme for the rectangular basement model.

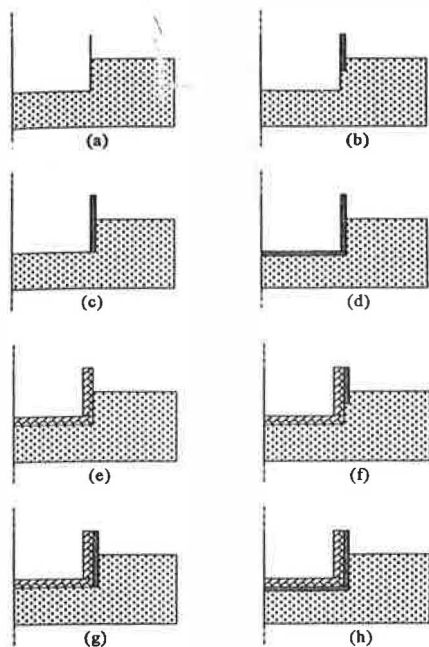
$$+1 = 0.5 \text{ or } \times \tag{5}$$

$$+1 = 0.5 \text{ or } \times \tag{6}$$

**Steady-State Heat Transfer**

For steady-state conditions, the interior air temperature is assumed to be constant throughout the building and is set at  $T_i = 20^\circ\text{C}$  (68°F), while the soil surface temperature is  $T_s = 15^\circ\text{C}$  (59°F). A water table 14 m (46 ft) deep below the soil surface has a temperature of  $T_w = 10^\circ\text{C}$  (50°F). Convective film coefficients at the inner surface of the basement envelope and at the soil surface are used. Eight insulation configurations are considered for four soil conditions: homogeneous soil, a homogeneous soil with a backfill and drain layer, a two-layered soil medium, and a five-layered soil medium (i.e., a total of 32 cases). The eight insulation configurations are illustrated in Figure 4 and are briefly described below:

- No actual wall and floor and no insulation. In this case, the physical properties of the basement walls and floor are assumed to be the same as those of the soil adjacent to the building. This assumption is common in foundation heat transfer literature. In addition, no thermal insulation is considered.
- No actual wall and floor and 1 m (3.28 ft) wall partial R-10 (R-value =  $0.5 \text{ m}^2\cdot\text{K/W}$  [ $10.0 \text{ ft}^2\cdot^\circ\text{F}\cdot\text{h/Btu}$ ]) insulation on the upper part.
- No actual wall and floor and R-10 (R-value =  $0.5 \text{ m}^2\cdot\text{K/W}$  [ $10.0 \text{ ft}^2\cdot^\circ\text{F}\cdot\text{h/Btu}$ ]) uniform wall insulation.
- No actual wall and floor and R-10 (R-value =  $0.5 \text{ m}^2\cdot\text{K/W}$  [ $10.0 \text{ ft}^2\cdot^\circ\text{F}\cdot\text{h/Btu}$ ]) uniform wall and floor insulation.
- Actual wall and floor and no insulation. In this case, the physical properties of concrete were used to model the basement walls and floor. Obviously, this model is more realistic than the model of case a.
- Actual wall and floor and 1 m (3.28 ft) wall partial R-10 (R-value =  $0.5 \text{ m}^2\cdot\text{K/W}$  [ $10.0 \text{ ft}^2\cdot^\circ\text{F}\cdot\text{h/Btu}$ ]) insulation on the upper part.



**Figure 4** Insulation and basement walls and floor configurations.

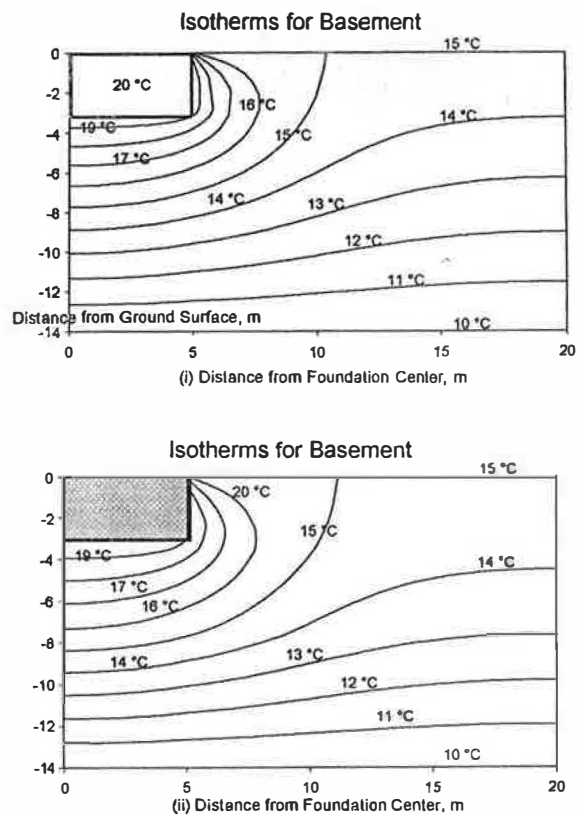
- g. Actual wall and floor and R-10 (R-value = 0.5 m<sup>2</sup>·K/W (10.0 ft<sup>2</sup>·°F·h/Btu)) uniform wall insulation.
- h. Actual wall and floor and R-10 (R-value = 0.5 m<sup>2</sup>·K/W (10.0 ft<sup>2</sup>·°F·h/Btu)) uniform wall and floor insulation.

Basically, cases e through h are the same as cases a through d with the exception of using the actual physical properties of the basement walls and floor. Cases a through d were investigated to determine the significance of properly modeling basement envelope on the foundation heat transfer.

**Temperature Distribution.** Figure 5 shows the temperature field around the rectangular basement for case a (i.e., no insulation, without actual wall and floor, and with homogeneous soil) and case e (i.e., no insulation, with actual wall and floor, five-layered soil, and backfill-drain layer).

The rectangular basement is 10 m wide and 3 m high. The interior air temperature is assumed to be constant throughout the building and is set to  $T_i = 20^\circ\text{C}$ , while the soil surface temperature is  $T_s = 15^\circ\text{C}$ . A water table 14 m deep below the soil surface has a temperature of  $T_w = 10^\circ\text{C}$ .

As shown in Figures 5(i) and 5(ii), the effect of the increased soil thermal conductivity on the temperature distribution around the basement is apparent when comparing the soil distribution between the two cases. In general, the high thermal conductivity values at the upper layers of the soil (i.e., case e) significantly increases the thermal interaction between the soil surface and the basement. The increased soil thermal conductivity for the actual wall/floor and backfill-drain layer case (case e) significantly decreases the temperature around the basement wall. For example, the temperature along the basement wall decreases from 19°C in case a to 18°C in case



**Figure 5** Isotherms of the rectangular basement. (i) No actual wall and floor and no insulation with homogeneous soil. (ii) Actual wall and floor and no insulation with backfill-drain and five-layered soil.

e. Moreover, the wall surface temperature varies abruptly from 19°C to 15°C within less than 0.2 m in the case of isotropic soil, while the wall surface changes from 18°C to 15°C within 0.7 m in the case of five-layered soil. This gradual temperature change implies that the rate of the heat transfer from the upper portion of the basement wall is lower for case e than that for case a. It is clear that the increased thermal properties at the upper layers of the soil increase the thermal interaction between the soil surface and the upper part of the basement wall.

It is very interesting to notice that the soil temperature in the middle section of the basement floor in case e is a little higher than that of case a. This increased soil temperature is mainly due to the increased thermal conductivity of the backfill-drain layer beneath the floor.

It is apparent that the cold water table does not have a significant effect on the soil temperature distribution around the basement when it is located 14 m below the basement floor.

**Total Basement Heat Transfer.** The total steady-state (i.e., annual average) heat transfer from the basement walls and basement floor for cases a through h are summarized in Table 2. In this section, the basement geometry, soil thermal

**TABLE 2**  
**Variation of Total Steady-State Heat Transfer for Basement Wall and Floor**

Case	Homogeneous Soil		w/ Backfill and Drain		w/ Backfill- Drain and Two-Layer Soil		w/ Backfill- Drain and Five-Layer Soil	
	Wall	Floor	Wall	Floor	Wall	Floor	Wall	Floor
(a)	1.00	1.00	1.29	1.03	1.39	1.04	1.58	1.22
(b)	0.63	1.01	0.78	1.04	0.82	1.05	1.00	1.23
(c)	0.39	1.13	0.40	1.25	0.42	1.26	0.45	1.47
(d)	0.42	0.80	0.45	0.83	0.46	0.83	0.49	0.93
(e)	1.01	1.01	1.12	1.05	1.19	1.06	1.36	1.24
(f)	0.87	1.02	0.93	1.06	0.97	1.07	1.13	1.25
(g)	0.68	1.08	0.69	1.15	0.71	1.15	0.75	1.36
(h)	0.68	0.81	0.70	0.82	0.71	0.83	0.75	0.92

properties, and temperatures are the same as those used above. Case a is chosen as the base case for this parametric analysis.

In general, the magnitude of the variation in the wall and floor heat loss increases with adding material of high thermal conductivity (i.e., actual wall/floor, backfill drain, soil layers). However, adding more insulation decreases the magnitude of the variation. The increasing magnitude of variation with the addition of material of high thermal conductivity results from the principle of Fourier's heat conduction law: *The conduction rate of the material is proportional to its thermal conductivity.* The decreasing magnitude of variation with the addition of insulation is mainly due to the fact that insulation blocks out thermal interaction between the basement and the surrounding ground, which is the *isolation effect*.

In particular, as shown in case a, the heat loss through the basement wall is increased 58% for the five-layered soil, while the heat loss increases only 39% for the two-layered soil and 29% for the case of a basement with backfill-drain layer.

It should be noted that the magnitude of heat loss reduction due to adding thermal insulation decreases when the actual wall and floor layers are accounted for. In particular, the heat loss for the basement walls (made up of dirt) in the homogeneous soil is 37% lower for case a when compared to case b, while the reduction in the heat loss from the basement wall is only 14% if partial wall insulation is added (i.e., case e vs. case f). This decreased magnitude is due to the thermal bridging effect within the basement envelope. When partial wall insulation is placed at the upper part of the wall, a significant amount of heat is transmitted to the ground through the remaining basement wall.

Generally, there is no significant change in heat loss through the basement floor.

### Transient Heat Transfer

Eight cases of various insulation configurations are considered for a homogeneous soil, a homogeneous soil and backfill-drain layer, a two-layered soil medium, and a five-layered soil medium (i.e., a total of 32 cases).

- a. No actual wall and floor and no insulation.
- b. No actual wall and floor and partial R-10.
- c. (RSI = 0.5 m<sup>2</sup>·K/W) wall insulation 1.0 m on the upper part.
- d. No actual wall and floor and R-10 (RSI = 0.5 m<sup>2</sup>·K/W) uniform wall insulation.
- e. No actual wall and floor and R-10 (RSI = 0.5 m<sup>2</sup>·K/W) uniform wall and floor insulation.
- f. Actual wall and floor and no insulation.
- g. Actual wall and floor and partial wall R-10 (RSI 0.5 m<sup>2</sup>·K/W) insulation 1.0 m along the upper part of the wall.
- h. Actual wall and floor and R-10 (RSI = 0.5 m<sup>2</sup>·K/W) uniform wall insulation.
- i. Actual wall and floor and R-10 (RSI = 0.5 m<sup>2</sup>·K/W) uniform wall and floor insulation.

The total heat loss through the basement floor requires two years to reach steady-periodic condition for the given basement configuration (using Denver, Colorado, climatic data), while the dynamic heat transfer from the basement wall requires only six months to reach steady-periodic conditions. The relatively long time period required for the basement floor to reach steady-periodic behavior is mainly due to the thermal mass of the ground and the indirect coupling between the soil surface and the basement floor.

**Temperature Distribution.** Only the temperature distributions in summertime (July 15) and wintertime

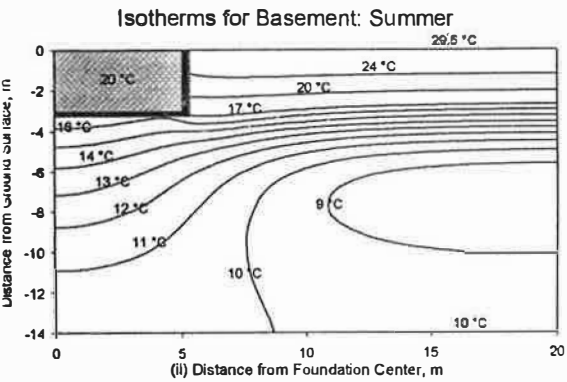
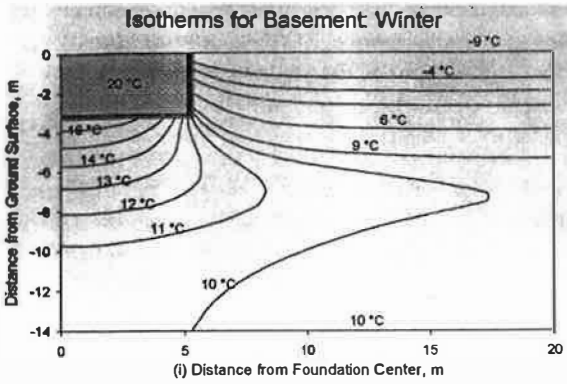


Figure 6 Soil temperature distribution around basement: (i) winter (January 15), (ii) summer (July 15).

January 15) for case h with five-layered soil are shown in Figure 6.

In particular, Figure 6(i) shows the wintertime temperature profile around a basement 10 m wide and 3 m high. The indoor air temperature is  $T_i = 20^\circ\text{C}$  and the mean and amplitude of the sol-air temperature are  $T_{s,m} = 10^\circ\text{C}$  and  $T_{s,a} = 20^\circ\text{C}$ , respectively (typical of Denver, Colorado, climate). A water table 14 m below the soil surface has a constant temperature  $T_w = 10^\circ\text{C}$ . For this configuration, the temperature along the basement wall increases from  $-9^\circ\text{C}$  (the wintertime sol-air temperature) to about  $11^\circ\text{C}$ . However, the floor temperature decreases from  $16^\circ\text{C}$  at the middle section to  $11^\circ\text{C}$  at the corners. The sudden temperature changes along the wall imply that the heat transfer rate is higher along the wall than along the floor.

Figure 6(ii) illustrates the summertime temperature distribution around the basement. The temperatures of the basement wall change from  $29.5^\circ\text{C}$  to  $16^\circ\text{C}$ , while the temperature of the floor is  $16^\circ\text{C}$ . The isotherm of  $20^\circ\text{C}$  near 2.5 m of the wall shows a double point in the wall. The double point indicates that the upper part of the wall gains heat from the hot soil surface while the lower portion of the wall loses heat to the water table. Just beneath the basement floor, the temperature profile is similar to that observed in wintertime (Figure 6(i)).

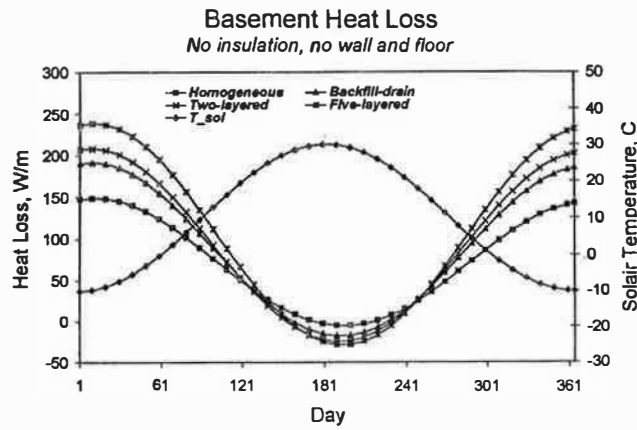


Figure 7 Total heat loss from the basement wall and floor without insulation.

This result is expected since there is a strong thermal interaction between the water table and the center of the floor.

**Basement Heat Loss.** The total heat transfer from the basement wall and basement floor is shown in Figures 6 and 7 for the cases described in this section. In general, as found in the steady-state heat transfer analysis, the magnitude of the variation in the total basement heat loss increases with the addition of material of high thermal conductivity. However, adding more insulation decreases the magnitude of the variation.

The increasing magnitude of variation due to adding high thermal conductivity is shown in Figure 7. For example, the total basement heat loss increases about 60% with a five-layered soil. It is almost the same magnitude as that obtained for steady-state heat transfer (see Table 2).

Figure 8 shows the total basement heat loss when it is uniformly insulated with R-10 ( $R = 0.5 \text{ m}^2\cdot\text{K}/\text{W}$ ) insulation. The decreased magnitude of heat loss variation with uniform insulation is mainly due to the “isolation effect” imposed by the thermal insulation. In addition, a time lag between the sol-air temperature and the basement heat loss increases about 10 days, as illustrated in Figure 7 when it is compared with that of Figure 6. This increased time lag between basement heat

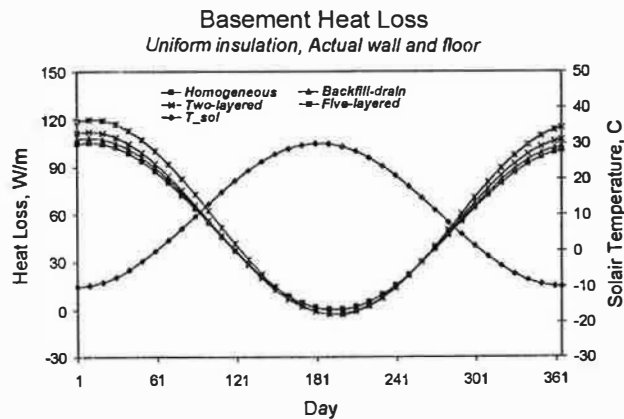


Figure 8 Total heat loss from the basement wall and floor with uniform insulation.

loss and the sol-air temperature is another consequence of the "isolation effect" due to the thermal insulation.

## SUMMARY AND CONCLUSIONS

It was found that when using an isotropic soil model, the total heat losses from a basement can be underestimated or overestimated by as much as 60% depending on the conditions of the soil and the insulation configuration. The largest discrepancies occur when the basement wall is uninsulated. The thermal performance of the basement floor—even uninsulated—and insulated basement walls is not significantly affected by the nonhomogeneity of the ground as long as the thermal properties selected for the isotropic soil model present average properties for the inhomogeneous soil.

Therefore, the homogeneous soil model can be used to model foundation heat transfer for insulated basements if soil thermal properties are appropriately selected. For an uninsulated basement (specially with uninsulated walls), the spatial variation of the soil thermal properties has to be accounted for to properly estimate the foundation heat transfer.

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