From the Building Energy Simulation User News, Vol. 19, No. 1 (Spring 1998)
Corrected and Revised in Vol. 23, No. 6 (November/December 2002)

UNDERGROUND SURFACES: HOW TO GET A BETTER UNDERGROUND SURFACE HEAT TRANSFER CALCULATION IN DOE-2.1E

by
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Note: The Spring 1998 issue (Vol. 19, No. 1) of the Building Energy Simulation User News described a simplified method for modeling foundation heat flows in DOE-2. The article contained three tables giving the perimeter conductance per perimeter foot for slab, basement, and crawl space conditions calculated using a two-dimensional finite-difference program*. The basic approach in this simplified procedure was to model the true foundation area as an underground surface[s], and add a fictitious insulating layer to the outside of the surface[s] so that the total foundation conductance equals the perimeter length times the perimeter conductance given in Tables 1, 2, and 3. For basements, the article recommended that the floor be modeled as an UNDERGROUND-FLOOR with zero conductance, and the walls as an UNDERGROUND-WALL with a conductance calculated as just described. It has been brought to our attention that this method presents a problem in some uninsulated basement cases where the required wall conductance may be greater than that of the basement wall, e.g., 4" concrete and 1 ft. of soil, without adding any insulating layer. In such instances the solution is to also model the basement floor as a heat transfer surface and then to add the same insulating layer to both so that the total foundation conductance from both equals the perimeter length times the conductance shown in Table 3.

Joe Huang and Jeff Warner, LBNL, October 2002

* Y.J. Huang, L. Shen, J. Bull, and L. Goldberg, "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program", ASHRAE Transactions 94(2), 1988.

Underground surfaces in DOE-2.1E are walls or floors that are in contact with the ground. An example is a slab-on-grade or a basement wall. Underground surfaces are entered using the UNDERGROUND-WALL command, or the equivalent command, UNDERGROUND-FLOOR. Check the description of these commands in the *Reference Manual* for information on the keywords for these surfaces.

Heat Transfer

Care needs to be taken in describing the construction of an underground surface in order to get a correct calculation of the heat transfer through the surface and a correct accounting for the thermal mass of the surface, which is important in the weighting factor calculation for the space. In the LOADS program, DOE-2 calculates the heat transfer through the underground surface as

$$Q = UA(T_g - T_i)$$

where U is the conductance of the surface, A is the surface area, T_g is the ground temperature and T_i is the inside air temperature. *If the raw U-value of the surface is used in this expression the heat transfer will be grossly overcalculated.* This is because the heat transfer occurs mainly through the surface's exposed perimeter region (since this region has relatively short heat flow paths to the outside air) rather than uniformly over the whole area of the surface. For this reason, users are asked to specify an effective U-value with the U-EFFECTIVE keyword. This gives

$$Q = [\text{U-EFFECTIVE}]*A(T_g - T_i)$$

In general U-EFFECTIVE is much less than the raw U-value.

The following procedure shows how to determine U-EFFECTIVE for different foundation configurations. It also shows how to define an effective construction for an underground surface that properly accounts for its thermal mass when custom weighting factors are specified. The procedure assumes that the monthly ground temperature is the average outside air temperature delayed by three months, which is similar to how the ground temperatures on the weather file are calculated. To force the program to use the weather file values, do *not* enter ground temperatures using the GROUND-T keyword in the BUILDING-LOCATION command.

Procedure for defining the underground surface construction

1. Choose a value of the perimeter conduction factor, $F2$, from Table 1, 2 or 3 for the configuration that best matches the type of surface (slab floor, basement wall, crawl-space wall), foundation depth and amount and/or location of insulation.

2. Using $F2$, calculate R_{eff}, the *effective resistance* of the underground surface, which is defined by the following equation:

   $$R_{eff} = A \,/\, (F2 * P_{exp})$$

   where A is the area of the surface (ft^2 or m^2) and P_{exp} is the length (ft or m) of the surface's perimeter that is exposed to the outside air. Figures 1 and 2 show values of P_{exp} for example foundation configurations. If P_{exp} is zero[**], set R_{eff} to a large value, e.g. $R_{eff} = 1000$.

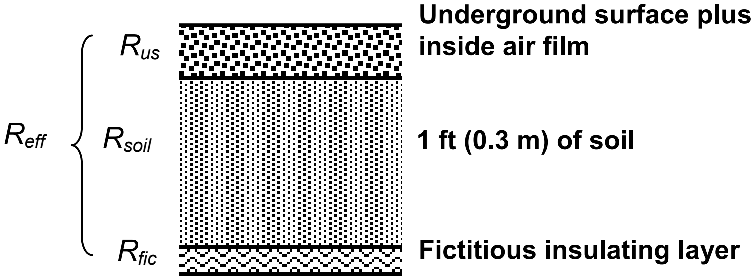
3. Set U-EFFECTIVE = $1/R_{eff}$.

   The program will calculate the heat transfer through the underground surface to be

   $$Q = [U\text{-}EFFECTIVE] * A\,(T_g - T_i)$$

4. Define a construction, shown in the figure below, consisting of the following:

   - The underground wall or floor, including carpeting, if present, and inside film resistance (overall resistance = R_{us})
   - A 1-ft (0.3-m) layer of soil (resistance = R_{soil} = 1.0 hr-ft^2-F/Btu [0.18 m^2-K/W])
   - A fictitious insulating layer (resistance = R_{fic})



   The layer of a soil represents the thermal mass of the ground in contact with the underground surface (a 1-ft [0.3-m] layer is sufficient to account for most of the thermal mass effect). The fictitious insulating layer is required to give the correct effective resistance for the construction, i.e.

$$\boldsymbol{R_{eff} = R_{us} + R_{soil} + R_{fic}}$$

From this we get

$$\boldsymbol{R_{fic} = R_{eff} - R_{us} - R_{soil}}$$

The procedure for defining this construction is shown in the following example.

[**] *The procedure makes the approximation that the heat transfer through an underground surface with no exposed perimeter, such as a basement floor, is zero.*

Example: 50' x 100' slab-on-grade.

The slab consists of uncarpeted, 4-in (10-cm) heavy-weight concrete (CC03 in the DOE-2.1E library), with resistance = 0.44 hr-ft^2-F/Btu (0.078 m^2-K/W). The foundation depth is 4 ft (1.22 m) with R-10 (1.76 m^2-K/W) exterior insulation, which gives F2 = 0.50 Btu/hr-F-ft (0.86 W/m-K) from Table 1. We then have:

Slab surface area: $A = 50\text{x}100 = 5000\ \text{ft}^2$
Slab exposed perimeter: $P_{exp} = (2\text{x}50) + (2\text{x}100) = 300$ ft
Effective slab resistance: $R_{eff} = A/(F2{*}P_{exp}) = 5000/(0.90{*}300) = 33.3$
Effective slab U-value: U-EFFECTIVE = $1/R_{eff} = 0.030$
Actual slab resistance: $R_{us} = 0.44 + R_{film} = 0.44 + 0.77 = 1.21$
Resistance of fictitious layer: $R_{fic} = R_{eff} – R_{us} – R_{soil} = 33.3 – 1.21 – 1.0 = 31.1$

Here, 0.77 hr-ft^2-F/Btu (0.14 m^2-K/W) is the average of the air film resistance for heat flow up— 0.61 hr-ft^2-F/Btu (0.11 m^2-K/W)—and heat flow down— 0.92 hr-ft^2-F/Btu (0.16 m^2-K/W). For vertical surfaces, such as basement walls, you can use R_{film} = 0.68 hr-ft^2-F/Btu (0.12 m^2-K/W).

The input would look like:

```
$ Slab-on-grade $
MAT-FIC-1  = MATERIAL  RESISTANCE = 31.1  .. $ the Rfic value
SOIL-12IN = MATERIAL  THICKNESS = 1.0  CONDUCTIVITY = 1.0
                      DENSITY = 115  SPECIFIC-HEAT = 0.1 ..

LAY-SLAB-1 = LAYERS  MATERIAL = (MAT-FIC-1,SOIL-12IN,CC03)
                     INSIDE-FILM-RES = 0.77 ..

CON-SLAB-1 = CONSTRUCTION LAYERS = LAY-SLAB-1 ..
   .
   .
SLAB-1 = UNDERGROUND-FLOOR HEIGHT = 50
                           WIDTH = 100
                           TILT = 180
                           U-EFFECTIVE = 0.030
                           CONSTRUCTION = CON-SLAB-1 ..
```

Caution: If you change the dimensions of the slab later, be sure to recalculate R_{fic}. For example, if the 50x100-ft slab is changed to 50x80-ft exposed perimeter becomes 260-ft, and we get R_{eff} = 4000/(0.50*260) = 30.8 (rather than 33.3), U-EFFECTIVE = 1/30.8 = 0.033 (rather than 0.030), and R_{fic} = 30.8 – 1.21 – 1.0 = 28.6 (rather than 31.1).

Note (1):

For basements (Table 2) and crawl spaces (Table 3) an 8-in (20.3-cm) high section between ground level and the top of the underground wall is included in the F2 calculation and so does not have to be entered as a separate exterior wall. However, for shallow basements (Table 2) the wall section between the top of the underground wall and main level of the building should be entered as a separate exterior wall.

Note (2):

The floor of a crawl space (Table 3) should be entered as an UNDERGROUND-FLOOR consisting of a 1-ft (0.3-m) layer of soil with a fictitious insulation layer underneath it. Because the exposed perimeter of the floor in this case is zero, the heat transfer is zero, so the fictitious insulation layer should have a very high resistance and U-EFFECTIVE should be close to zero. The input would look like:

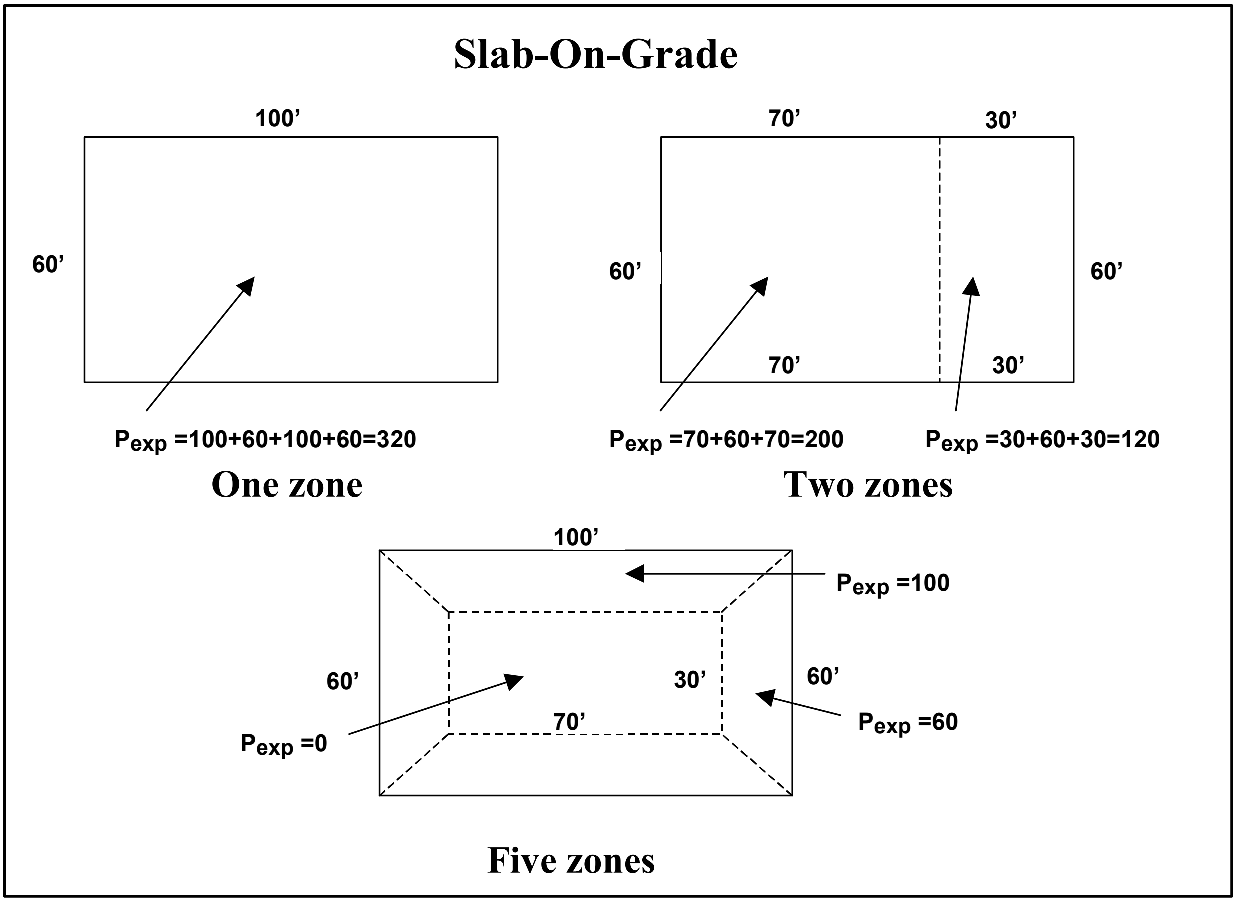
```
$ Crawl space floor $
MAT-FIC-1  = MATERIAL RESISTANCE = 1000  ..
SOIL-12IN = MATERIAL  THICKNESS = 1.0
                      CONDUCTIVITY = 1.0
                      DENSITY = 115
```

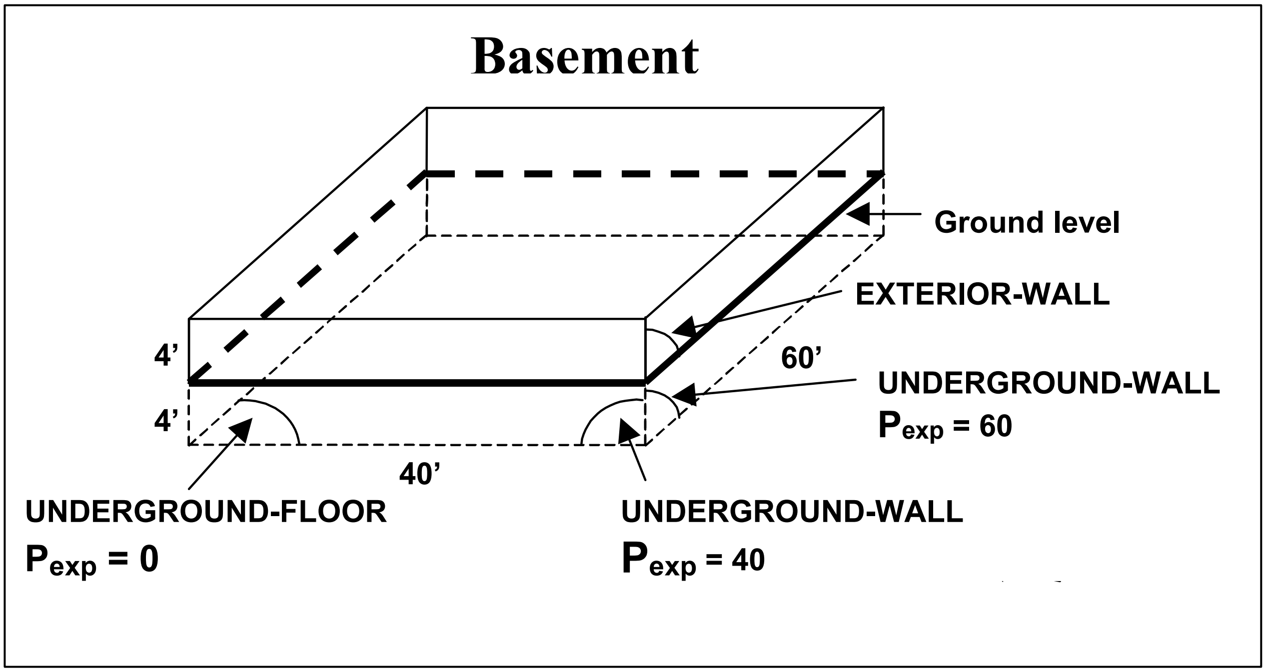
```
                          SPECIFIC-HEAT = 0.1 ..

   LAY-FLOOR-1 = LAYERS   MATERIAL = (MAT-FIC-1, SOIL-12IN)
                          INSIDE-FILM-RES = 0.77 ..

   CON-FLOOR-1 = CONSTRUCTION LAYERS = LAY-FLOOR-1 ..
    ....
   FLOOR-1 = UNDERGROUND-FLOOR HEIGHT = 50
                                WIDTH = 100
                                TILT = 180
                                U-EFFECTIVE = 0.001
                                CONSTRUCTION = CON-SLAB-1 ..
```

Thermal Mass

Underground surfaces are usually concrete and therefore have high thermal mass. Because of its heat storage capacity, this mass attenuates loads due to heat gains (from lights, solar, people, etc.) and causes a time delay between when the heat gain occurs and when it appears as a load on the HVAC system. In general, the higher the heat capacity and the more closely coupled the mass is to the room air, the larger this delay and attenuation will be.

DOE-2 will account for thermal mass only if (1) the underground surface is entered with a layers-type construction, following the procedure described in the previous section; and (2) custom weighting factors are calculated for the space, i.e., FLOOR-WEIGHT = 0 in the SPACE or SPACE-CONDITIONS command.





Exposed perimeter calculation for slab-on-grade examples.

*Table 1: Perimeter Conduction Factors for Concrete Slab-On-Grade**

Slab-On-Grade			
Foundation depth	**Insulation Configuration (see sketch for location of insulation)**	**PERIM-CONDUCT Btu/hr-F-ft (W/m-K)**	
		1.1.1.1 UNCARPETED	***1.1.1.2 CARPETED***
2 ft	Uninsulated	1.10 (1.90)	0.77 (1.33)
	R-5 exterior	0.73 (1.26)	0.54 (0.93)
	R-10 exterior	0.65 (1.12)	0.49 (0.85)
	R-5 interior; R-5 gap	0.75 (1.30)	0.57 (0.98)
	R-10 interior	0.89 (1.54)	0.46 (0.79)
	R-10 interior; R-5 gap	0.70 (1.21)	0.53 (0.92)
	R-10 interior; R-10 gap	0.68 (1.17)	0.52 (0.90)
	R-5 2-ft perimeter; R-5 gap	0.78 (1.35)	0.60 (1.04)
	R-10 2-ft perimeter; R-5 gap	0.73 (1.26)	0.57 (0.98)
	R-10 4-ft perimeter	0.79 (1.36)	0.59 (1.02)
	R-10 15-ft perimeter, R-5 gap	0.39 (0.67)	0.34 (0.59)
	R-5 16-in exterior, R-5 2-ft horizontal	0.65 (1.12)	0.48 (0.83)
	R-5 16-in exterior, R-5 4-ft horizontal	0.58 (1.00)	0.43 (0.74)
	R-10 16-in exterior, R-5 2-ft horizontal	0.56 (0.97)	0.41 (0.71)
	R-10 16-in exterior, R-5 4-ft horizontal	0.47 (0.81)	0.35 (0.60)
4 ft	*Uninsulated*	1.10 (1.90)	0.77 (1.33)
	R-5 exterior	0.61 (1.05)	0.46 (0.79)
	R-10 exterior	0.50 (0.86)	0.37 (0.64)
	R-15 exterior	0.44 (0.76)	0.33 (0.57)
	R-20 exterior	0.40 (0.69)	0.30 (0.52)
	R-5 interior; R-5 gap	0.63 (1.09)	0.48 (0.83)
	R-10 interior; R-5 gap	0.54 (0.93)	0.42 (0.73)
	R-15 interior; R-5 gap	0.50 (0.86)	0.38 (0.66)
	R-20 interior; R-5 gap	0.47 (0.81)	0.36 (0.62)
	R-5 4-ft perimeter; R-5 gap	0.68 (1.17)	0.54 (0.93)
	R-10 4-ft perimeter; R-5 gap	0.61 (1.05)	0.49 (0.85)
	R-10 4-ft perimeter	0.79 (1.36)	0.59 (1.02)
	R-10 15-ft perimeter, R-5 gap	0.39 (0.67)	0.34 (0.59)
	R-5 16-in exterior, R-5 2-ft horizontal	0.65 (1.12)	0.48 (0.83)
	R-5 16-in exterior, R-5 4-ft horizontal	0.58 (1.00)	0.43 (0.74)
	R-10 16-in exterior, R-5 2-ft horizontal	0.56 (0.97)	0.41 (0.71)
	R-10 16-in exterior, R-5 4-ft horizontal	0.47 (0.81)	0.35 (0.60)

*Source: Y.J.Huang, L.S.Shen, J.C.Bull and L.F.Goldberg, “Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program,” ASHRAE Trans. 94 (2), 1988, updated by Y.J.Huang, private communication.

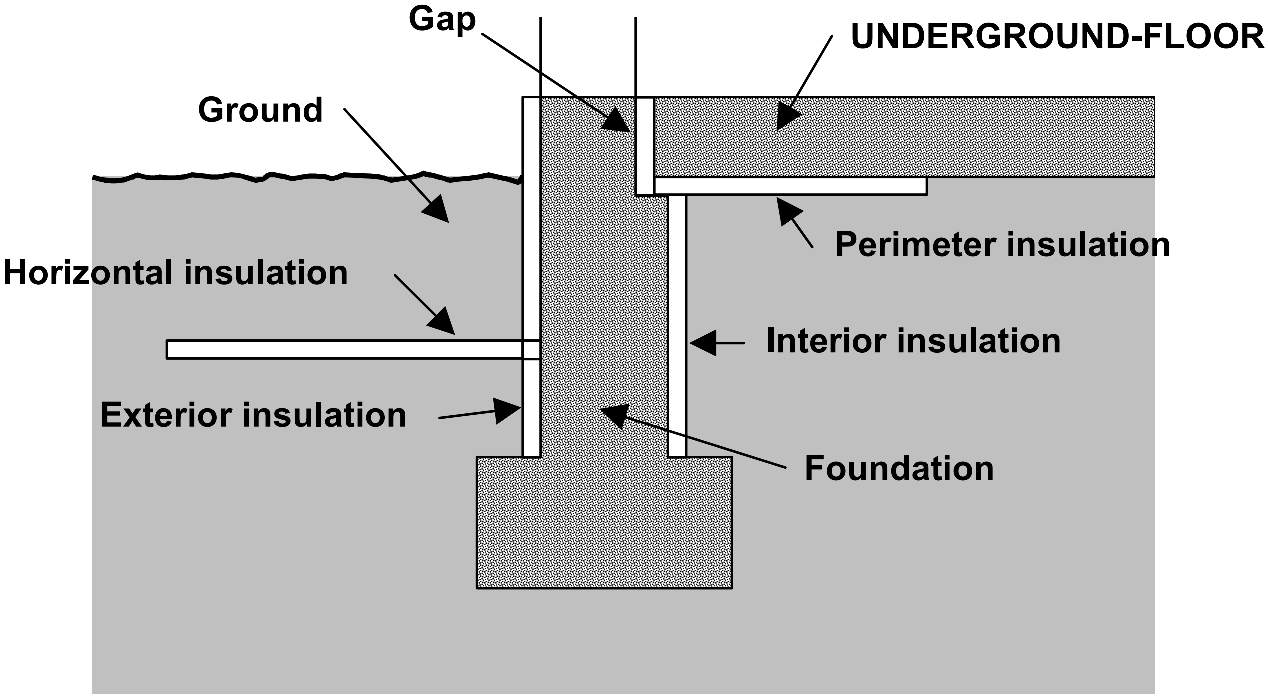
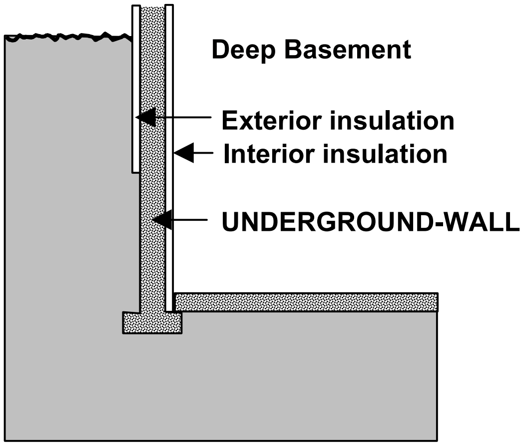

Gap
UNDERGROUND-FLOOR
Ground
Perimeter insulation
Horizontal insulation
Interior insulation
Exterior insulation
Foundation

*Table 2: Perimeter Conduction Factors for Basement Walls**

Basement Wall		
Underground Wall Height	**Construction (see sketch for location of insulation)**	**PERIM-CONDUCT Btu/hr-F-ft (W/m-K)**
8 ft (deep basement)	R-0 (uninsulated), concrete	1.94 (3.35)
	4-ft R-5 exterior, concrete	1.28 (2.21)
	8-ft R-5 exterior, concrete	0.99 (1.71)
	4-ft R-10 exterior, concrete	1.15 (1.99)
	8-ft R-10 exterior, concrete	0.75 (1.30)
	8-ft R-15 exterior, concrete	0.63 (1.09)
	8-ft R-20 exterior, concrete	0.56(0.97)
	8-ft R-10 interior, concrete	0.78 (1.35)
	R-0, wood frame	1.30 (2.25)
	R-11, wood frame	0.88 (1.52)
	R-19, wood frame	0.79 (1.37)
	R-30, wood frame	0.66 (1.14)
4 ft (shallow basement)	R-0 (uninsulated), concrete	1.61 (2.78)
	R-5 exterior, concrete	0.89 (1.54)
	R-10 exterior, concrete	0.73 (1.26)
	R-15 exterior, concrete	0.66 (1.14)
	R-20 exterior, concrete	0.65 (1.12)
	R-10 interior, concrete	0.79 (1.37)
	R-0, wood frame	1.10 (1.90)
	R-11, wood frame	0.80 (1.38)
	R-19, wood frame	0.74 (1.28)

*Source: Y.J.Huang, L.S.Shen, J.C.Bull and L.F.Goldberg, "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program," ASHRAE Trans. 94 (2), 1988, updated by Y.J. Huang, private communication.



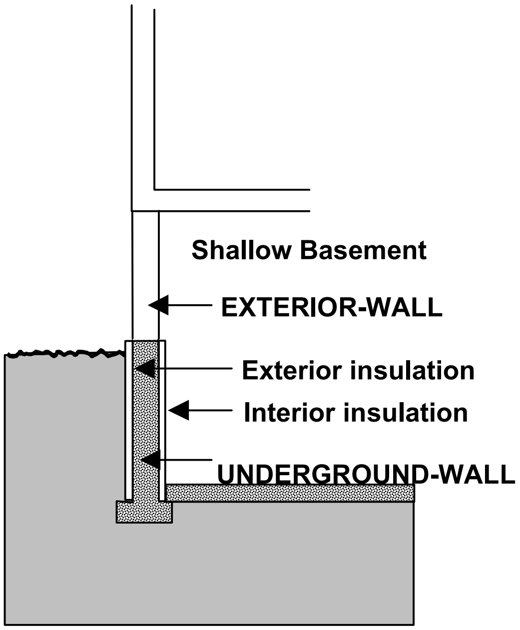
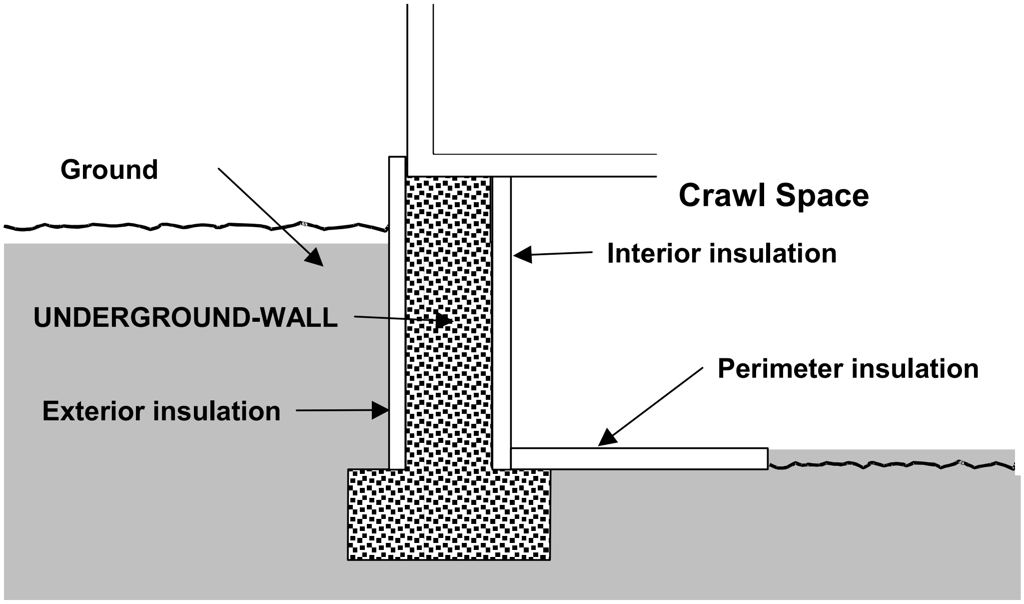


*Table 3: Perimeter Conduction Factors for Crawl Space Walls**

Crawl Space Wall		
Wall Height	***Construction (see sketch for location of insulation)***	***PERIM-CONDUCT Btu/hr-F-ft (W/m-K)***
2 ft	*R-0 (uninsulated), concrete*	*1.29 (2.23)*
	R-5 exterior, concrete	*0.93 (1.61)*
	R-10 exterior, concrete	*0.87 (1.95)*
	R-5 interior, concrete	*0.97 (1.50)*
	R-10 interior, concrete	*0.91 (1.57)*
	R-5 interior; R-5 4-ft perimeter, concrete	*0.73 (1.26)*
	R-10 interior; R-10 4-ft perimeter, concrete	*0.68 (1.18)*
	R-0, wood frame	*1.00 (1.73)*
	R-11, wood frame	*0.88 (1.52)*
	R-19, wood frame	*0.86 (1.49)*
4 ft	*R-0 (uninsulated), concrete*	*1.28 (2.21)*
	R-5 exterior, concrete	*0.71 (1.23)*
	R-10 exterior, concrete	*0.59 (1.02)*
	R-15 exterior, concrete	*0.54 (0.93)*
	R-20 exterior, concrete	*0.50 (0.86)*
	R-5 interior; R-5 4-ft perimeter, concrete	*0.64 (1.11)*
	R-10 interior; R-10 4-ft perimeter, concrete	*0.58 (1.00)*
	R-0, wood frame	*0.83 (1.44)*
	R-11, wood frame	*0.59 (1.02)*
	R-19, wood frame	*0.55 (0.95)*

*Source: Y.J.Huang, L.S.Shen, J.C.Bull and L.F.Goldberg, "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program," ASHRAE Trans. 94 (2), 1988, updated by Y.J. Huang, private communication.


Ground
Crawl Space
Interior insulation
UNDERGROUND-WALL
Perimeter insulation
Exterior insulation