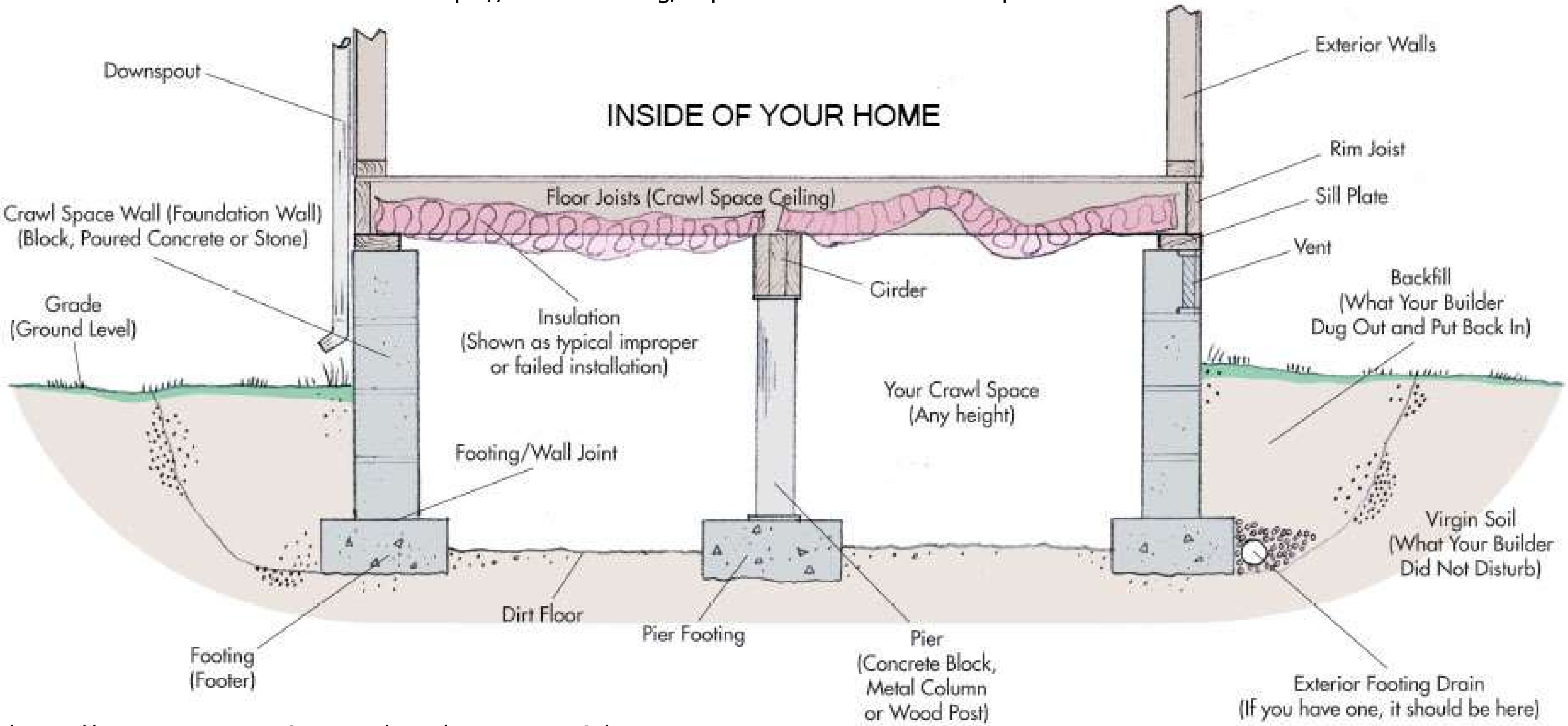
Crawl space

https://www.nachi.org/inspect-correct-vented-crawlspace.htm



https://eco-proconstruction.com/crawl-space-repair/

Doors

- Table E.10

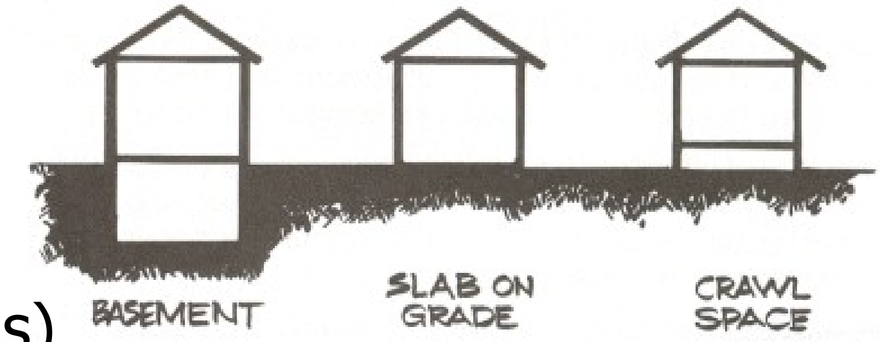
Table E.10 Transmission Coefficients (U-Factors) for Wood and Steel Doors

Nominal Door Thickness			*Wood Storm Door*[a]		*Metal Storm Door*[b]		*No Storm Door*	
			I-P	*SI*	*I-P*	*SI*	*I-P*	*SI*
in.	*mm*		Btu/h ft² °F	W/m² K	Btu/h ft² °F	W/m² K	Btu/h ft² °F	W/m² K
Unglazed Wood Doors[c, d]								
1 3/8	35	Panel door with 7/16-in. (11-mm) panels[e]	0.33	1.87	0.37	2.10	0.57	3.24
1 3/8	35	Hollow core flush door	0.30	1.70	0.32	1.82	0.47	2.67
1 3/8	35	Solid core flush door	0.26	1.48	0.28	1.59	0.39	2.21
1 3/4	45	Panel door with 7/16-in. (11-mm) panels	0.32	1.82	0.36	2.04	0.54	3.07
1 3/4	45	Hollow core flush door	0.29	1.65	0.32	1.82	0.46	2.61
1 3/4	45	Panel door with 1 1/8-in. (29-mm) panels	0.26	1.48	0.28	1.59	0.39	2.21
1 3/4	45	Solid core flush door	—	—	0.26	1.48	0.40	2.27
2 1/4	57	Solid core flush door	0.20	1.14	0.21	1.19	0.27	1.53
Unglazed Steel Doors[d]								
1 3/4	45	Fiberglass or mineral wool core with steel stiffeners, no thermal break[f]			—	—	0.60	3.41
1 3/4	45	Paper honeycomb core without thermal break[f]			—	—	0.56	3.18
1 3/4	45	Solid urethane foam core without thermal break[c]			—	—	0.40	2.27
1 3/4	45	Solid fire-rated mineral fiberboard core without thermal break[f]			—	—	0.38	2.16
1 3/4	45	Polystyrene core without thermal break[f] (18-gage [1.31-mm] commercial steel)			—	—	0.35	1.99
1 3/4	45	Polyurethane core without thermal break[f] (24-gage [0.70-mm] residential steel)			—	—	0.29	1.65
1 3/4	45	Polyurethane core with thermal break and wood perimeter[f] (24-gage [0.70-mm] residential steel)			—	—	0.20	1.14
1 3/4	45	Solid urethane foam core with thermal break[c]			0.16	0.91	0.20	1.14

Special envelope heat flow conditions

- Ex.: Slab-on-grade floors, below-ground walls and floors
- Typically, data from empirical studies are used in lieu of conventional heat transfer equations.
- Because the concept of U-factor is so simple to understand and apply, much of the empirical data are presented in terms of equivalent U-factors.

Floor



- Above grade
  - $Q=UA(T_i - T_o)$ (same as walls)
- Slab on grade
  - Heat flow is strongly related to slab perimeter length
  - $Q=F_2P(T_i - T_o)$ (P: perimeter of slab, F_2:Tables E.11-12)
- Basement: below grade (floor, wall)
  - $Q=U_{avg}A(T_i - T_g)$
    - U_{avg}: average U-factor for basement walls and floors. Refer to Table E.13
    - T_i=inside air temperature
  - $T_g=T_{avg} - Amp$
    - T_g=design ground surface temperature (refer to Ex. 9.4)
    - T_{avg}: average winter air temperature (refer to Ex. 9.4)
    - Amp from Fig.9.10 (refer to Ex. 9.4)
    - In the textbook, T_{avg} is assumed to be the average of the ambient temperature (TA) for January and for the year

Slab on grade (ASHRAE F.28.12, 2001)

- Concrete slab floors may be (1) unheated, relying for warmth on heat delivered above floor level by the heating system, or (2) heated, containing heated pipes or ducts that constitute a radiant slab or portion of it for complete or partial heating of the house.
- Wang (1979) and Bligh et al. (1978) found that heat loss from an concrete slab floor is mostly through the perimeter rather than through the floor and into the ground.
- Total heat loss is more nearly proportional to the length of the perimeter than to the area of the floor, and it can be estimated by the following equation for both unheated and heated slab floors:

$$Q=F_2P(T_i - T_o)$$

F_2 = heat loss coefficient per foot of perimeter, W/(m·K)

P = perimeter or exposed edge of floor, m

T_i = indoor temperature, °C

T_o = outdoor temperature, °C

Slab-on-grade floors

- The ground temperature is different from outdoor air temperature, and earth is more conductive than air.
- The heat flow is strongly dependent on the slab perimeter length.
- Table E.11 presents F_2 for three climate zones. Interpolation can be used for other climate zones (correlated to Heating Degree Days).

Table E.11 Heat Loss Coefficients (F_2) for Slab-on-Grade Floors

		I-P *Btu/h °F ft Perimeter* *Degree Days (65°F base)*			*SI* *W/K m Perimeter* *Degree Days (18°C base)*		
Construction[a]	**Insulation**	**2950**	**5350**	**7433**	**1640**	**2970**	**4130**
(a) Block wall, 8 in. (200 mm), brick facing	Uninsulated	0.62	0.68	0.72	1.07	1.17	1.24
	Insulated from edge to footer: R-5.4 h ft² °F/Btu (SI: R-0.95 m² K/W)	0.48	0.50	0.56	0.83	0.86	0.97
(b) Block wall, 4 in. (100 mm), brick facing	Uninsulated	0.80	0.84	0.93	1.38	1.45	1.61
	Insulated from edge to footer: R-5.4 h ft² °F/Btu (SI: R-0.95 m² K/W)	0.47	0.49	0.54	0.81	0.85	0.93
(c) Metal stud wall, stucco	Uninsulated	1.15	1.20	1.34	1.99	2.07	2.32
	Insulated from edge to footer: R-5.4 h ft² °F/Btu (SI: R-0.95 m² K/W)	0.51	0.53	0.58	0.88	0.92	1.00
(d) Poured concrete wall with duct near perimeter[b]	Uninsulated	1.84	2.12	2.73	3.18	3.67	4.72
	Insulated from edge to footer, and 3 ft. [910 mm] under floor slab R-5.4 h ft² °F/Btu (SI: R-0.95 m² K/W)	0.64	0.72	0.90	1.11	1.24	1.56

Source: Reprinted with permission; ©ASHRAE, www.ashrae.org. 2017 *ASHRAE Handbook—Fundamentals*. The SI units for F_2 shown in the last three columns were appended to the ASHRAE I-P data by the authors.

[a]See Fig.E.1 for illustrations of the listed constructions.

[b]Weighted average temperature of heating duct was assumed to be 110°F (43°C) during the heating season (outdoor air temperature less than 65°F [18°C]).

Note: To use this table:

$q = F_2 P \Delta t$

where

q = heat loss through perimeter (Btu/h or W)

F_2 = heat loss coefficient from above

P = perimeter of exposed slab edge (ft or m)

Δt = temperature difference between indoor and outdoor air (°F or °C).

Do not assume additional losses from the slab to the earth below. Heat gains are assumed to be nonexistent.

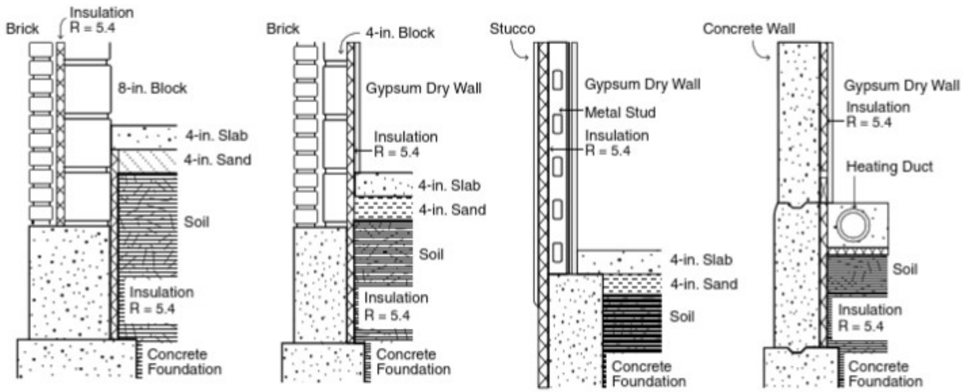


Fig. E.1 *Insulation and construction configurations for Table E.11 data (heat loss coefficients for slab-on-grade floors). (Redrawn by Martin Lee; data used with the permission of ASHRAE, from the* 2001 ASHRAE Handbook—Fundamentals. *This citation to an older version of the* Handbook *is intentional and provides access to historic reference information of ongoing interest.)*

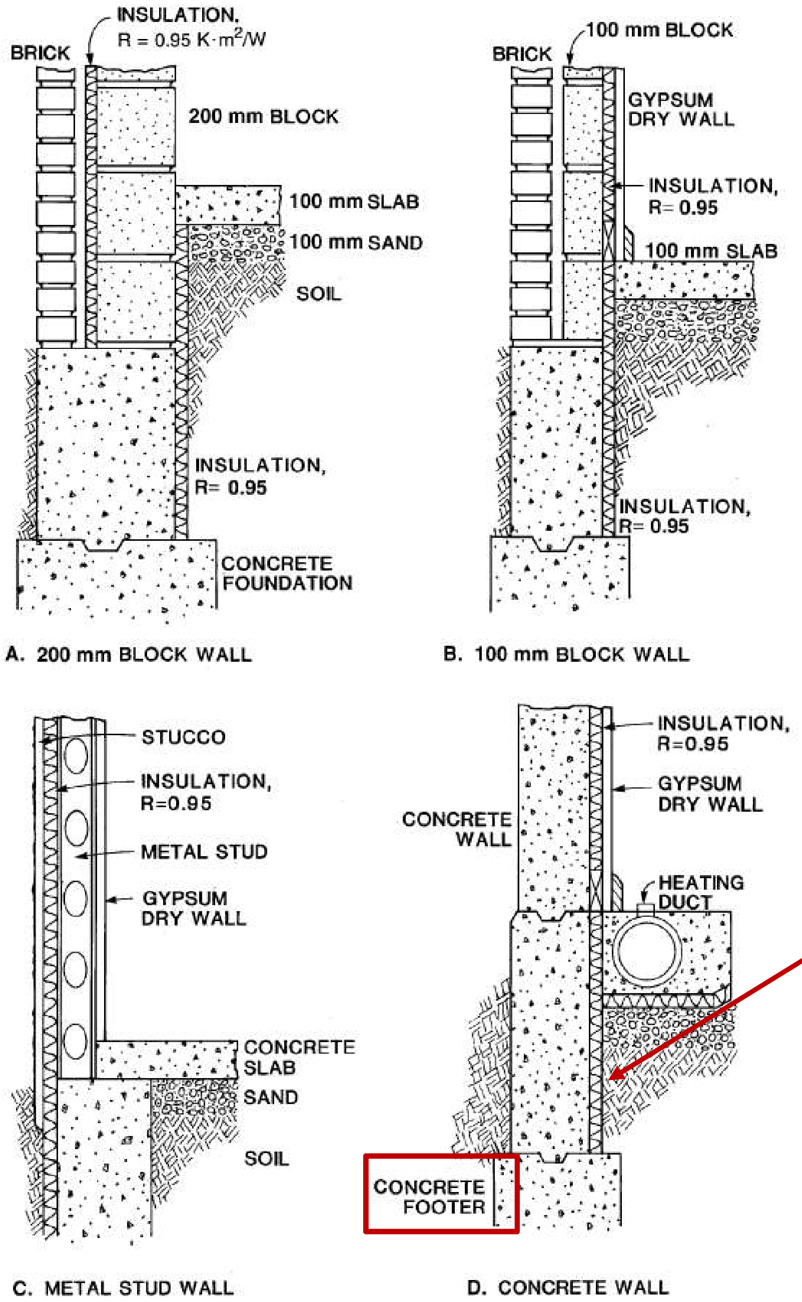


Fig. 8 Slab-on-Grade Foundation Insulation

Table 16 Heat Loss Coefficient F_2 of Slab Floor Construction, W/K per metre of Perimeter

		Kelvin Days (18°C Base)		
Construction	**Insulation**	**1640 K·d/yr**	**2970 K·d/yr**	**4130 K·d/yr**
200 mm block wall, brick facing	Uninsulated	1.07	1.17	1.24
	$R = 0.95\ K \cdot m^2/W$ from edge to footer	0.83	0.86	0.97
100 mm block wall, brick facing	Uninsulated	1.38	1.45	1.61
	R = 0.95 from edge to footer	0.81	0.85	0.93
Metal stud wall, stucco	Uninsulated	1.99	2.07	2.32
	R = 0.95 from edge to footer	0.88	0.92	1.00
Poured concrete wall with duct near perimeter[a]	Uninsulated	3.18	3.67	4.72
	R = 0.95 from edge to footer, 910 mm under floor	1.11	1.24	1.56

ASHRAE F.28.13, 2001

To determine whether more slab-edge insulation seems desirable → consult Table E.12

TABLE E.12 Heat Flow Coefficients (F_2) for Slab-on-Grade Floors with Various Insulation Strategies

R-Value, Position, and Width (or Depth) of Insulation	F_2 I-P Btu/h ft °F	F_2 SI W/m K
Uninsulated slab	0.73	1.26
R-5 (SI: R-0.88) Horizontal insulation, 2 ft (0.6 m), no thermal break	0.70	1.21
R-10 (SI: R-1.76) Horizontal insulation, 2 ft (0.6 m), no thermal break	0.70	1.21
R-15 (SI: R-2.64) Horizontal insulation, 2 ft (0.6 m), no thermal break	0.69	1.19
R-5 (SI: R-0.88) Horizontal insulation, 4 ft (1.2 m), no thermal break	0.67	1.16
R-10 (SI: R-1.76) Horizontal insulation, 4 ft (1.2 m), no thermal break	0.64	1.11
R-15 (SI: R-2.64) Horizontal insulation, 4 ft (1.2 m), no thermal break	0.63	1.09
R-5 (SI: R-0.88) Vertical insulation, 2 ft (0.6 m)	0.58	1.00
R-10 (SI: R-1.76) Vertical insulation, 2 ft (0.6 m)	0.54	0.93
R-15 (SI: R-2.64) Vertical insulation, 2 ft (0.6 m)	0.52	0.90
R-5 (SI: R-0.88) Vertical insulation, 4 ft (1.2 m)	0.54	0.93
R-10 (SI: R-1.76) Vertical insulation, 4 ft (1.2 m)	0.48	0.83
R-15 (SI: R-2.65) Vertical insulation, 4 ft (1.2 m)	0.45	0.78
R-10 (SI: R-1.76) Fully insulated slab (insulated under entire slab as well as around edge)	0.36	0.62

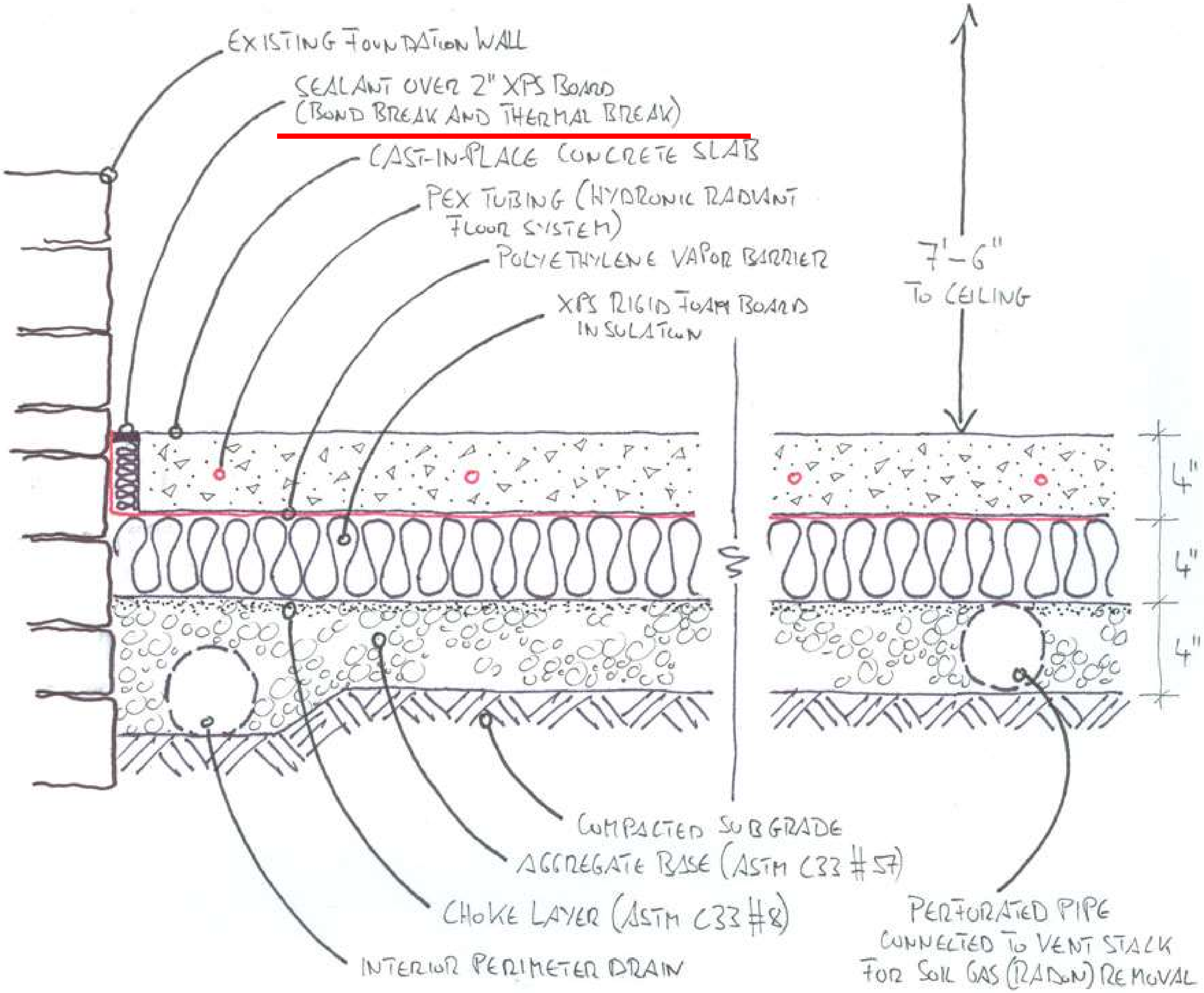
Source: Reprinted with permission; ©ASHRAE, ANSI/ASHRAE/IESNA Standard 90.1-2013: *Energy Standard for Buildings Except Low-Rise Residential Buildings*.

Insulation is extruded polystyrene, R = 5.0 h ft² °F/Btu-in. (SI: R = 34.7 m K/W).

Soil conductivity is 0.75 Btu/h ft °F (1.30 W/K m).

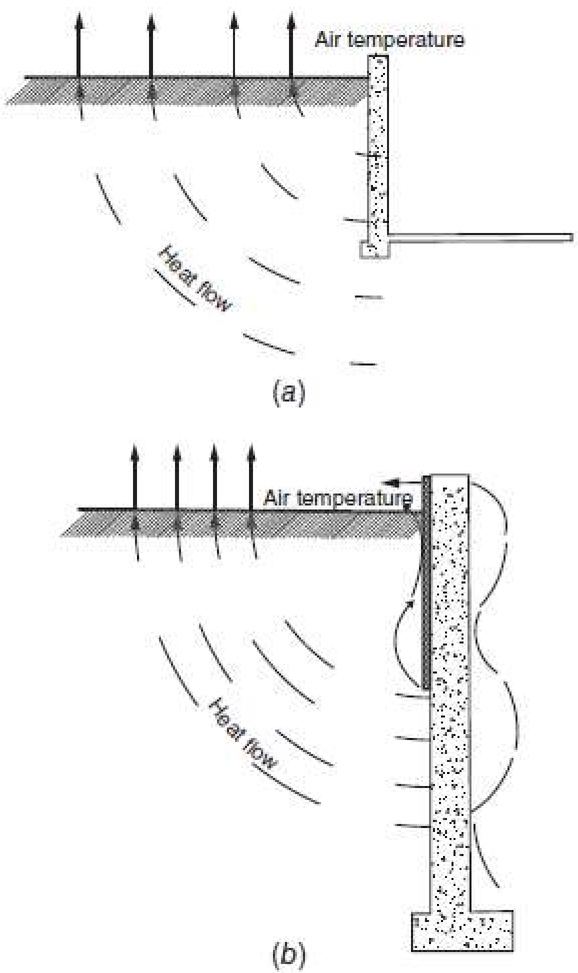
No thermal break at edge of slab, where so indicated. If a thermal break is provided with horizontal insulation, use the corresponding value for vertical insulation.

Values assume an unheated slab; F_2 values increase substantially when slab is heated.


EXISTING FOUNDATION WALL
SEALANT OVER 2" XPS BOARD (BOND BREAK AND THERMAL BREAK)
CAST-IN-PLACE CONCRETE SLAB
PEX TUBING (HYDRONIC RADIANT FLOOR SYSTEM)
POLYETHYLENE VAPOR BARRIER
XPS RIGID FOAM BOARD INSULATION
7'-6" TO CEILING
4"
4"
4"
COMPACTED SUBGRADE
AGGREGATE BASE (ASTM C33 #57)
CHOKE LAYER (ASTM C33 #8)
INTERIOR PERIMETER DRAIN
PERFORATED PIPE CONNECTED TO VENT STACK FOR SOIL GAS (RADON) REMOVAL

Basement

- Heat flow through basement walls and floors is complicated by an increasing length of heat flow path with increasing depth, as shown in Fig 9.10a and b.



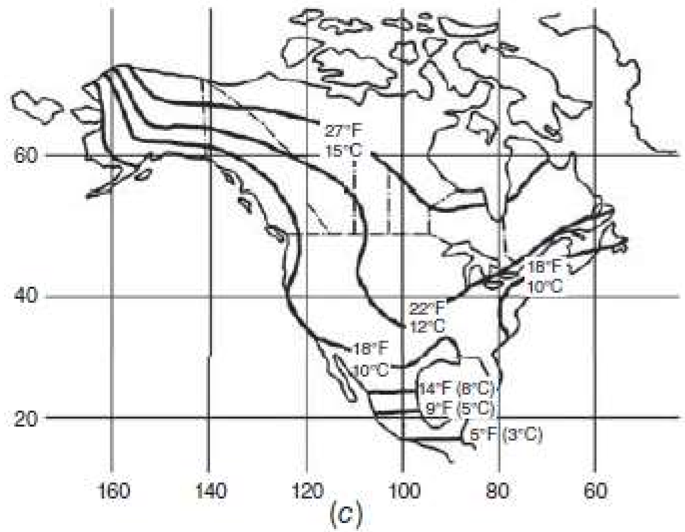
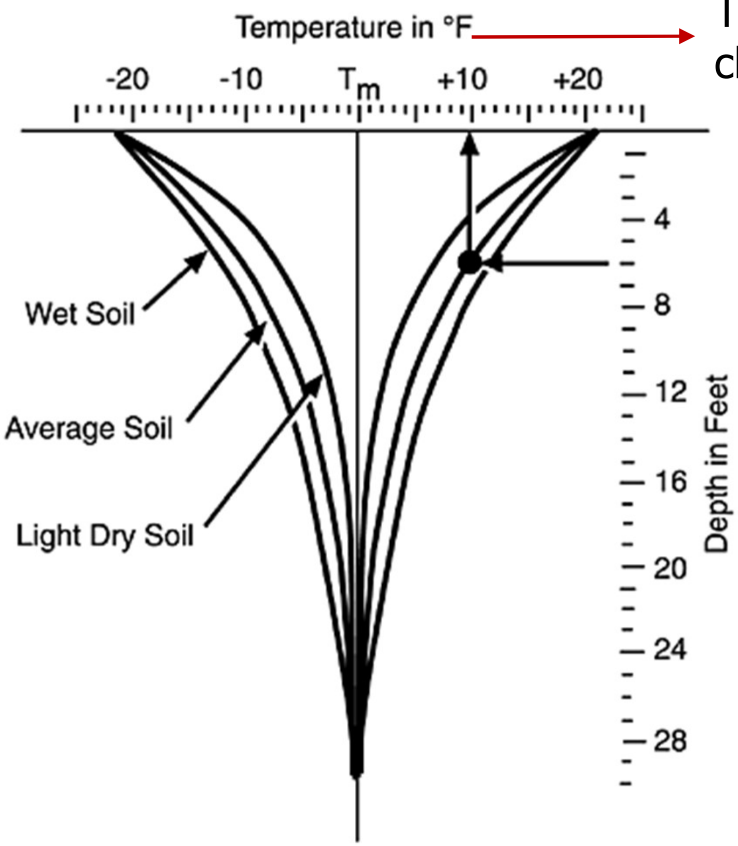


Fig. 9.10 Heat flow below grade. (a) Heat flow through basement walls and floors follows radial paths (that are generally perpendicular to soil isotherms). (b) Heat flow paths of differing lengths for a partially insulated basement wall. (c) Lines of constant amplitude of ground temperature; just below the surface, the ground temperature fluctuates around a mean annual temperature by this amplitude. (a: Reprinted with permission; ©ASHRAE, www.ashrae.org. 2017 ASHRAE Handbook—Fundamentals; b: Reprinted with permission of ASHRAE, from the 2001 ASHRAE Handbook—Fundamentals; redrawn by Sharon Alitema; the referral to an older version of the ASHRAE Handbook is intentional and provides access to historic reference information of ongoing interest; c: Reprinted with permission; © ASHRAE, 2017 ASHRAE Handbook—Fundamentals.)

- A further complication is that the temperature of the earth is not equal to ambient air temperature and becomes more and more out of phase with air temperature at increasing depths.



The amplitude of seasonal changes in soil temperature

Figure 3. Amplitude of seasonal soil temperature change as a function of depth below ground surface.

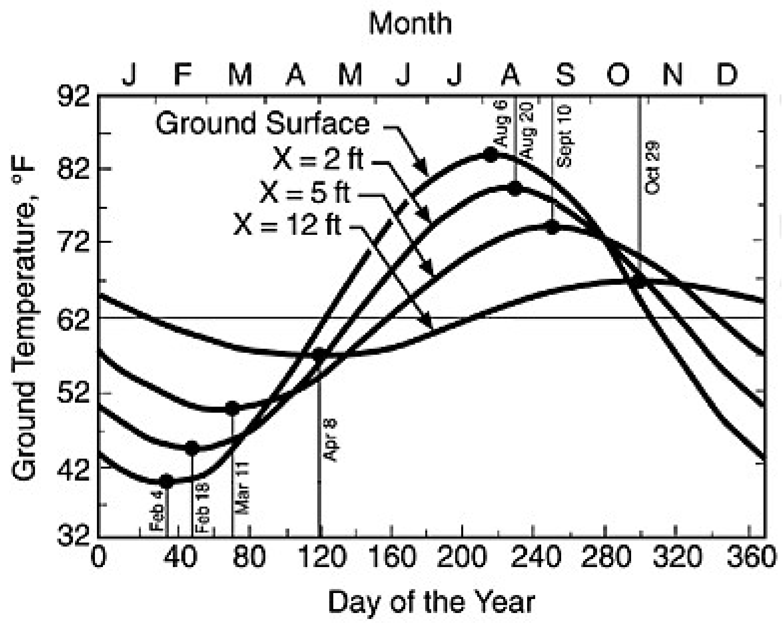


Figure 4. Seasonal soil temperature change as a function of depth below ground surface for an average moist soil.

Image sources: https://www.builditsolar.com/Projects/Cooling/EarthTemperatures.htm

Attic temperature (ASHRAE F.28.8, 2001)

Attic Temperature

An attic is a space having an average distance of 0.3 m or more between a ceiling and the underside of the roof. Estimating attic temperature is a special case of estimating temperature in an adjacent unheated space and can be done using

$$t_a = \frac{A_c U_c t_c + t_o(\rho c_p A_c V_c + A_r U_r + A_w U_w + A_g U_g)}{A_c(U_c + \rho c_p V_c) + A_r U_r + A_w U_w + A_g U_g} \quad (3)$$

where

ρc_p = air density times specific heat = 1.20 kJ/($m^3 \cdot K$) for standard air
t_a = attic temperature, °C
t_c = indoor temperature near top floor ceiling, °C
t_o = outdoor temperature, °C
A_c = area of ceiling, m^2
A_r = area of roof, m^2
A_w = area of net vertical attic wall surface, m^2
A_g = area of attic glass, m^2
U_c = heat transfer coefficient of ceiling, W/($m^2 \cdot K$), based on surface conductance of 12.5 W/($m^2 \cdot K$) (upper surface, see Table 2 in Chapter 25); 12.5 = reciprocal of one-half the air space resistance
U_r = heat transfer coefficient of roof, W/($m^2 \cdot K$), based on surface conductance of 12.5 W/($m^2 \cdot K$) (upper surface, see Table 2 in Chapter 25); 12.5 = reciprocal of one-half the air space resistance
U_w = heat transfer coefficient of vertical wall surface, W/($m^2 \cdot K$)
U_g = heat transfer coefficient of glass, W/($m^2 \cdot K$)
V_c = rate of introduction of outside air into the attic space by ventilation per square metre of ceiling area, L/($s \cdot m^2$)

Example 3. Calculate the temperature in an unheated attic assuming t_c = 21°C; t_o = −12°C; A_c = 100 m²; A_r = 120 m²; A_w = 10 m²; A_g = 1.0 m²; U_r = 2.8 W/(m²·K); U_c = 2.3 W/(m²·K); U_w = 1.7 W/(m²·K); U_g = 6.4 W/(m²·K); and V_c = 2.5 L/(s·m²).

Solution: Substituting these values into Equation (3),

$$\begin{aligned} t_a &= [(100 \times 2.3 \times 20) + (-12)(1.2 \times 100 \times 2.5 \\ &\quad + 120 \times 2.8 + 10 \times 1.7 + 1.0 \times 6.4)] \\ &\quad \div [100(2.3 + 1.2 \times 2.5) \\ &\quad + 120 \times 2.8 + 10 \times 1.7 + 1.0 \times 6.4] \\ t_a &= -3313/889 = -3.7\,°C \end{aligned}$$

EXAMPLE 9.3 A warehouse will be built with a slab-on-grade floor. The warehouse is 80 ft (24.4 m) square in plan. What is the relationship between total slab insulation and rate of heat flow through the slab?

SOLUTION

From Table E.12, F_2 is related to total insulation as follows: building slab perimeter—four sides at 80 ft (24.4 m) each = 320 ft (97.5 m); building slab area: 80 ft (24.4 m) × 80 ft (24.4 m) = 6400 ft² (595 m²).

Baseline: $F_2P = 1.26 * 24.4 * 4 = 123$

<calculation of $\triangle F_2P$>

Baseline vs. Case I : 123 – 97.6 = 25.4

Case I vs. Case II : 97.6 – 81.0 = 16.6

Case II vs. Case III: 81.0 - 60.5 = 20.5

<calculation of $\triangle$insulation (m³) >

Baseline vs. Case I : 1.5 – 0 = 1.5m³

Case I vs. Case II : 6.0- 1.5 = 4.5m³

Case II vs. Case III: 33.3 – 6.0 = 27.3m³

< calculation of $\triangle F_2P/\triangle$insulation (m³) >

25.4/1.5 = 16.9 reduction in $\triangle F_2P$ per unit insulation (m³)

16.6/4.5 = 3.69

20.5/27.3 = 0.75

SI Units:

	Insulation Approach	Total Volume of Slab Insulation Used (m³)	~~F_2 (W/K)~~	F_2 × Perimeter = Rate of Heat Flow ~~(W/m·K)~~	Reduction in Heat Flow (W/K)	Reduction per Unit (m³) of Insulation
baseline	Uninsulated slab	None	1.26	123	None	—
Case I (2'vertical+ 1"thick)	R-0.9 vertical, 0.6 m, 25 mm	(0.6 m) (97.8 m) (0.025 m) = 1.5	1.0	97.5	25.5	17.0
Case II (4' vertical, 2" thick)	R-1.8 vertical, 1.2 m, 50 mm	(1.2 m) (97.8 m) (0.051 m) = 6.0	0.83	80.9	16.6	2.8
Case III (2' vertical, 2" thick & insulated under entire floor slab)	R-1.8 fully insulated 50 mm	(0.6 m) (97.8 m) (0.051 m) + (595 m²) (0.051 m) = 33.3	0.62	60.5	20.4	0.6

→ =24.4²

Thus, a minimal initial investment of 640 ft² (60 m²) of 1-in.- (25-mm)-thick insulation cuts the uninsulated slab heat flow by one-fifth. However, a vastly greater investment of 7040 ft² (654 m²) of 2-in.- (50 mm)-thick insulation (22 times as much!) cuts the less-insulated heat flow only by one-fourth. ■

Principle of diminishing returns !!

EXAMPLE 9.4 Calculate the design heat loss for a basement in Minneapolis, Minnesota, which is 28 ft (8.5 m) wide by 30 ft (9.1 m) long, sunk 6 ft (1.8 m) below grade. An insulation of R-10 (SI: R-1.8) is applied to this wall to a depth of 2 ft (0.6 m) below grade. An internal temperature of 70°F (21°C) is to be maintained.

SOLUTION

The soil-path design temperature is estimated from Tables C.19 and C.20; for Minneapolis, the TA in January is 12°F (−11°C); TA for the year is 44°F (6.7°C); the average of these is 28°F (−2°C). From Fig. 9.10c, the amplitude at Minneapolis is about 24F° degrees (13.3C°). The design temperature at the ground surface is therefore 28 − 24 = 4°F (−2 − −13.3 = −15.3°C).

The heat loss through the basement wall is estimated using Table E.13, Part A, by determining the loss per degree of temperature difference per 1-ft-(0.305-m)-high strip of wall and then summing for the full height of the wall:

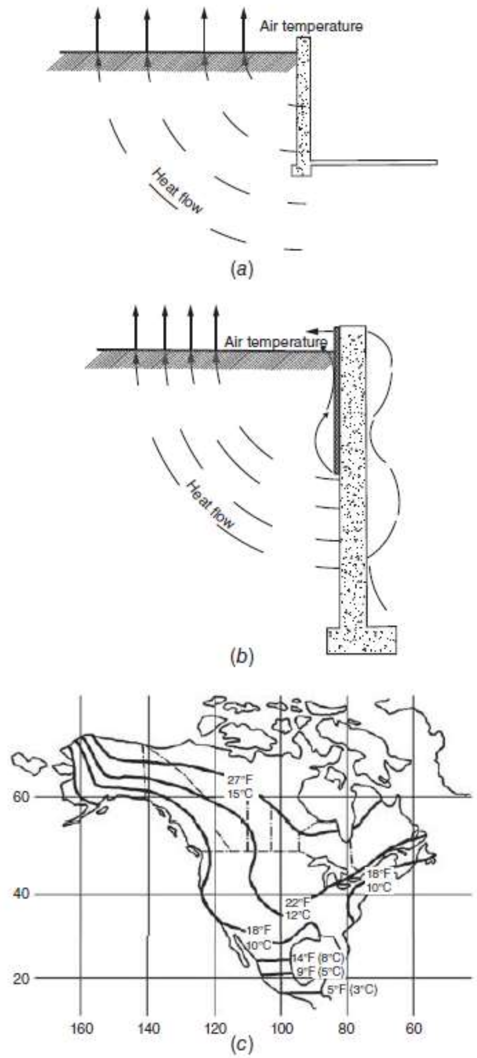


Fig. 9.10 Heat flow below grade. (a) Heat flow through basement walls and floors follows radial paths (that are generally perpendicular to soil isotherms). (b) Heat flow paths of differing lengths for a partially insulated basement wall. (c) Lines of constant amplitude of ground temperature; just below the surface, the ground temperature fluctuates around a mean annual temperature by this amplitude. (a: Reprinted with permission; ©ASHRAE, www.ashrae.org. 2017 ASHRAE Handbook—Fundamentals; b: Reprinted with permission of ASHRAE, from the 2001 ASHRAE Handbook—Fundamentals; redrawn by Sharon Alitema; the referral to an older version of the ASHRAE Handbook is intentional and provides access to historic reference information of ongoing interest; c: Reprinted with permission; © ASHRAE, 2017 ASHRAE Handbook—Fundamentals.)

1st ft below grade (insulated)	0.080 Btu/h ft °F
SI: 1st 0.3 m: per m height (0.458) (0.305)	= 0.140 W/m K
2nd ft below grade (insulated)	0.075
SI: 2nd 0.3 m: (0.427) (0.305)	= 0.130
3rd ft below grade (uninsulated)	0.273[3]
SI: 3rd 0.3 m: (1.571) (0.305)	= 0.479[3]
4th ft below grade (uninsulated)	0.235
SI: 4th 0.3 m: (1.353) (0.305)	= 0.413
5th ft below grade (uninsulated)	0.208
SI: 5th 0.3 m: (1.195) (0.305)	= 0.364
6th ft below grade (uninsulated)	0.187
SI: 6th 0.3 m: (1.075) (0.305)	= 0.328
Total per 6-ft height and 1-ft length of wall	1.058 Btu/h ft °F
Total per 1.8-m height and 1-m length of wall	1.854 W/m K

Basement perimeter = 2 (28 + 30 ft) = 116 ft

SI: 2 (8.5 + 9.1 m) = 35.2 m

Total wall heat loss = 1.058 Btu/h ft °F × 116 ft = 123 Btu/h °F

SI: 1.854 W/m K × 35.2 m = 65.3 W/K

The heat loss through the basement floor is calculated using Table E.13, Part B.

Average heat loss per ft^2 floor

= 0.030 Btu/h ft^2°F (for 28-ft width, 6-ft depth);

SI: per m^2 floor = 0.171 W/m^2 K

(for 8.5-m width, 1.8-m depth)

Floor area = 28 ft × 30 ft = 840 ft^2

SI: area = 8.5 m × 9.1 m = 77.4 m^2

Total floor heat loss = 0.030 Btu/h ft^2 °F × 840 ft^2 = 25 Btu/h °F

SI: ~~0.171~~ 0.176 W/m^2K × 77.4 m^2 = 13.2 W/K

Total heat loss per degree of temperature difference for the basement below grade: walls 123 + floor 25 = 148 Btu/h °F

SI: walls 65.3 + floor 13.2 = 78.5 W/K

Design temperature difference: (from text above) = 48°F (26.4°C)

Design heat loss below grade = 148 Btu/h °F × 48 °F = 7104 Btu/h

SI: design below-grade heat loss = 78.5 W/K × ~~26.4~~ 36.4 °C or K = ~~2072~~ 2824.7 W ■

Source: ASHRAE F. 29.12

$$\mathrm{HF} = U_{avg}(t_{in} - t_{gr}) \quad (35)$$

where

U_{avg} = average U-factor for below-grade surface, W/($m^2 \cdot$K), from Equation (37) or (38)

t_{in} = below-grade space air temperature, °C

t_{gr} = design ground surface temperature, °C, from Equation (36)

The effect of soil heat capacity means that none of the usual external design air temperatures are suitable values for t_{gr}. Ground surface temperature fluctuates about an annual mean value by amplitude A, which varies with geographic location and surface cover. The minimum ground surface temperature, suitable for heat loss estimates, is therefore

$$t_{gr} = \bar{t}_{gr} - A \quad (36)$$

where

$\bar{t}_{gr}$ = mean ground temperature, °C, estimated from the annual average air temperature or from well-water temperatures, shown in Figure 18 of Chapter 32 in the 2003 *ASHRAE Handbook—HVAC Applications* (Alternatively, t_{gr} may also be estimated as the mean air temperature during the coldest month.)

A = ground surface temperature amplitude, °C, from Figure 2 for North America

TABLE E.13 Heat Flow through Below-Grade Walls and Floors[a]

SI Units

Part A: Average U-Factor for Basement Walls with Uniform Insulation				
	$U_{avg,bw}$ from Grade to Depth, W/m²·K			
Depth, m	**Uninsulated**	**R-0.88**	**R-1.76**	**R-2.64**
0.3	2.468	0.769	0.458	0.326
0.6	1.898	0.689	0.427	0.310
0.9	1.571	0.628	0.401	0.296
1.2	1.353	0.579	0.379	0.283
1.5	1.195	0.539	0.360	0.272
1.8	1.075	0.505	0.343	0.262
2.1	0.980	0.476	0.328	0.252
2.4	0.902	0.450	0.315	0.244

Part B: Average U-Factor for Basement Floors				
	$U_{avg,bf}$, W/m²·K			
	w_b (Shortest Width of Basement), m			
Depth of Floor Below Grade, m	**6**	**7**	**8**	**9**
0.3	0.370	0.335	0.307	0.283
0.6	0.310	0.283	0.261	0.242
0.9	0.271	0.249	0.230	0.215
1.2	0.242	0.224	0.208	0.195
1.5	0.220	0.204	0.190	0.179
1.8	0.202	0.188	0.176	0.166
2.1	0.187	0.175	0.164	0.155

For empirical equations regarding $U_{avg,bw}$ & $U_{avg,bf}$, refer to ASHRAE F. 2017. 18.39

Predicting surface temperatures

- Determine the thermal gradient under winter design conditions through the wall assembly as shown in Fig. 9.11. The interior T is 68°F(20°C) and the exterior air T is 32°F(0°C)

The dotted line represents inside air film

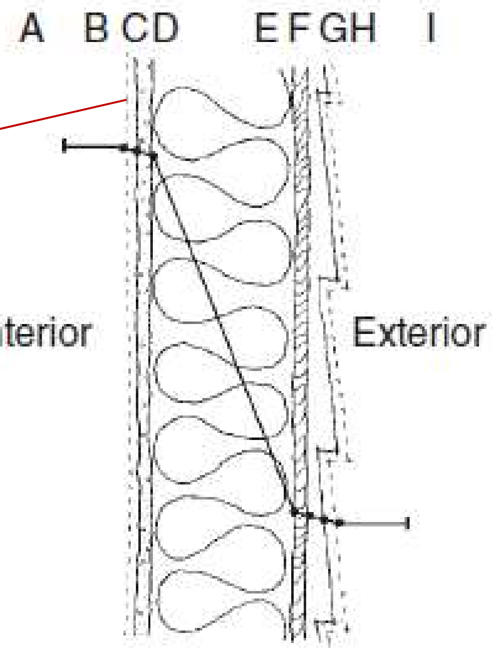


Fig. 9.11 *Wall section used in Example 9.5 to illustrate the procedure for calculating a thermal gradient through a construction assembly. (Drawing by Jonathan Meendering.)*

Only valid under steady state condition →

SI Units: Resistance values are from Example 9.1; "reference point" is a shorthand means of describing a series of locations throughout the wall assembly, each on the exterior side of a component; the total temperature gradient spans (20 – 0) = 20°C:

Thermal Component	Component Resistance	Cumulative Resistance	Reference Point	Temperature Difference to Reference Point (°C)	Temperature at Reference Point (°C)
Room air	—	—	A	—	20.0
Inside air film	0.12	0.12	B	(0.12/3.81) × (20) = 0.6	19.4
Gypsum board	0.056	0.18	C	(0.18/3.81) × (20) = 0.9	19.1
Vapor retarder	nil	0.18	D	(0.18/3.81) × (20) = 0.9	19.1
Batt insulation	3.35	3.53	E	(3.53/3.81) × (20) = 18.5	1.5
Plywood sheathing	0.11	3.64	F	(3.64/3.81) × (20) = 19.1	0.9
Wood siding	0.14	3.78	G	(3.78/3.81) × (20) = 19.8	0.2
Outside air film	0.03	3.81	H	(3.81/3.81) × (20) = 20	0.0
Outside air	—	—	I	—	0.0