

# ASCE STANDARD

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American Society of Civil Engineers

## Design and Construction of Frost-Protected Shallow Foundations

American Society of Civil Engineers

# Design and Construction of Frost-Protected Shallow Foundations

This document uses both Système International (SI) and customary units.



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## ABSTRACT

This standard addresses the design and construction of frost-protected shallow foundations in areas subject to seasonal ground freezing. Foundation insulation requirements to protect heated and unheated buildings from frost heave are presented in easy-to-follow steps with reference to design tables, climate maps, and other necessary data to furnish a complete frost-protection design. The advantages of this technology include improved construction efficiency over conventional practices, increased energy efficiency, minimized site disturbance, and enhanced frost protection. A commentary is included to provide background information and important technical insights.

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- ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs
- ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
- Building Code Requirements for Masonry Structures (ACI 530-99/ASCE 5-99/TMS 402-99) and Specifications for Masonry Structures (ACI 530.1-99/ASCE 6-99/TMS 602-99)
- ASCE 7-98 Minimum Design Loads for Buildings and Other Structures
- ANSI/ASCE 8-90 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
- ANSI/ASCE 9-91 listed with ASCE 3-91
- ASCE 10-97 Design of Latticed Steel Transmission Structures
- SEI/ASCE 11-99 Guideline for Structural Condition Assessment of Existing Buildings
- ANSI/ASCE 12-91 Guideline for the Design of Urban Subsurface Drainage
- ASCE 13-93 Standard Guidelines for Installation of Urban Subsurface Drainage
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- ASCE 25-97 Earthquake-Actuated Automatic Gas Shut-Off Devices
- ASCE 26-97 Standard Practice for Design of Buried Precast Concrete Box Sections
- ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction
- ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction
- EWRI/ASCE 33-01 Comprehensive Transboundary International Water Quality Management Agreement
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# CONTENTS

1. Scope and Limitations .....	1
2. References .....	1
3. Symbols, Units, and Definitions .....	1
3.1 Symbols and Units .....	1
3.2 Definitions .....	1
4. Design Principles .....	3
4.1 General .....	3
4.1.1 Bearing Capacity .....	3
4.1.2 Drainage .....	3
4.1.3 Compaction .....	3
4.1.4 Insulation Protection .....	3
4.1.5 Termite Protection .....	3
4.2 Foundations on Non–Frost-Susceptible Ground or Fill Material .....	4
4.3 Foundations with Insulation to Prevent Ground Freezing .....	4
5. Simplified FPSF Design Method for Heated Buildings with Slab-On-Ground Foundations .....	4
6. FPSF Design Method for Heated Buildings .....	6
6.1 Slab-on-Ground Foundations .....	6
6.2 Unvented Crawlspace Foundations .....	7
6.3 Walk-Out Basements .....	8
7. FPSF Design Method for Unheated Buildings .....	8
7.1 Slab-on-Ground Foundation .....	8
7.2 Continuous Foundation Wall .....	11
7.3 Column Foundation .....	11
8. Special Design Conditions for FPSF .....	11
8.1 Small Unheated Areas in Otherwise Heated Buildings .....	11
8.2 Large Unheated Areas in Heated Buildings .....	12
8.3 Semi-Heated Buildings .....	12
8.4 Cold-Bridges .....	14
Appendix A: Design Data .....	15
Commentary .....	25
Index .....	35

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# Design and Construction of Frost-Protected Shallow Foundations

## 1. SCOPE AND LIMITATIONS

This Standard addresses the design and construction of frost-protected shallow foundations to prevent frost damage in cold climates with seasonal ground freezing. For the purpose of this Standard, a frost-protected shallow foundation is a foundation that does not extend below the design frost depth, but is protected against effects of frost. This Standard applies to buildings on potentially frost-susceptible ground with slab-on-ground or suspended floor foundations. This Standard does not apply to buildings on permafrost, to areas with mean annual outdoor air temperatures less than 32°F (0°C), or to areas with design air-freezing indexes greater than 4,500°F-days (60,000°C-hr).

This Standard addresses heated, unheated, and semi-heated structures, as classified by the minimum average monthly indoor temperature expected during the building's intended useful life. For the purpose of using this Standard, the building shall be classified in accordance with Table 1.

This Standard does not preclude the judgment and practice of those competent in foundation design and the prevention of frost damage, nor does it preclude compliance with other design considerations or local building code requirements. Structural requirements, other than frost protection, shall be in accordance with the building code or accepted design practices and are not included in this Standard.

**TABLE 1. Classification of Building Based on Indoor Air Temperature**

Minimum Average Monthly Indoor Temperature, T	Thermal Classification
$T \geq 63^\circ\text{F}$ (17°C)	Heated
$41^\circ\text{F}$ (5°C) < T < 63°F (17°C)	Semi-heated
$T \leq 41^\circ\text{F}$ (5°C)	Unheated

## 2. REFERENCES

American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). *Handbook of Fundamentals*, Atlanta, GA (1997).

American Society for Testing and Materials (ASTM). ASTM C578-95. *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*, West Conshohocken, PA (1995).

American Society for Testing and Materials. ASTM D422-63 (90). *Test Method for Particle-Size Analysis of Soils*, West Conshohocken, PA (1990).

American Society for Testing and Materials. ASTM D2487-93. *Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, West Conshohocken, PA (1993).

## 3. SYMBOLS, UNITS, AND DEFINITIONS

### 3.1 SYMBOLS AND UNITS

The symbols and units used throughout this Standard are found in Table 2. Conversion factors for units are found in Table 3. English units accompanied by soft conversions to SI units (shown in parentheses) are used throughout the Standard.

### 3.2 DEFINITIONS

**Approved:** Accepted by the building official of the jurisdiction as the result of investigations, analysis, tests, or any combination of these evaluation approaches or by reason of accepted principles or local experience.

**Air-Freezing Index (AFI):** Determined from cumulative degree days above and below 32°F (0°C), recorded for an annual cycle. The AFI for a given winter is the largest difference between the maximum freezing degree day cumulative total reached at the start of the winter season and the minimum total reached during the winter.

**Cold-Bridges:** Discontinuities in insulation that create thermally conductive pathways and increase the potential for frost damage.

**Design Air-Freezing Index ( $F_{100}$ ):** The 100-year mean return period AFI used in this Standard for protection of building foundations against frost damage.

**Design Frost Depth:** The minimum depth at which the soil temperature remains above freezing for an extreme winter event, based on analysis, local regulations, or experience.

**Effective Thermal Resistivity ( $r_{\text{eff}}$ ):** An adjusted thermal resistivity to account for long-term use in a moist, below-ground condition. Commonly referred to in this Standard as an effective R per inch.

**Effective Thermal Resistance ( $R_{\text{eff}}$ ):** An adjusted R-value to account for long-term use in a moist, below-ground condition.



**TABLE 2. Symbols and Units**

Symbol	Description	SI Units	English Units
D <sub>h</sub>	Width of horizontal wing insulation along walls	m	ft or in
D <sub>hc</sub>	Width of horizontal wing insulation at corners	m	ft or in
D <sub>g</sub>	Width of ground insulation beyond the perimeter of an unheated building	m	ft or in
F <sub>100</sub>	100-year mean return period AFI	° C-hr	° F-days
h	Floor height above finished grade	m	ft or in
h <sub>f</sub> , h <sub>fc</sub>	Foundation depth along walls or at corners	m	ft or in
h <sub>v</sub>	Depth of vertical wall insulation into ground (minimum footing depth)	m	ft or in
L <sub>1</sub> , L <sub>2</sub> , L <sub>3</sub>	Length of unheated portion of otherwise heated building	m	ft or in
L <sub>c</sub>	Length (along a wall) of corner insulation	m	ft or in
MAT	Mean annual air temperature	° C	° F
R <sub>f</sub>	R-value of floor/slab construction or assembly	m <sup>2</sup> -° K/W	hr-ft <sup>2</sup> -° F/Btu
R <sub>v</sub>	Required R-value of vertical wall insulation	m <sup>2</sup> -° K/W	hr-ft <sup>2</sup> -° F/Btu
R <sub>h</sub>	Required R-value of horizontal wing insulation	m <sup>2</sup> -° K/W	hr-ft <sup>2</sup> -° F/Btu
R <sub>hc</sub>	Required R-value of horizontal wing insulation at corner	m <sup>2</sup> -° K/W	hr-ft <sup>2</sup> -° F/Btu
R <sub>g</sub>	Required R-value of ground insulation for unheated buildings	m <sup>2</sup> -° K/W	hr-ft <sup>2</sup> -° F/Btu
R <sub>eff</sub>	Effective R-value (thermal resistance) of an insulation material in service conditions	m <sup>2</sup> -° K/W	hr-ft <sup>2</sup> -° F/Btu
r <sub>eff</sub>	Effective resistivity (R <sub>eff</sub> per inch) of an insulation material in service conditions	m-° K/W	hr-ft <sup>2</sup> -° F/Btu-in

**Frost Heave:** The expansion of soil due primarily to the growth of ice lenses in the soil. Frozen soil beneath a foundation can cause upward movement of the foundation and/or settlement from thaw weakening of the soil.

**Frost-Protected Shallow Foundation (FPSF):** Foundations protected from frost heave by insulating in accordance with these provisions. Insulation is provided to retard frost penetration below the foundation and to retard heat flow from beneath the foundation, allowing shallower footing depths to be possible with no added risk of frost damage. Use of non-frost-susceptible soils is also included in certain applications.

**Ground Insulation:** Insulation extending horizontally underneath a foundation to create an insulated pad for the building.

**Mean Return Period Air-Freezing Index:** A probability estimate of the average number of years between which a number of total winter season freezing degree days will be equaled or exceeded; a 100-year mean return period occurs in 1% of the years (1/100), has a 1% annual probability of exceedance, or is exceeded once every 100 years on average.

**Mean Annual Air Temperature (MAT):** The average of all daily average outdoor air temperatures (minimum plus maximum daily temperature divided by two) in one or more years.

**Mean Return Period (Mean Recurrence Interval):** A probability estimate of the average number of years between which an event of a given magnitude

will be equaled or exceeded (1/p, where p is the probability of an event happening over a specified period).

**Non-Frost-Susceptible Soil:** A soil that does not display significant detrimental ice segregation (i.e., ice lens development) during freezing. Generally, granular soils with less than 6% by mass passing a #200 sieve (0.074 mm) have low frost susceptibility, whereas silts and clays or sands and gravels (i.e., granular soils) with high fines content generally have medium to high frost susceptibility.

**TABLE 3. Unit Conversions**

Length	1 m = 100 cm = 3.28 ft = 39.4 in
Mass	1 kg = 2.2 lbm (0.0683 slugs)
Weight	1 N = 0.225 lbf
Area	1 m <sup>2</sup> = 10,000 cm <sup>2</sup> = 10.8 ft <sup>2</sup> = 1550 in <sup>2</sup>
Volume	1 m <sup>3</sup> = 1 × 10 <sup>6</sup> cm <sup>3</sup> = 35.3 ft <sup>3</sup> = 6.1 × 10 <sup>4</sup> in <sup>3</sup>
Density	1 kg/m <sup>3</sup> = 0.0624 lbf/ft <sup>3</sup> (pcf)
Pressure	1 kPa = 0.145 lbf/in <sup>2</sup> (psi) = 20.8 lbf/ft <sup>2</sup> (psf)
Temperature	° F = 1.8 (° C + 32)
Freezing index	1° C-hr = 0.075° F-days
Thermal properties:	
• resistance	1 m <sup>2</sup> -° K/W = 5.68 hr · ft <sup>2</sup> -° F/Btu {R-value}
• resistivity	1 m-° K/W = 0.144 hr · ft <sup>2</sup> -° F/(Btu · in) {R/in}

**Permafrost:** Soil that, in its natural state, remains frozen throughout the year. Generally occurs in regions where the mean annual soil surface temperature is below freezing.

**R-Value (Thermal Resistance):** A measure of the ability to retard heat flow for a given thickness ( $\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$ ) [ $\text{m}^2 \cdot \text{K}/\text{W}$ ]. It is calculated by dividing the material's thickness by its thermal conductivity. The thermal resistance of material assembled in layers is calculated by summing the thermal resistances of the individual components.

**Suspended Floor:** A floor not directly supported by the earth, such as a floor over a basement or crawlspace.

**Thermal Resistivity:** The insulative capability of a material to retard heat flow for a unit thickness of homogeneous material over a unit area, commonly given as R per inch.

**Vertical Insulation:** Insulation placed vertically against the exterior perimeter surface of the foundation.

**Wing (Horizontal) Insulation:** Insulation placed in a horizontal position or sloped downward and away from exterior walls of a foundation (abuts the vertical foundation wall insulation).

## 4. DESIGN PRINCIPLES

### 4.1 GENERAL

In regions of seasonal ground freezing, shallow foundations not extending below the design frost depth shall be protected against frost heave by one or more of the following methods:

1. use of non-frost-susceptible layers of undisturbed ground or fill materials (Section 4.2);
2. insulation of foundations to mitigate frost penetration and effects of frost heave (Section 4.3); or
3. approved design and details supported by engineering analysis.

#### 4.1.1 Bearing Capacity

The allowable bearing capacity of the undisturbed soil, fill materials, or insulating materials supporting the foundation shall be equal to or greater than the structural loads imposed by the building in accordance with the local building code or engineering analysis. The foundation depth, as measured from finished grade to bottom of footing, shall be the greater of that required by this Standard or that required for adequate bearing capacity on soil or fill. The foundation depth,

as measured from finished grade to bottom of footing, shall not be less than 12 inches (0.3 m).

#### 4.1.2 Drainage

The site shall be graded to drain surface water away from foundation walls, in accordance with local building code provisions or approved practice. In soils other than GW, GP, SW, SP, GM, and SM (Unified Soil Classification System, ASTM D2487), a layer of screened and washed gravel or crushed stone shall be placed beneath the horizontal insulation and drained to daylight, or an approved foundation drainage system shall be provided.

#### 4.1.3 Compaction

Fill materials shall be placed and compacted in accordance with an approved design or approved practice. An approved design shall be required for fill materials that support foundation loads and are more than 12 inches (0.3 m) thick or vary in thickness by more than 6 inches (0.15 m).

#### 4.1.4 Insulation Protection

Vertical insulation placed externally on foundation walls or along edges of slab-on-ground floors shall have an opaque and weather-resistant protective covering to mitigate degradation of thermal performance from ultraviolet radiation, physical damage, or other sources of deterioration. Protective coverings or coatings shall be compatible with the insulation material and extend a minimum of 6 inches (0.15 m) below finished grade. Polystyrene insulation shall not be exposed to petroleum-based products. Horizontal insulation placed less than 12 inches (0.3 m) below the ground surface, or any portion extending outward more than 24 inches (0.6 m) from the foundation edge, shall be protected against damage by concrete or asphalt pavement on the ground surface directly above the insulation by cementitious board or plywood rated for below-ground use, or by other approved materials placed directly on the top surface of the insulation.

#### 4.1.5 Termite Protection

Buildings with underground foam insulation in geographic areas subject to termite infestation with structural members constructed of materials susceptible to termite damage shall comply with local building code requirements for termites and shall be protected against termite infestation. Methods of protection shall include chemical soil treatment, physical barriers (such as termite shields), or any combination of these methods.

## 4.2 FOUNDATIONS ON NON-FROST-SUSCEPTIBLE GROUND OR FILL MATERIAL

Foundations placed on a layer of well-drained, undisturbed ground or fill material that is not susceptible to frost shall have the thickness of such a layer included in meeting the design frost depth defined in Section 3.2. Undisturbed granular soils or fill material with less than 6% of mass passing a #200 (0.074 mm) mesh sieve in accordance with ASTM D422 and other approved non-frost-susceptible materials shall be considered non-frost-susceptible. Classification of frost susceptibility of soil shall be determined by a soils or geotechnical engineer, unless otherwise approved.

## 4.3 FOUNDATIONS WITH INSULATION TO PREVENT GROUND FREEZING

Frost-protected shallow foundations (FPSF) shall be designed in accordance with the following sections of this Standard using the design data from Appendix A:

- Section 5 Simplified FPSF Design Method for Heated Buildings with Slab-on-Ground Foundations
- Section 6 FPSF Design Method for Heated Buildings
- Section 7 FPSF Design Method for Unheated Buildings
- Section 8 Special Design Conditions for FPSF

Buildings with foundations designed in accordance with Section 5 or 6 that are not completed and not heated before the time of first ground freezing shall have additional temporary ground protection or temporary heating of internal space in accordance with Table 1, or the foundation shall be designed in accordance with provisions for unheated buildings (Section 7).

## 5. SIMPLIFIED FPSF DESIGN METHOD FOR HEATED BUILDINGS WITH SLAB-ON-GROUND FOUNDATIONS

Designs based on the following simplified procedure shall be permitted to be used to specify insulation for slab-on-ground foundations of heated buildings, in lieu of the detailed design in Section 6. Design procedures of Section 6 shall be used when buildings include suspended floors. Unheated areas, such as attached garages, shall be designed in accordance with Section 7, except when designed in accordance with Section 4.2 or when the foundation of the unheated area extends below the design frost depth. Cold-bridges shall be prevented (see Section 8.4).

### Step 1: Select the Site's Design Air-Freezing Index, $F_{100}$

The 100-year mean return period AFI,  $F_{100}$ , shall be selected from Figure A1 or Table A3 of Appendix A.

### Step 2: Determine Insulation R-Value, Dimensions, and Footing Depth

Using  $F_{100}$  from Step 1, select vertical and horizontal insulation R-values, horizontal insulation dimensions, and minimum footing depth from Table 4. Verti-

**TABLE 4. Minimum Insulation Requirements for Frost-Protected Shallow Foundations of Heated Buildings<sup>1</sup>**

Air-Freezing Index, $F_{100}$ ( $^{\circ}$ F-days)	Vertical Insulation R-value, $R_v$	Horizontal Insulation R-value, $R_h$ ( $\text{hr} \cdot \text{ft}^2 \cdot ^{\circ}\text{F}/\text{Btu}$ )		Horizontal Insulation Dimensions per Figure 1 (in)			Minimum Footing Depth (in)
		Along Walls	At Corners	$D_h$	$D_{hc}$	$L_c$	
500 or less	0	NR	NR	NR	NR	NR	12
1,500	4.5	NR	NR	NR	NR	NR	12
2,000	5.6	NR	NR	NR	NR	NR	14
2,500	6.7	1.7	4.9	12	24	40	16
3,000	7.8	6.5	8.6	12	24	40	16
3,500	9.0	8.0	11.2	24	30	60	16
4,000	10.1	10.5	13.1	24	36	60	16
4,500	12.0	12.0	15.0	36	48	80	16

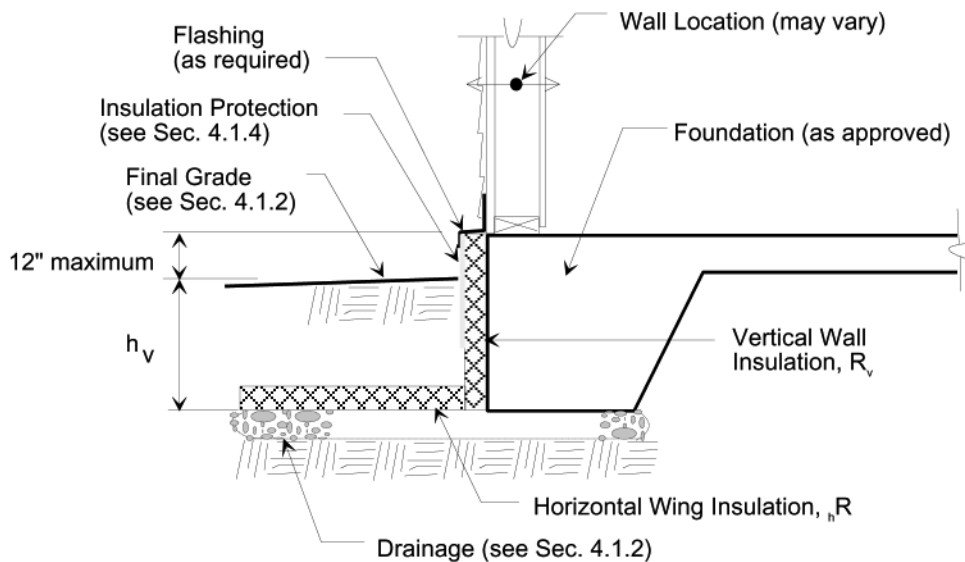
<sup>1</sup> Insulation requirements are for protection against frost damage in heated buildings. Interpolation between values is permissible. For interpolation purposes, NR = 0 (NR = not required).

cal and horizontal insulation shall be located on the foundation in accordance with Figure 1. The insulation shall be placed to prevent cold-bridging between the foundation wall or other thermally conductive materials of the building foundation and the adjacent soil or outside air (see Section 8.4). Horizontal insulation shall be bedded firmly on a smooth ground surface or, where required by Section 4.1.2, a drained granular base. When foundation depths,  $h_v$ , greater than 12 inches (0.3 m) are required by Table 4, the increase in depth may be satisfied by substituting non-frost-susceptible fill materials, as defined in Section 4.2. Insulation placed below

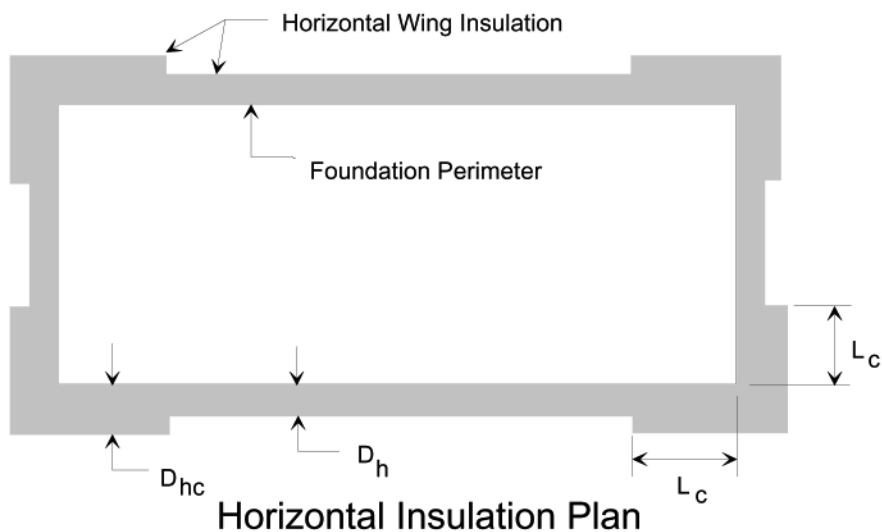
the floor slab shall not exceed a nominal R-value of 10 ( $\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$ ) [ $1.76 \text{ m}^2 \cdot ^\circ\text{K}/\text{W}$ ].

### Step 3: Select Insulation Types, Calculate Thicknesses, and Provide Protection

An approved insulation material type shall be selected in accordance with Section A.2.2 of Appendix A. Insulation thicknesses shall be determined by dividing the required vertical and horizontal insulation R-values (thermal resistance),  $R_v$  and  $R_h$ , from Step 2 by the selected insulation material's effective resistivity,  $r_{\text{eff}}$ , in accordance with Table A1 of Appendix A. The insulation material thickness of individual panels shall



### Insulation Detail



### Horizontal Insulation Plan

FIGURE 1. FPSF Design Parameters for Heated Buildings Using the Simplified Design Procedure

DESIGN AND CONSTRUCTION OF FROST-PROTECTED SHALLOW FOUNDATIONS

not be less than the minimum insulation thickness in Table A1 of Appendix A. Insulation materials shall be protected in accordance with Section 4.1.4.

See Figure A1 to determine design AFI ( $F_{100}$ ).

**6. FPSF DESIGN METHOD FOR HEATED BUILDINGS**

**6.1 SLAB-ON-GROUND FOUNDATIONS**

The design procedure in this section shall be used to specify foundation insulation for slab-on-ground

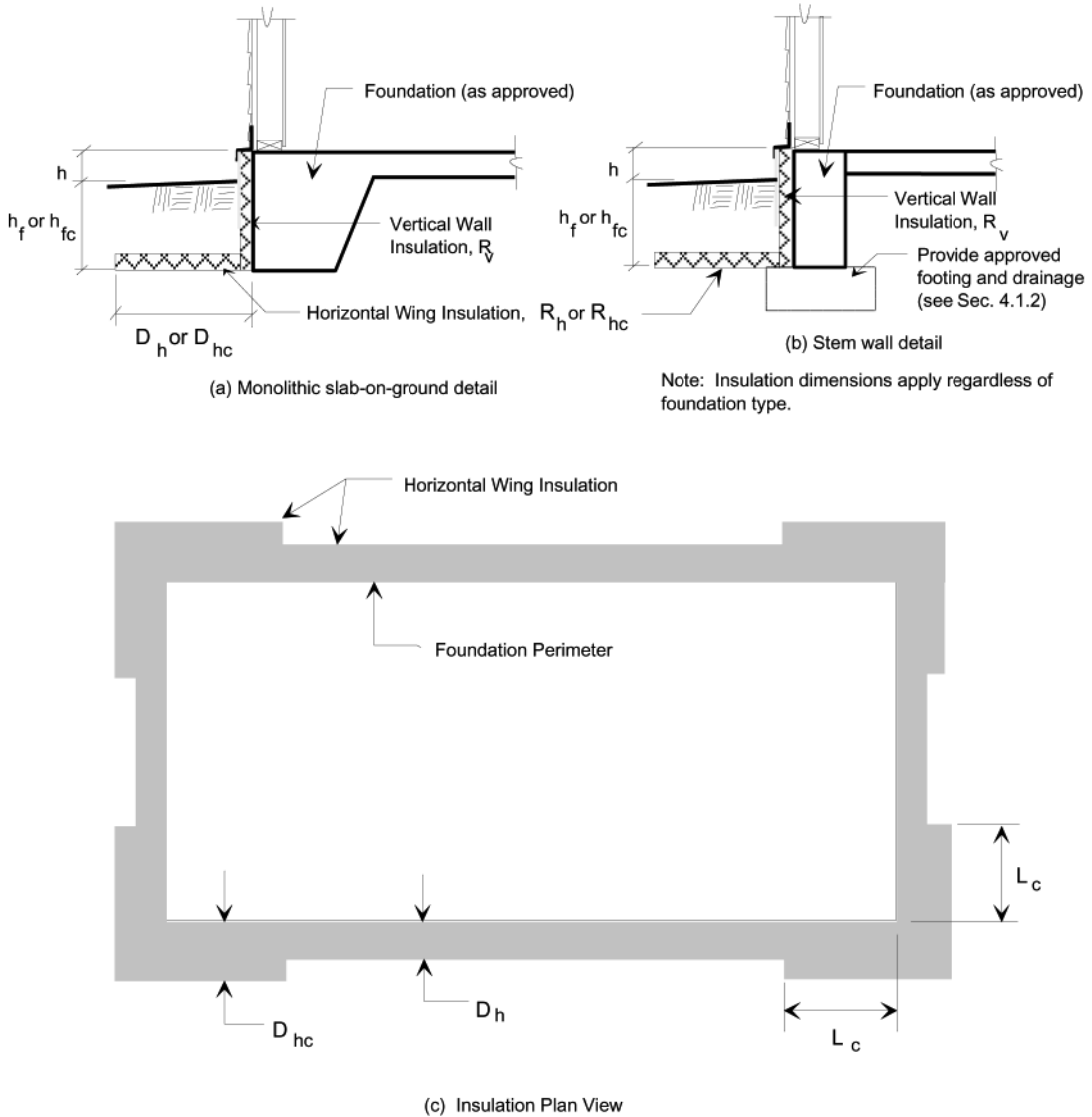
foundations of heated buildings in accordance with Figure 2 and the design data in Appendix A. For semi-heated buildings, the additional requirements of Section 8.3 shall apply. Cold-bridges shall not be permitted (see Section 8.4).

**Step 1: Select the Site's Design Air Freezing Index,  $F_{100}$**

The 100-year mean return period AFI,  $F_{100}$ , shall be selected from Figure A1 or Table A3 of Appendix A.

**Step 2: Determine the R-Value for the Floor Slab,  $R_f$**

Determine the thermal resistance of the floor system,  $R_f$ , by multiplying the nominal dry resistivity in



**FIGURE 2. Slab-on-Ground Foundation for Heated Buildings**

Table A2 of each material in the cross-section, including any floor coverings, by its thickness. Sum the thermal resistances of the materials to obtain total  $R_f$ . If no portion of the outer 3 feet (0.9 m) of the slab exceeds  $R_f = 28$ , proceed to Step 3. Treat small portions of the slab in the outer 3 feet (0.9 m) that exceed  $R_f = 28$  as small unheated areas in otherwise heated buildings in accordance with Section 8.1. Where the  $R_f$  value of the entire slab exceeds 28, follow the design procedure for unheated buildings.

**Step 3: Select the Required R-Value for Vertical Wall Insulation,  $R_v$**

The minimum required thermal resistance of vertical wall insulation,  $R_v$ , shall be selected from Table A4, given a site-specific value for  $h$  as shown in Figure 2,  $F_{100}$  from Step 1, and  $R_f$  from Step 2.

**Step 4: Select Vertical Insulation Type, Calculate Thickness, and Provide Protection**

An approved insulation material type shall be selected in accordance with Section A.2.2 of Appendix A. Based on the required  $R_v$  value from Step 3, calculate the required thickness of vertical wall insulation by dividing  $R_v$  by the insulation material's effective resistivity,  $r_{eff}$ , for vertical applications provided in Table A1 of Appendix A. The insulation material thickness of individual panels shall not be less than the minimum insulation thickness in Table A1 of Appendix A. The insulation shall extend from a depth of  $h_f$  or  $h_{fc}$  to the exterior, above-grade wall without exposing the foundation wall or other thermally conductive materials as shown in Figure 2. Vertical wall insulation shall be protected in accordance with Section 4.1.4.

**Step 5: Select Foundation Depth or Horizontal Wing Insulation for Walls**

Horizontal wing insulation is placed as shown in Figure 2. For climates where  $F_{100}$  is less than 2,250°F-days (30,000°C-hr), wing insulation along the walls is not required, and the designer shall proceed to Step 7. If horizontal wing insulation is not desired in more severe climates, select the minimum foundation depth,  $h_f$ , from Table A5 in Appendix A. If a foundation depth of 16 inches (0.41 m) is desired in severe climates ( $F_{100} > 2,250^\circ\text{F-days}$  [30,000°C-hr]), select the minimum width of wing insulation,  $D_h$ , and the required minimum thermal resistance of insulation,  $R_h$ , from Table A6 in Appendix A.

**Step 6: Select Horizontal Insulation Type, Calculate Thickness, and Provide Protection**

Select an approved insulation material type in accordance with Section A.2.2 of Appendix A. Determine the required insulation thickness by dividing  $R_h$  by the insulation material's effective resistivity,  $r_{eff}$ , provided in Table A1 in Appendix A. The thickness of

individual panels shall not be less than the minimum insulation thickness in Table A1 of Appendix A. Wing insulation shall meet flush with the vertical wall insulation in accordance with Figure 2. Insulation materials shall be protected in accordance with Section 4.1.4.

**Step 7: Select Foundation Depth or Horizontal Wing Insulation at Corners**

Where horizontal wing insulation is not desired, select the minimum foundation depth at corners,  $h_{fc}$ , from Table A5 of Appendix A. For a uniform foundation depth,  $h_f = h_{fc}$ , use Table A5 with  $R = 5.7$  wing insulation applied to the corner regions. The minimum thickness of the wing insulation at corners shall be determined by dividing  $R$  by the insulation material's effective resistivity,  $r_{eff}$ , provided in Table A1. If a foundation depth of 16 inches (0.4 m) is desired in severe climates ( $F_{100} > 2,250^\circ\text{F-days}$ ), select the minimum width the wing insulation shall extend from the foundation wall,  $D_{hc}$ , and the minimum required thermal resistance of the insulation,  $R_{hc}$ , from Table A7.

Calculate the required minimum thickness of the corner wing insulation by dividing  $R_{hc}$  by the insulation material's effective resistivity,  $r_{eff}$ , for horizontal applications provided in Table A1. Determine the minimum distance the corner insulation shall extend from the corners,  $L_c$ , from Table A7. Protect horizontal insulation at corners in accordance with Section 4.1.4.

**Step 8: Check Compressive Load on Horizontal Insulation**

If horizontal wing insulation extends under the footing, compressive loads from the foundation shall not exceed allowable insulation bearing capacity provided in Table A1 of Appendix A.

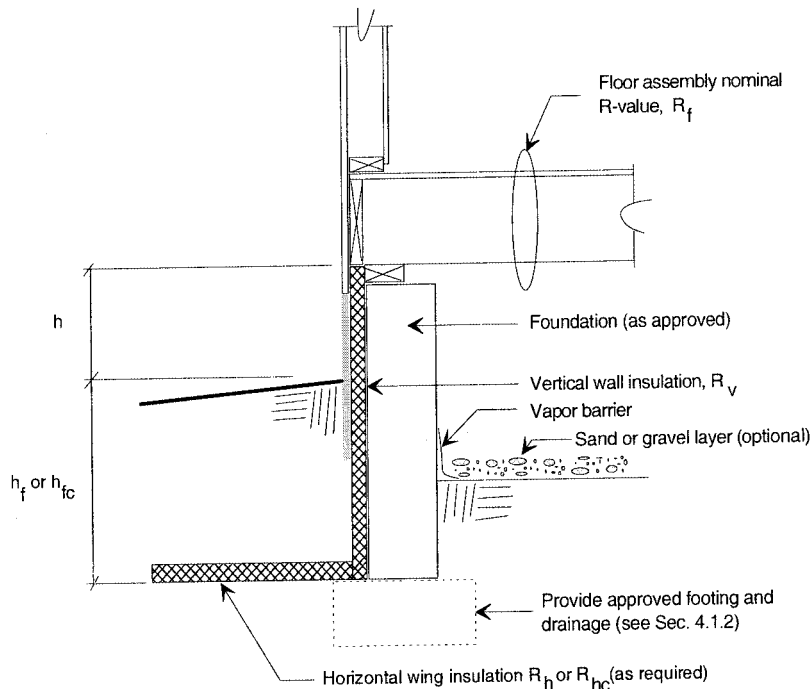
## 6.2 UNVENTED CRAWLSPACE FOUNDATIONS

The design procedure in this section shall be used to specify foundation insulation for unvented crawlspace foundations of heated buildings in accordance with Figure 3 and the design data in Appendix A.

**Step 1: Review Important Design Considerations**

Crawl spaces that are unvented during the heating season shall be permitted to have the foundation insulation design as required for heated or semi-heated buildings (Table 1), provided the following conditions are met:

- The floor assembly nominal R-value,  $R_f$ , does not exceed  $28 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$  ( $4.9 \text{ m}^2 \cdot ^\circ\text{K}/\text{W}$ ) in accordance with Table A4 of Appendix A, or the crawlspace is conditioned as a heated or semi-heated space (Table 1).



**FIGURE 3. Insulation Placement for Crawlspace Foundation for Heated or Semi-Heated Buildings**

- The height from the exterior ground elevation to the underside of the floor joist,  $h$ , is not greater than 24 inches (0.6 m) in all areas.

The provisions of Section 7.2 shall be used for vented or unheated crawlspaces.

**Step 2: Follow the Detailed Method for Heated Buildings**

Follow the eight design steps of Section 6.1 for slab-on-ground construction to determine insulation requirements for crawlspace foundations. For semi-heated buildings, the additional requirements of Section 8.3 shall apply. Cold-bridges shall not be permitted (see Section 8.4).

**6.3 WALK-OUT BASEMENTS**

The design procedure in this section shall be used to specify foundation insulation for heated, walk-out basements in accordance with Figure 4 and design data in Appendix A.

**Step 1: Review Important Design Considerations**

Basements shall be designed as heated or semi-heated buildings, provided the following conditions are met:

- The basement is sufficiently conditioned to be considered a heated or semi-heated space (Table 1).

- The vertical insulation extends from a depth of  $h_f$  or  $h_{fc}$  or frost depth, if higher, to the top of the basement wall without interruption, and without cold-bridging (see Section 8.4).

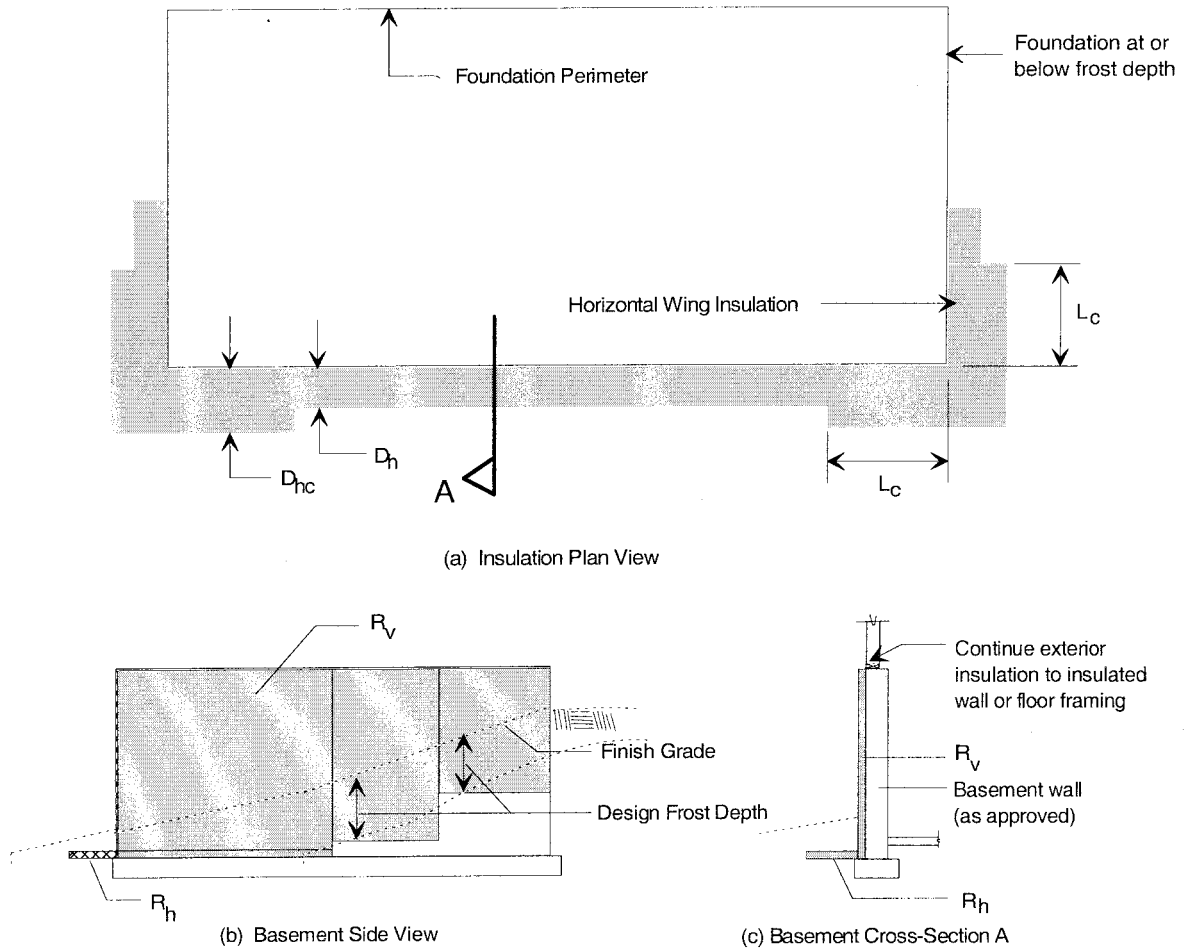
**Step 2: Follow the Detailed Method for Heated Buildings**

Follow the eight design steps of Section 6.1 for slab-on-ground construction to determine insulation requirements for a basement foundation. When required, horizontal wing insulation shall be applied only to the shallow, walk-out portions of the basement as shown in Figure 4. Vertical insulation on the basement wall shall be applied as shown in Figure 4. For semi-heated basements, additional requirements of Section 8.3 shall apply. Cold-bridges shall not be permitted (see Section 8.4).

**7. FPSF DESIGN METHOD FOR UNHEATED BUILDINGS**

**7.1 SLAB-ON-GROUND FOUNDATION**

The design procedure in this section shall be used to specify foundation insulation for unheated buildings with slab-on-ground foundations in accordance with Figure 5 and the design data in Appendix A.



**FIGURE 4. Walk-Out Basement Details for Heated or Semi-Heated Buildings**

**Step 1: Select the Design Air-Freezing Index,  $F_{100}$ , and Mean Annual Temperature**

The 100-year mean return period AFI,  $F_{100}$ , shall be selected from Figure A1 or Table A3. Select the mean annual exterior temperature, MAT, from Figure A2 or Table A3.

**Step 2: Determine Placement of Ground Insulation**

A continuous ground insulation layer over a minimum 6-inch (0.15-m) non-frost-susceptible soil layer shall be placed below the entire foundation of unheated buildings. The non-frost-susceptible soil layer shall be increased to 12 inches (0.3 m) if placed above the insulation layer. The ground insulation layer and the non-frost-susceptible layer shall be additive to the minimum footing depth of 12 inches (0.3 m), as shown in Figure 5. The ground insulation shall extend outside the foundation a minimum width,  $D_g$ , as determined from Table A8 and shown in Figure 5. In unheated buildings,  $D_g$  is the same at both corner and wall locations. Outside

the foundation perimeter, the insulation shall have a minimum of 10 inches of soil cover.  $D_g$  may be reduced by 1.25 inches for every 1 inch the insulation is buried beyond the 10-inch minimum cover. Ground insulation shall be protected in accordance with Section 4.1.4.

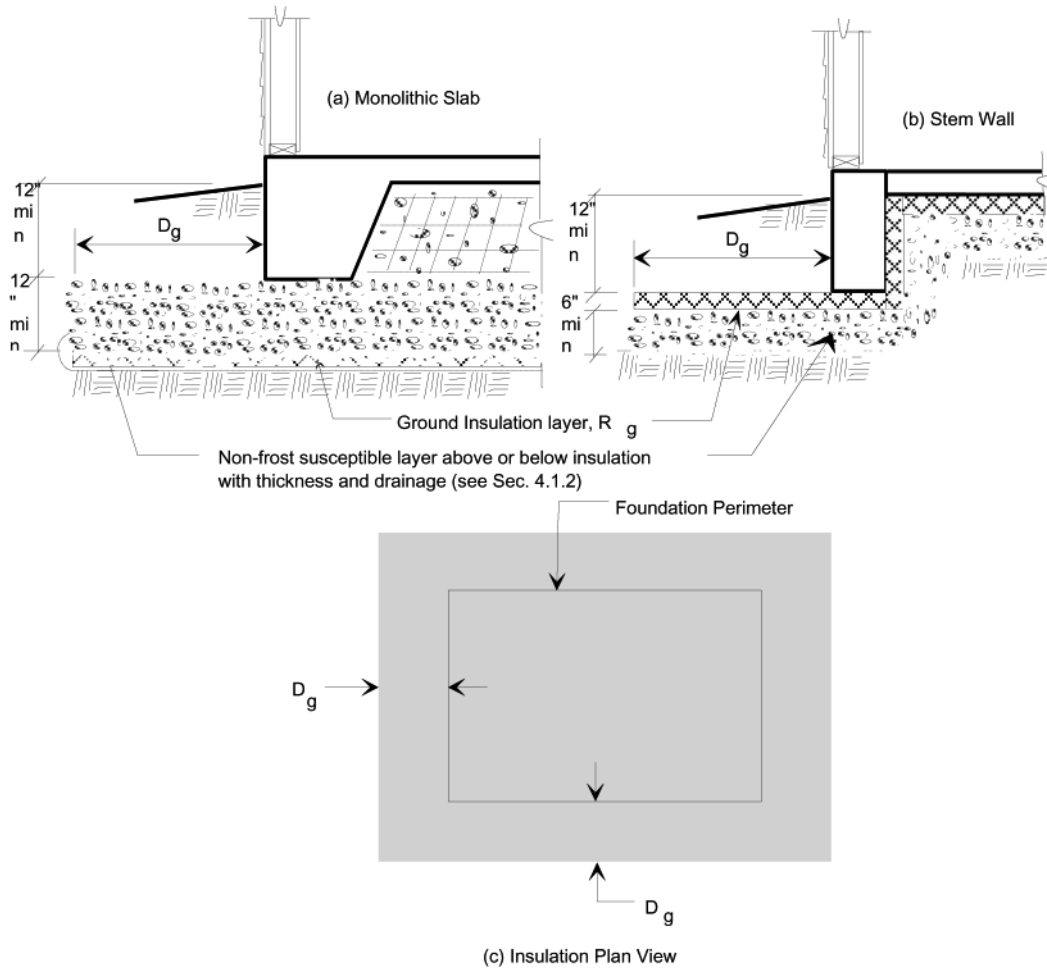
**Step 3: Select the Required R-value of Ground Insulation,  $R_g$**

Select the minimum R-value,  $R_g$ , required for the ground insulating layer from Table A8 based on  $F_{100}$  and MAT from Step 1.  $R_g$  may be reduced by 0.3 R for every 1-inch thickness that the non-frost-susceptible layer is increased beyond that required in Step 2.  $R_g$  may also be reduced by 0.3 R for every 1-inch increase in soil cover thickness, above the 10-inch minimum, over the ground insulation.

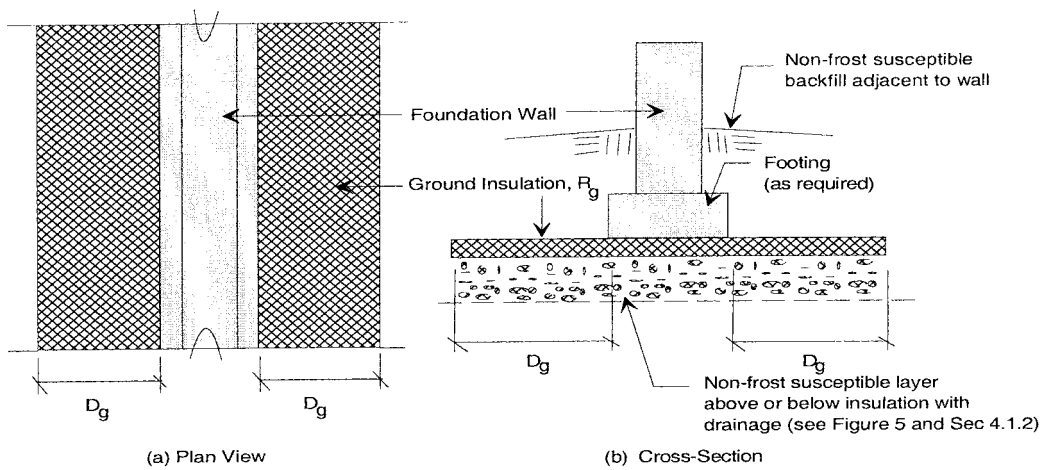
**Step 4: Select Ground Insulation Type, Calculate Thickness, and Provide Protection**

An approved insulation material type shall be selected in accordance with Section A.2.2 of Appendix A. Based on the required  $R_g$  value determined in Step 3,





**FIGURE 5. Slab-on-Ground Foundation for Unheated Buildings**



**FIGURE 6. Continuous Foundation Wall (Unheated Buildings)**

calculate the required thickness of the ground insulation by dividing  $R_g$  by the insulation material's effective resistivity,  $r_{eff}$ , provided in Table A1 of Appendix A. The insulation material thickness of individual panels shall not be less than the minimum insulation thickness in Table A1 of Appendix A.

#### Step 5: Check Compressive Load on Ground Insulation

Compressive loads on insulation materials supporting building foundation loads shall not exceed the allowable compressive properties in accordance with Table A1 of Appendix A. Structural loads imposed by the building shall be in accordance with local building code or approved design.

### 7.2 CONTINUOUS FOUNDATION WALL

For continuous foundation walls exposed to exterior climate conditions on both sides (i.e., vented crawlspaces), follow the design steps in Section 7.1. Insulation shall be selected and installed in accordance with Figure 6 and Table A8 of Appendix A.

Values for  $D_g$  and  $R_g$  may be adjusted for increased ground cover or thickness of non-frost-susceptible layer, in accordance with Steps 2 and 3 of Section 7.1.

### 7.3 COLUMN FOUNDATION

For column or pier foundations exposed to exterior climate conditions, follow the design steps in Section 7.1. Insulation shall be selected and installed in ac-

cordance with Figure 7 and Table A8 of Appendix A. Values for  $D_g$  and  $R_g$  may be adjusted for increased ground cover or thickness of non-frost-susceptible layer, in accordance with Steps 2 and 3 of Section 7.1.

## 8. SPECIAL DESIGN CONDITIONS FOR FPSF

### 8.1 SMALL UNHEATED AREAS IN OTHERWISE HEATED BUILDINGS

Where small unheated perimeter areas (as defined in Figure 8) of an otherwise heated building are encountered, follow the design procedure for heated buildings in Section 6, and address each small unheated area as follows:

- Continue the vertical wall insulation of the heated area along the exterior face of the small unheated area in accordance with Figure 9.
- Consider the small unheated area in a corner location and provide frost protection with horizontal wing insulation or increased foundation depth, according to Step 7 of the design procedure for heated buildings (Section 6.1). When required, wing insulation shall be placed at the small unheated area.
- Provide ground insulation as required for unheated buildings under the small unheated area in accordance with Steps 1, 3, and 4 of Section 7.1 and Figure 9.
- Insulation materials supporting structural foundation loads shall be designed in accordance with Step 5 of Section 7.1.

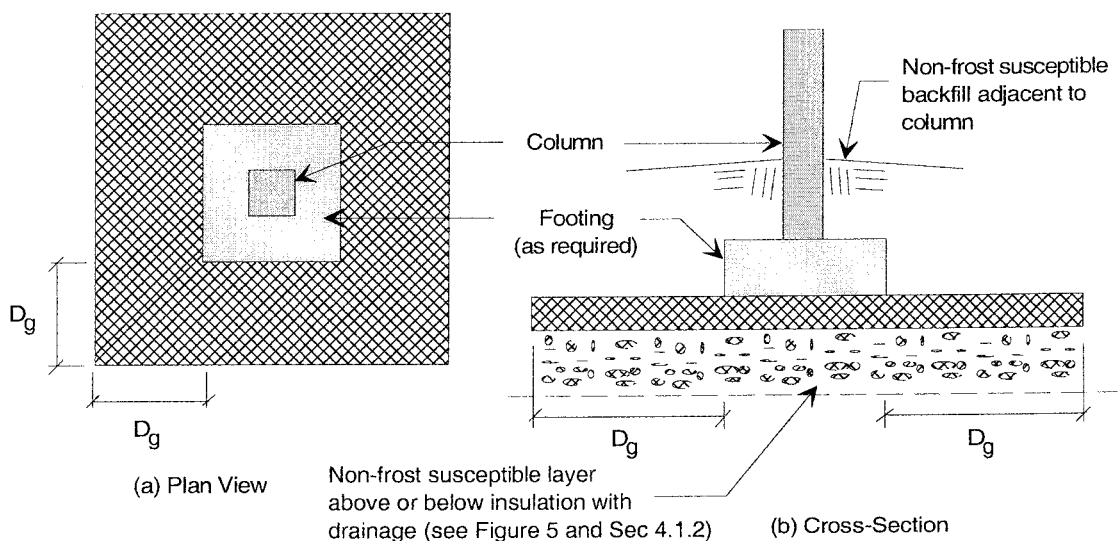


FIGURE 7. Column Foundation (Unheated Building)

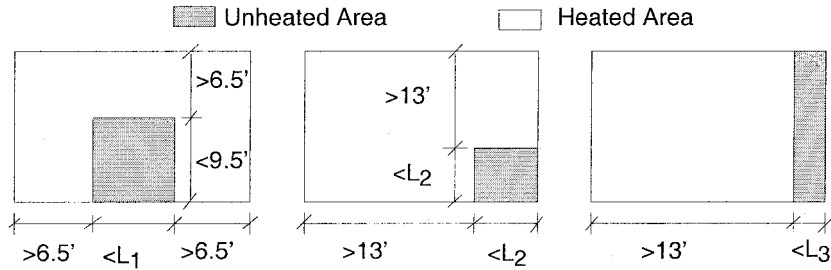
**8.2 LARGE UNHEATED AREAS IN HEATED BUILDINGS**

When an unheated area is larger than that shown in Figure 8, regard the heated and unheated sections as separate buildings and design the insulation for the large unheated area in accordance with Section 7.1. Insulation shall be installed in accordance with Figure 10

without interruption of the vertical insulation on the heated area of the building.

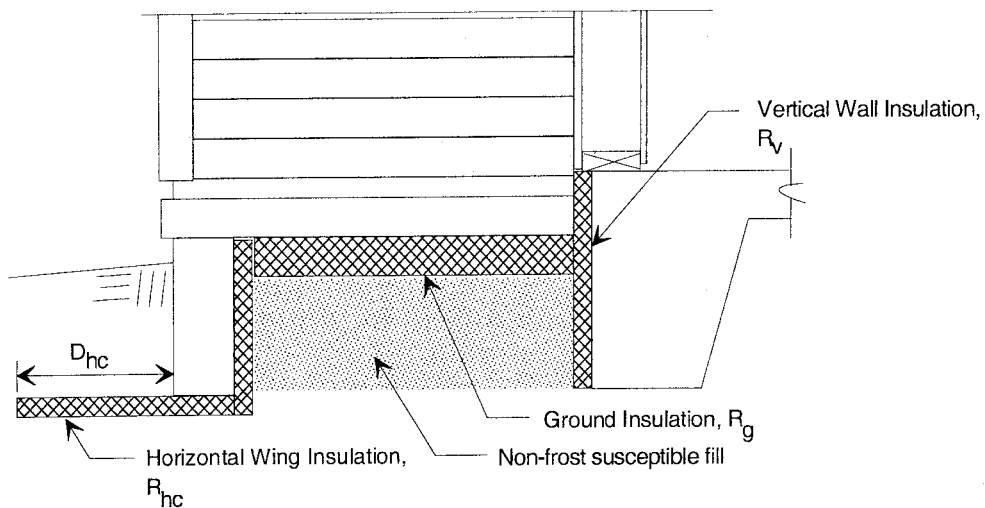
**8.3 SEMI-HEATED BUILDINGS**

If the anticipated operating conditions of the building are such that the lowest average monthly internal temperature of a building falls between 41°F

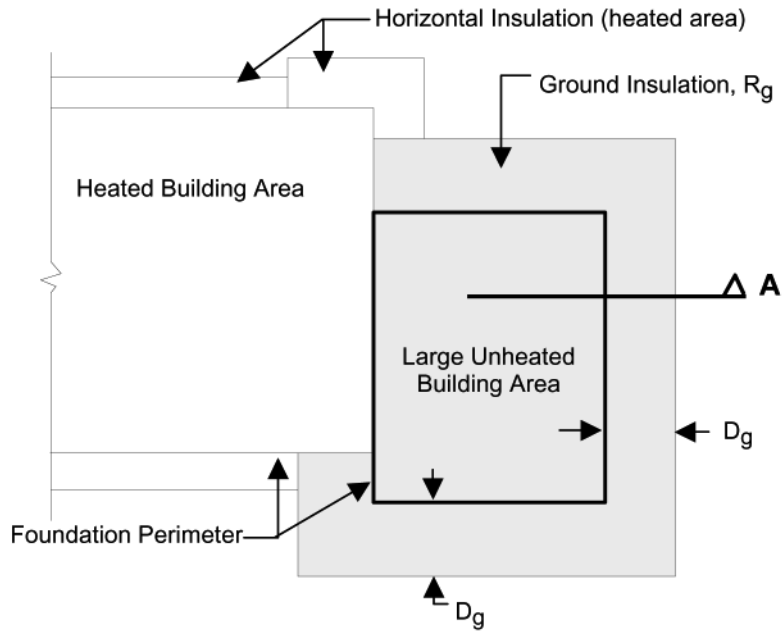


Maximum Size Limit	$F_{100}$ ( $^{\circ}\text{F-days}$ )			
	$\leq 2,250$	2,251 to 3,000	3,001 to 3,750	$>3,750$
$L_1$	13'-0"	11'-6"	10'-0"	6'-6"
$L_2$	9'-9"	8'-8"	7'-6"	4'-11"
$L_3$	6'-6"	5'-10"	5'-0"	3'-3"

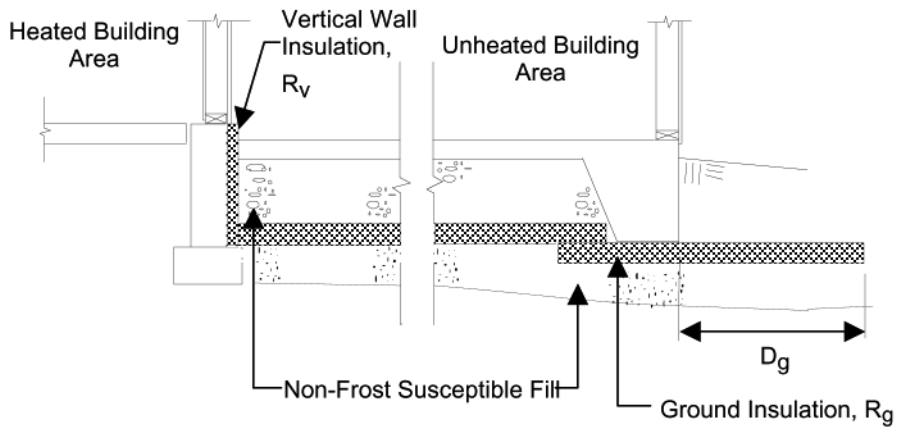
**FIGURE 8. Definition of a Small Unheated Area of a Floor Slab**



**FIGURE 9. Insulation Detail for a Small Unheated Area**



**Insulation Plan**



**Cross-Section A**

**FIGURE 10. Insulation Detail for a Large Unheated Area**

(5°C) and 63°F (17°C), the building shall be considered semi-heated (see Table 1). In this case, the foundation shall be designed as a heated building in accordance with Section 6 and the minimum required foundation depth increased by 8 inches (0.2 m) in both wall and corner areas of the semi-heated building.

### 8.4 COLD-BRIDGES

Cold-bridging shall be prevented unless accounted for in accordance with an approved design. Illustrations for correcting typical cold-bridges are provided in Figure 11.

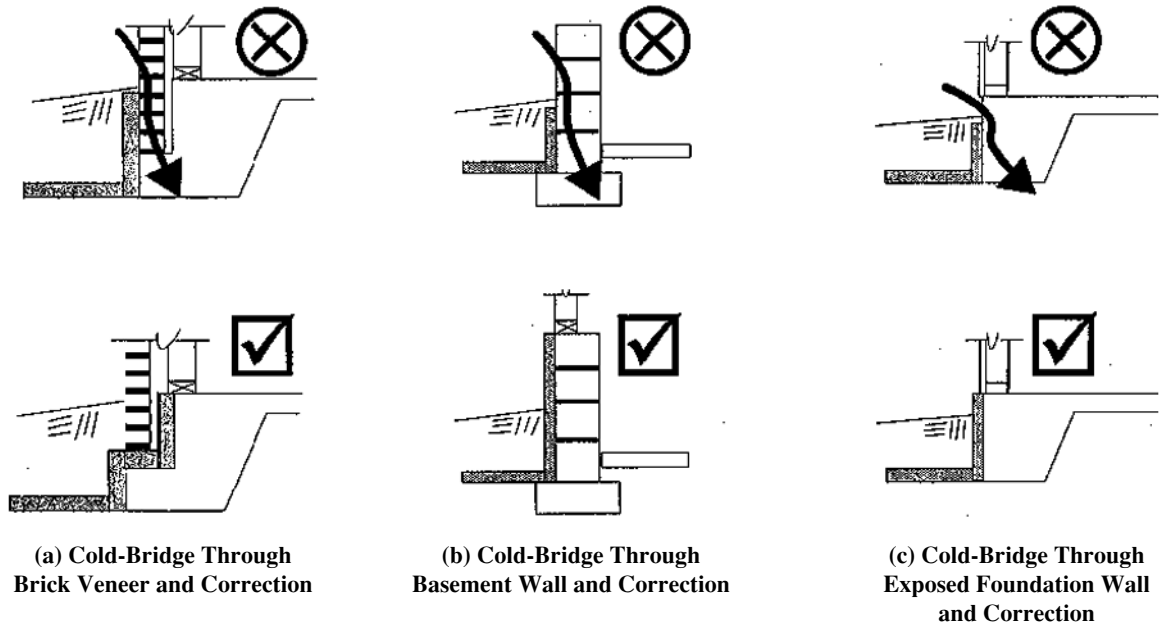


FIGURE 11. Typical Cold-Bridges

# APPENDIX A

## A. DESIGN DATA

### A.1 PURPOSE

This Appendix provides mandatory design data supporting frost-protected shallow foundation (FPSF) design in accordance with this Standard.

### A.2 MATERIAL PROPERTIES

#### A.2.1 Soil Properties

The soil shall be considered to be frost-susceptible unless otherwise classified as non-frost-susceptible in accordance with Section 4.2 of the Standard.

#### A.2.2 Insulation Materials

The insulation products used to meet the requirements of this Standard shall be expanded polystyrene

or extruded polystyrene manufactured in compliance with ASTM C578, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation. The effective resistivity,  $r_{\text{eff}}$ , (R per inch) in Table A1 shall be used to determine insulation thicknesses required for below-ground application. Insulation materials shall be permitted to be placed in multiple layers to meet required insulation thickness, provided the thickness of any individual layer is not less than the minimum thickness required in Table A1.

When these insulation materials are subject to compression from soil and building loads, the insulation shall be supported on suitable bearing material and shall have adequate compressive strength and long-term deformation (creep) characteristics to resist the sustained loads (live and dead) during the expected life of the structure. Compressive (bearing) loads supported by polystyrene insulation shall not exceed the allowable bearing capacities given in Table A1 for each type of insulation.

**TABLE A1. Design Values for FPSF Insulation Materials**

Insulation Type per ASTM C578	Minimum Insulation Density per ASTM C578 (pcf)	Effective Resistivity, $r_{\text{eff}}$ <sup>1</sup> (R per Inch)		Nominal Resistivity per ASTM C578 (R per inch)	Allowable Bearing Capacity <sup>2</sup> (psf)	Minimum Insulation Thickness (inches)	
		Vertical	Horizontal			Vertical	Horizontal
Expanded Polystyrene							
Type II	1.35	3.2	2.6	4.0	N/A	2	3
Type IX	1.8	3.4	2.8	4.2	1,200	1.5	2
Extruded Polystyrene							
Type X	1.35	4.5	4.0	5.0	N/A	1.5	2
Type IV	1.6	4.5	4.0	5.0	1,200	1	1.5
Type VI	1.8	4.5	4.0	5.0	1,920	1	1
Type VII	2.2	4.5	4.0	5.0	2,880	1	1
Type V	3.0	4.5	4.0	5.0	4,800	1	1

<sup>1</sup> Effective resistivity is based on tests from laboratory and field studies of insulation products under long-term exposure to moist, below-ground conditions. ‘Vertical’ effective resistivity shall be used for insulation placed vertically on exterior foundation walls. ‘Horizontal’ effective resistivity shall be used for insulation placed horizontally, below ground.

<sup>2</sup> Allowable bearing capacity is based on ASTM C578 compressive strength at 10% deformation divided by a safety factor of 3.0 for conditions without cyclic loading (i.e., highway vehicle loading).

‘N/A’ prohibits use where structural foundation loads are supported (i.e., insulation below footings).

### A.2.3 Nominal Thermal Properties for Common Building Materials

**TABLE A2. Thermal Properties of Some Foundation and Floor Construction Materials (ASHRAE Handbook of Fundamentals, 1997)**

Description	Resistivity (hr-ft <sup>2</sup> -°F/Btu-in) [R per inch]
<b>Building Materials</b>	
Plywood or wood subfloor	1.25
Particleboard, low density (37 pcf)	1.41
Particleboard, high density (62.5 pcf)	0.85
Particleboard, underlayment (40 pcf)	1.31
Wood (lumber)	0.90
Brick	0.25
8" Concrete masonry unit (cmu), perlite fill	2.10
Cement mortar	0.15
Concrete	0.05
6 mil plastic	Negligible
<b>Finish Flooring Materials</b>	
Carpet and fibrous pad	R = 2.08
Carpet and rubber pad	R = 1.23

## A.3 CLIMATE DATA

**TABLE A3. Estimates of the Mean Annual Temperature (MAT) and the Design Air-Freezing Index ( $F_{100}$ ) at Select Locations**

Location	Mean Annual Temperature <sup>1</sup> (°F)	Design AFI Estimates <sup>2</sup> 100-Year Mean Return Period, $F_{100}$ (°F-days)
Alaska, Anchorage (Elmendorf AFB)	35.0	3,430
Colorado, Denver	50.3	710
Connecticut, Hartford	49.7	940
Idaho, Idaho Falls	43.8	2,350
Illinois, Chicago	50.6	1,430
Indiana, South Bend	49.4	1,380
Iowa, Fort Dodge	47.4	2,130
Kansas, Topeka	54.1	1,000
Kentucky, Lexington	54.9	720
Maine, Portland	45.0	1,410
Michigan, Lansing	47.2	1,530
Minnesota, Duluth	38.2	3,130
Missouri, Jefferson City	55.1	900
Montana, Lewistown	41.9	2,470
Nebraska, North Platte	48.1	1,690
Nevada, Elko	46.2	1,530
New Hampshire, Concord	45.3	1,600
New York, Syracuse	47.7	1,210
North Dakota, Bismarck	41.3	3,360
Ohio, Mansfield	48.2	1,370
Oregon, Baker	45.6	1,450
Pennsylvania, State College	49.3	1,170
South Dakota, Redfield	43.9	3,010
Utah, Ogden	50.8	1,080
Vermont, Burlington	44.1	2,050
Virginia, Big Meadows	47.2	1,150
Washington, Spokane	47.2	1,230
West Virginia, Elkins	49.4	1,050
Wisconsin, Wausau	42.4	2,490
Wyoming, Sheridan	44.6	2,280

<sup>1</sup> Climatology of the United States No. 81, Supplement No. 3, "Maps of Annual 1961–1990 Normal Temperature, Precipitation, and Degree Days" U.S. Dept of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center, Asheville NC.

<sup>2</sup> Steurer, Peter M. Methods Used to Create an Estimate of the 100-year Return Period of the Air-Freezing Index. U.S. Dept of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center, Asheville NC (1989).





**FIGURE A1. United States Design Air-Freezing Index (°F-Days) Contour Map (an Estimate of the 100-Year Mean Return Period),  $F_{100}$**



**FIGURE A1, Continued. United States Design Air-Freezing Index (°F-Days) Contour Map (an Estimate of the 100-Year Mean Return Period),  $F_{100}$**

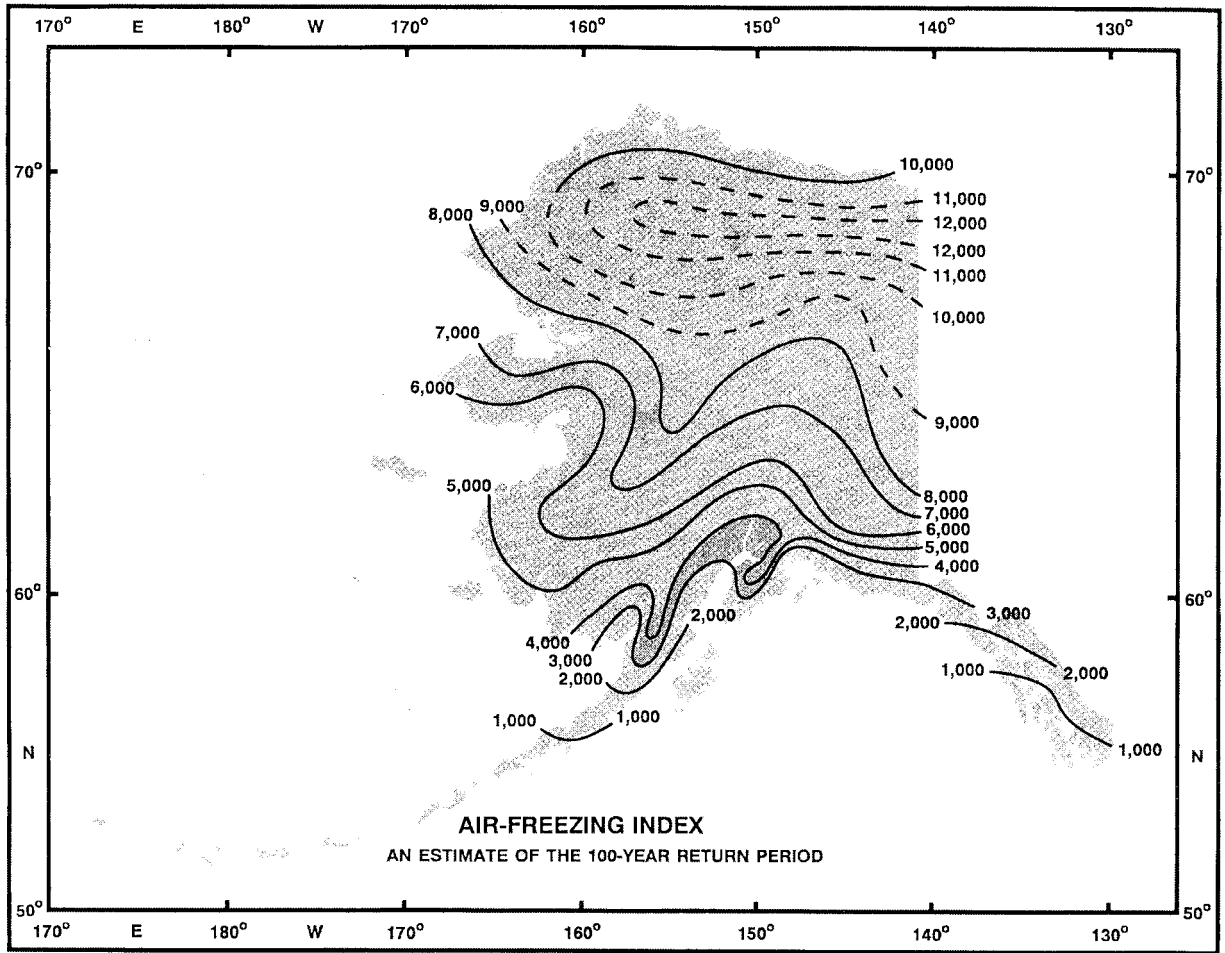


FIGURE A1a. United States Design Air-Freezing Index (°F-Days) Contour Map (an Estimate of the 100-Year Mean Return Period),  $F_{100}$

## A.4 FOUNDATION INSULATION DESIGN

**TABLE A4. Minimum Thermal Resistance of Vertical Wall Insulation  $R_v$  (hr-ft<sup>2</sup>-°F/Btu)**

$F_{100}$ (°F-days)	$R_f \leq 6.0$		$R_f = 15.0$		$R_f = 28.0$	
	$h \leq 12$ in	$h = 24$ in	$h \leq 12$ in	$h = 24$ in	$h \leq 12$ in	$h = 24$ in
375 or fewer	0.0	3.0	4.5	5.7	5.7	8.5
750	3.0	4.6	5.7	5.7	8.5	11.4
1,500	4.5	5.7	5.7	5.7	8.5	11.4
2,250	5.7	5.7	5.7	7.4	8.5	14.2
3,000	5.7	5.7	6.8	8.5	9.7	15.3
3,750	5.7	6.8	8.0	9.7	11.4	17.0
4,500	6.8	8.0	10.2	11.9	13.6	19.3

Interpolation shall be permitted.

**TABLE A5. Minimum Foundation Depths Without Wing Insulation or with Wing Insulation at Corners Only**

$F_{100}$ (°F-days)	Foundation Depth Along Walls with No Wing Insulation	Foundation Depth at Corners with No Wing Insulation		Foundation Depth at Corners with $R = 5.7$ Wing Insulation at Corners Only		
	$h_f$ (in)	$L_c$ (in)	$h_{fc}$ (in)	$L_c$ (in)	$h_{fc}$ (in)	$D_{hc}$ (in)
1,500 or fewer	12	—	12	—	12	—
2,250	14	—	14	—	14	—
2,625	16	40	24	40	16	20
3,000	20	40	32	40	20	20
3,375	24	60	40	60	24	20
3,750	30	60	51	60	30	24
4,125	36	60	63	60	36	32
4,500	43	80	71	80	43	32

Interpolation shall be permitted.

**TABLE A6. Minimum Thermal Resistance of Wing Insulation,  $R_h$ , for Use Along Walls with 16-inch (0.4-m) Footing Depth**

$F_{100}$ (°F-days)	R-values for Various Wing Widths Along Walls, $D_h$ (inches)						
	12	18	24	30	36	42	48
2,250 or fewer	0.0						
2,625	2.5						
3,000	6.5	6.1	5.3	4.5			
3,375		8.2	7.4	6.5			
3,750			9.1	8.5	7.7		
4,125			11.2	10.2	9.6	8.9	
4,500				12.3	11.4	10.7	10.0

Interpolation shall be permitted.

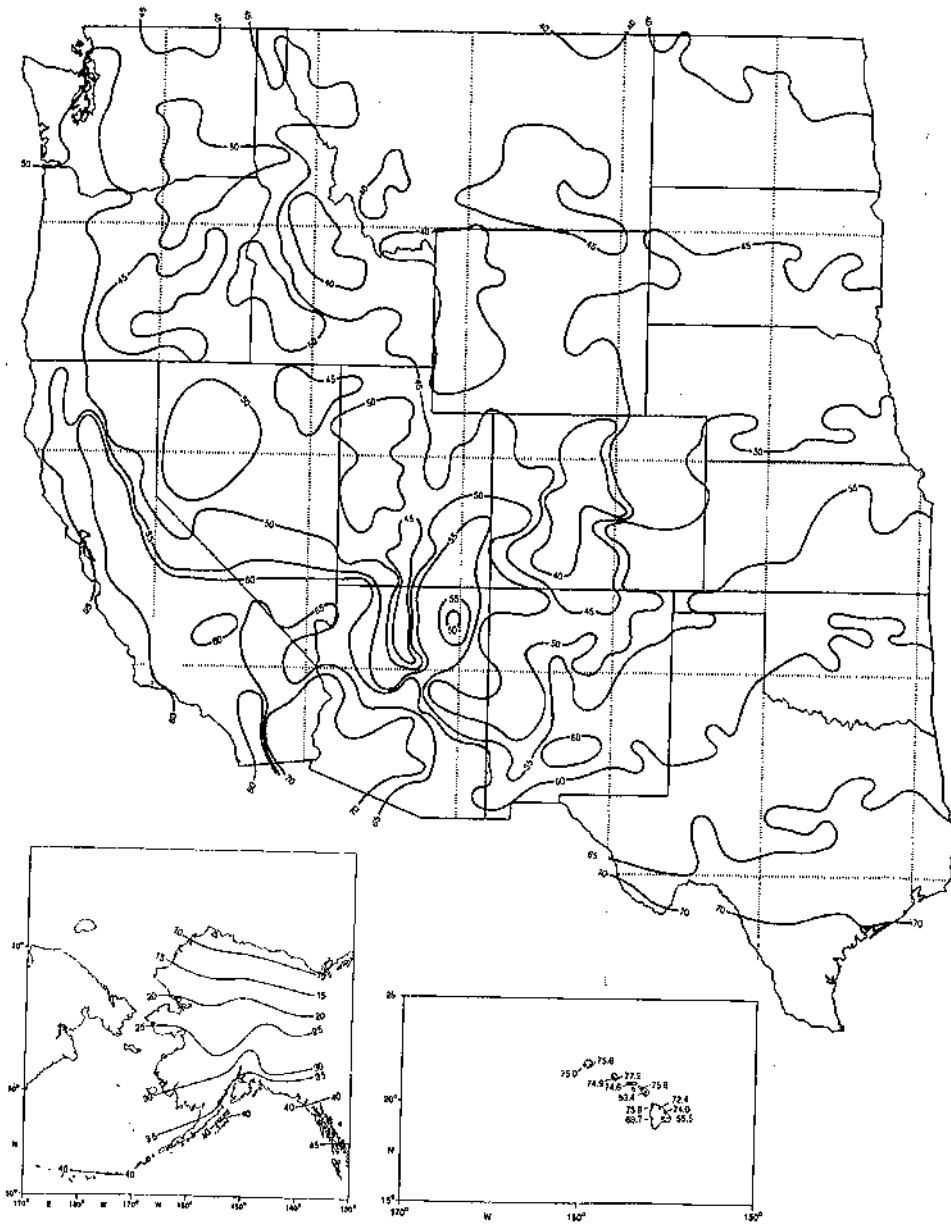
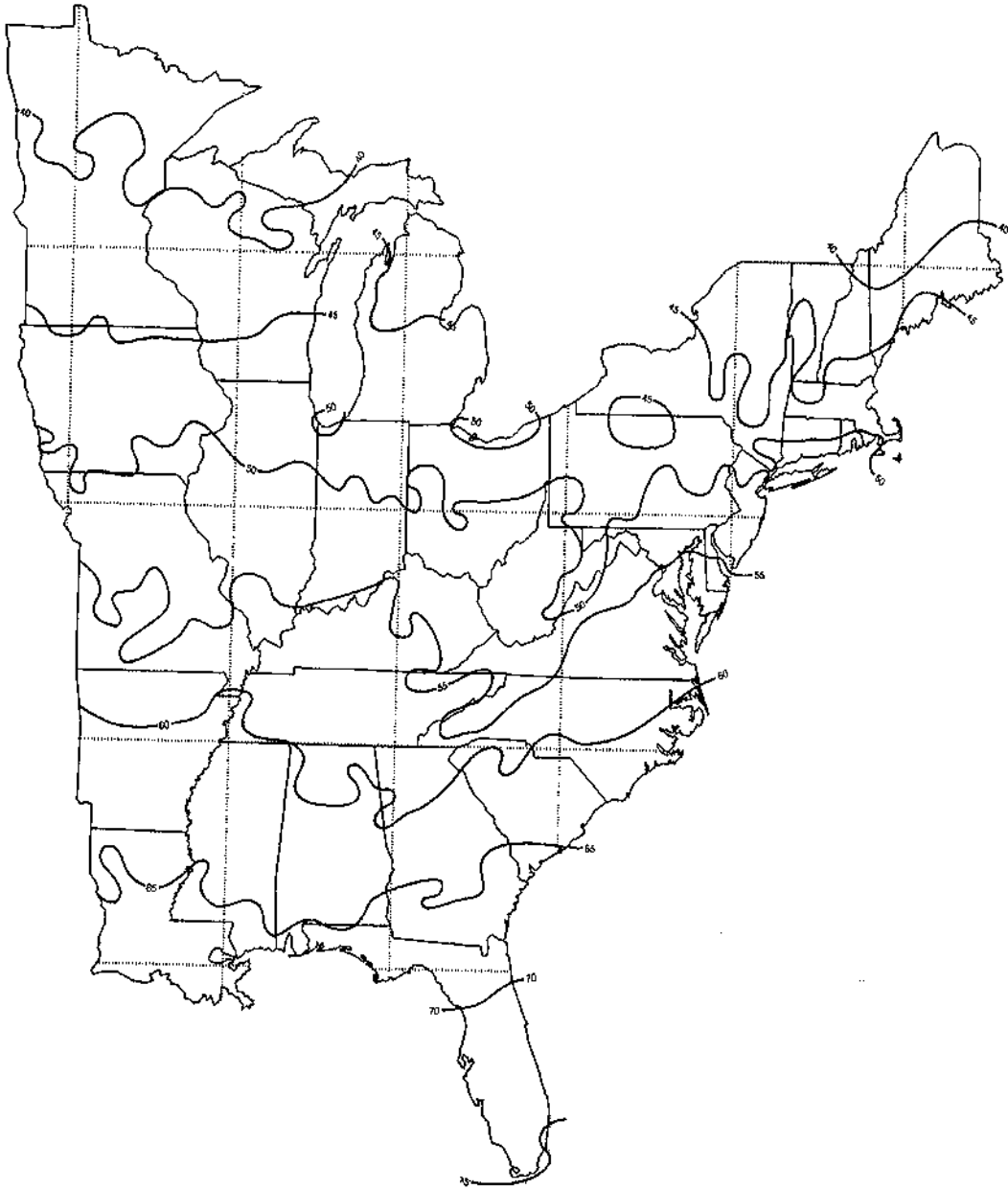


FIGURE A2. Mean Annual Temperature (°F) Contour Map For The United States.



**FIGURE A2, Continued. Mean Annual Temperature (°F) Contour Map For The United States.**

**TABLE A7. Minimum Thermal Resistance of Wing Insulation,  $R_{hc}$ , for Use at Corners with 16-inch (0.4-m) Footing Depth**

$F_{100}$ (°F-days)	$L_c$ (in)	R-values for Various Wing Widths at Corners, $D_{hc}$ (inches)					
		16	24	30	36	42	48
2,250 or fewer	0	0.0					
2,625	40	6.5	4.9	4.0			
3,000	40	9.6	8.6	8.0	7.4		
3,375	60		11.1	10.5	9.8	9.1	
3,750	60		13.1	12.5	12.0	11.2	10.8
4,125	60			14.5	13.7	13.0	12.5
4,500	80				15.9	15.1	14.8

Interpolation shall be permitted.

**TABLE A8. Minimum Thermal Resistance (R-Value) of Ground Insulation,  $R_g$ , and Horizontal Extension,  $D_g$ , for Unheated Buildings**

$F_{100}$ (°F-days)	$D_g$ (inches)	Mean Annual Temperature (°F):				
		$\leq 32$	36	38	40	$\geq 41$
750 or fewer	30	5.7	5.7	5.7	5.7	5.7
1,500	49	13.1	9.7	8.5	8.0	6.8
2,250	63	19.4	15.9	13.6	11.4	10.2
3,000	79	25.0	21.0	18.2	15.3	14.2
3,750	91	31.2	26.1	22.7	—	—
4,500	108	37.5	31.8	—	—	—

Interpolation shall be permitted.

# COMMENTARY

## INTRODUCTION

Much of this introduction to the commentary is devoted to some fundamental back ground related to frost penetration, foundation design, and frost-protected shallow foundations (FPSF). The remainder of the commentary gives additional background information, data, references, and explanations in accordance with the content and organization of the Standard.

An FPSF is an alternative to deeper conventional foundations in regions that experience seasonal ground freezing and the potential for frost heave. Figure C1 illustrates an FPSF for a heated building, and a conventional foundation with the footing extending below the design frost depth. An FPSF incorporates strategically placed insulation to effectively raise the frost depth around a building, thereby allowing structurally sound foundations at depths as shallow as 12 to 16 inches (0.4 m) in cold climates with seasonal ground freezing. For a building or portion of a building that is not heated, the insulation strategy involves the use of an insulated foundation pad to conserve geothermal heat and prevent ground freezing. Appropriate use of the above two insulation strategies, dependent upon the thermal conditioning of the interior environment, is critical to the intended performance of an FPSF.

The FPSF technology is applicable to a variety of foundation types including crawlspaces, slabs-on-

ground, and those portions of basements that are at or above grade. Slab-on-ground foundations may be monolithic (thickened edge) or have separate perimeter walls (or grade beams) as in crawlspace construction.

FPSFs may be constructed of concrete, concrete masonry, preservative-treated wood, insulating concrete form systems, and other suitable foundation construction materials and methods. The technology may also be used with isolated spread footings and with combined deep column, pile, or pier foundations with shallow grade beams in between. The primary concern in FPSF design is frost protection. Therefore, the technology may be applied to practically any structurally sound foundation system.

An extensive review of the FPSF technology was conducted prior to the development of this Standard (Morris, 1988; Farouki, 1992). These reviews were followed by several demonstration and monitoring projects sponsored by the US Department of Housing and Urban Development (HUD) to verify the performance of existing European design practices (Crandell, Steurer, and Freeborne, 1994; NAHB Research Center, 1994a). As a result of these efforts, an FPSF Design Guide was developed to serve as a basis for building code acceptance and standardization in the United States (NAHB Research Center, 1994b). The Design Guide was later expanded under sponsorship of the US Department of Energy to include provisions for

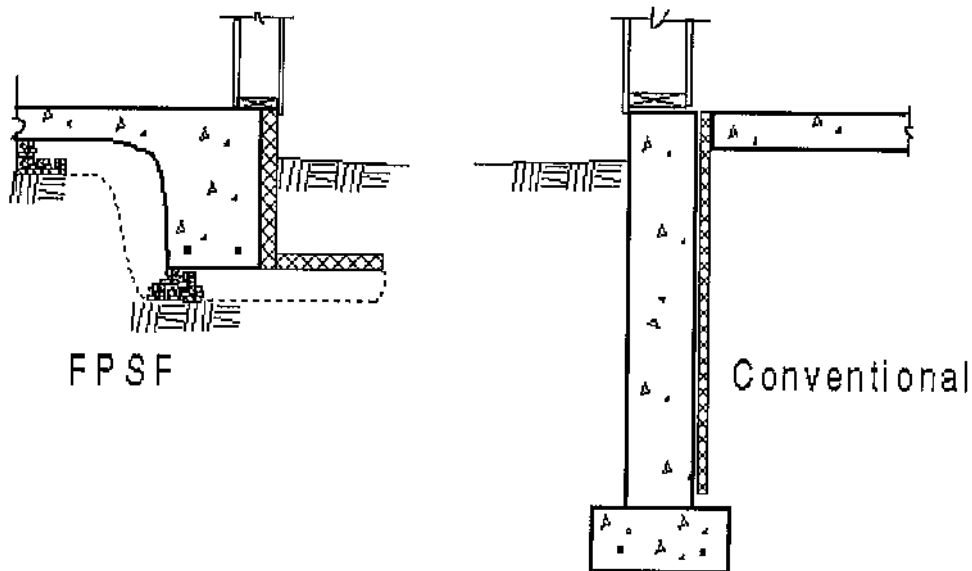


FIGURE C1. Schematic of FPSF and Conventional Foundation Systems



crawlspace foundations and additional construction details for walk-out basements and other conditions (NAHB Research Center, 1996). Also during this time, climate data in the United States was extensively analyzed and a map of the 100-year mean return period Air-Freezing Index (AFI) was developed for use with the FPSF Design Guide (Steurer, 1989; Steurer and Crandell, 1995).

The earliest documented use of the FPSF concept in the United States was by Frank Lloyd Wright in the 1930s (Morris, 1988). However, the widest use of FPSF technology has been in Nordic countries, where well over one million FPSFs have been constructed successfully over the last 45 years (Morris, 1988). In Scandinavia, the FPSF is commonly used on both residential and commercial buildings—houses, townhouses, apartments, shopping malls, schools, low-rise office buildings, restaurants, gas stations, and so on. FPSFs have been standard practice for low-rise construction in Scandinavia since the early 1970s. Since the early 1970s, design guidelines have been developed and maintained in several countries for use of the technology (Robinsky and Bessflug, 1973; NBI, 1988; Adamson, Claesson, and Efring, 1973; Torgerson, 1975; Thue, 1974). More recently, efforts to produce uniform FPSF design guidelines by several European countries have resulted in the development of a European standard (CEN, 1996). That draft standard was instrumental in developing design guidance for use in the United States (NAHB Research Center, Inc., 1994b).

In the United States, a simplified form of FPSF was approved for residential construction in the *One- and Two-Family Dwelling Code* (CABO, 1995; ICC, 1998). It is also recognized in the *International Residential Code–2000* (ICC, 1999), and in various state and local building codes. In addition to residential and commercial buildings, the technology has been applied to highways, dams, shallow underground utilities, railroads, earth embankments, and agricultural structures (Morris, 1988; Jones et al, 1982). An FPSF is an energy-efficient solution to the adverse effects of seasonal ground freezing and frost heave.

Frost heave is the deformation of a building caused by uplift due to the expansion of excessive soil water as it freezes, or the formation of ice lenses in moist, frost susceptible ground underlying a foundation. Frost heave can also occur when moist, frost-susceptible soil freezes or adheres to the side of foundation members (i.e., “side-grip” or “ad-freezing”) and ice lenses, which are not below the foundation, deform the building by similar action. A related phenomenon, thaw-weakening, can also occur when moist, cohesive

soil weakens during the thawing process and causes settlement. The most highly frost-susceptible soils are generally considered to be silts, but other soils with a sufficient content of fine particles are also considered frost susceptible.

Frost heave can only occur when a soil is frost susceptible, contains sufficient moisture, and is subject to sub-freezing temperatures. Eliminating any one of these factors will prevent the occurrence of frost heave. Thus, the FPSF technology mitigates the potential for frost heave by preventing moist, frost-susceptible ground from experiencing sub-freezing temperatures. Because sub-freezing ground temperatures are prevented, the potential for thaw-weakening of cohesive soils is also mitigated.

The FPSF technology is based upon the thermal interaction of a building with the ground. Soil beneath foundations has a relatively high specific heat, and heat conducted from warm summer ambient air, heated buildings, and deep soil underlying foundations is stored in a “heat bulb” under the building over the winter (ASHVE, 1948 and 1951; Bareither, et al, 1948; Morris, 1988). This thermal condition effectively raises the frost depth at the perimeter of the building (Figure C2). This effect is magnified when insulation is strategically placed around the foundation, particularly when the average interior temperature is maintained well above that of the winter outdoor climate (i.e., for human occupancy or building operation and maintenance). The FPSF also works on unheated buildings or unheated parts of a building by use of a mat of insulation to conserve geothermal heat supplied to and stored below ground.

Figure C3 illustrates the heat exchange process in an FPSF, which results in a reduced frost depth around the building. The insulation around the foundation perimeter conserves and redirects heat loss through the slab toward the soil below the foundation. Geothermal heat from the underlying ground also helps raise the ground temperature underneath the building and the frost depth around the building. Heat loss through any building foundation also prevents damage from ad-freezing or lateral loads from moist, frozen ground adjacent to foundations.

The design provisions in the Standard are based on the following worst-case conditions to ensure adequate frost protection:

- use of a 100-year mean return period air-freezing index
- a highly frost-susceptible soil (silt) with relatively high thermal conductivity and with sufficient mois-

ture in the soil to promote frost heave, but not so much as to resist the penetration of the frost line through latent heat effects

- no insulating ground cover from snow, turf, and so on
- minimum indoor temperature conditions for “heated” and “semi-heated” building thermal classifications based on intended use and occupancy of the building
- no heat input to the ground from buildings classified as “unheated”

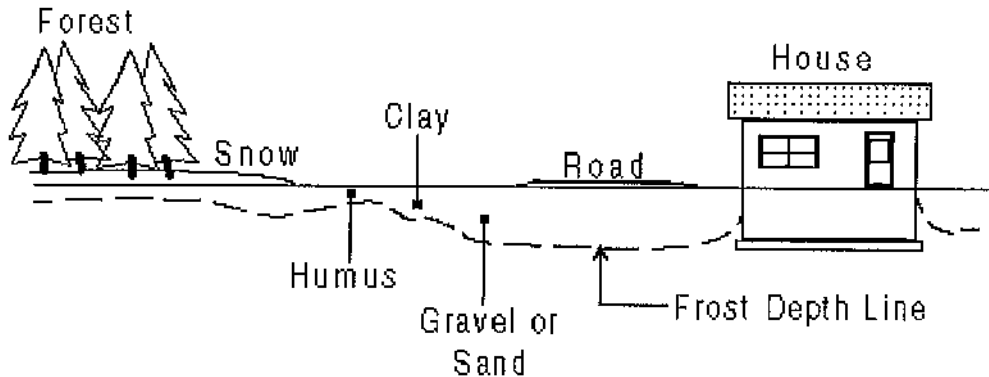
Several of these conditions would need to be violated simultaneously for frost heave to occur on a site that actually had frost-susceptible soils of a sufficiently high moisture content. Thus, frost heave is highly improbable for buildings with foundations properly designed using FPSF technology. The rare reported prob-

lems have typically been associated with designs or construction that are not in compliance with good design and construction practices.

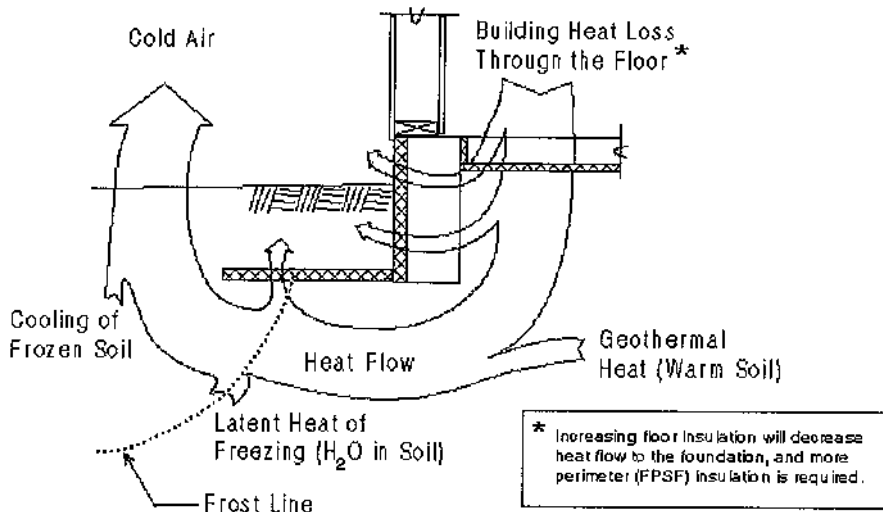
**C1. SCOPE AND LIMITATIONS**

The objective of this Standard is to assist US engineers, designers, builders, code officials, and others employ FPSF technology. However, it is not the intent for this Standard to limit the sound judgment and practice of those competent in foundation design and the prevention of frost damage.

Historically, foundations have been protected from frost by their extension below a locally prescribed design frost depth or by erecting them upon solid rock.



**FIGURE C2. Frost Penetration into the Ground Under Various Conditions**



**FIGURE C3. FPSF Heat Flow Diagram for a Heated Building with Optional Floor Insulation**

FPSF design allows footings to be founded above the design frost depth by insulating the foundation and ground in a manner that prevents ground freezing below the foundation.

The Standard applies to buildings with slab-on-ground or suspended floor foundations, as well as those portions of basement floor slabs and foundations that are above the design frost depth. The Standard is a frost-protection design standard, and not a structural or geotechnical design standard. Foundations meeting structural building code requirements or accepted structural design practices may be protected from frost heave using these methods. Application of this Standard is clearly limited to regions, climates, and sites where permafrost does not exist. Entirely different design strategies are used in permafrost foundation design to prevent heat from moving into the ground, melting the permafrost, and causing subsidence of foundations. The Standard is also not intended to provide any protection against expansive clay soils that expand and contract with variation in moisture content.

The Standard provides FPSF design methods for heated, semi-heated, and unheated structures based on the amount of heat or indoor conditioning provided to the structure as classified by the minimum average monthly indoor temperature expected during the building's intended useful life (see Table 1). Accordingly, the indoor temperature classification affects the frost protection approaches and insulation requirements in the Standard. This thermal classification of the building or even a part of a building (i.e., attached unheated garage) is an important consideration that deserves careful attention by the user of this Standard. It should also be noted that sub-floor insulation affects frost protection requirements. The Simplified Design Method in Section 5 does not permit sub-floor insulation greater than R-10. Section 6, Design Method for Heated Buildings limits it to R-28. If higher levels of insulation are used, the building must be designed as unheated. A monthly average indoor temperature is used due to the lag effect associated with ground temperatures at the footing depth.

The appropriate thermal classification should be selected based on the conditions that follow. Homes, businesses, and other buildings with year-round human occupancy are assumed to have an average monthly indoor air temperature of more than 63°F (17°C) and should be constructed as heated buildings. These buildings are typically conditioned to a minimum of 68°F (20°C) during the heating season. During non-heating seasons, temperatures are typically higher. Semi-heated buildings or parts of buildings are assumed to have an average monthly indoor air temperature between 41°F

(5°C) and 63°F (17°C). Included are unconditioned spaces that receive significant indirect heat from conditioned spaces, such as unfinished basements, unvented crawlspaces, and buildings that are maintained during the winter season with reduced heating.

Minor or temporary variations below the average monthly indoor temperature requirements are not detrimental to the performance of buildings classified as heated or semi-heated for the purposes of FPSF design. Unheated buildings are typically detached structures or parts of structures that are unheated and thermally separated from the ancillary heat transfer from conditioned areas of the building. Examples include attached and detached garages, exterior slabs, ventilated crawlspaces, and similar conditions, without conditioning of the indoor air.

Approved attached garage designs may be classified as semi-heated, where heat, provided to the garage by thermal conditioning, or heat loss from the building, maintains a minimum monthly average temperature of 41°F (5°C) during the design winter.

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### C3. SYMBOLS, UNITS, AND DEFINITIONS

No commentary is required for Section 3 of the Standard.

### C4. DESIGN PRINCIPLES

#### C4.1 GENERAL

Frost protection strategies are designed to prevent, avoid, or eliminate one or more of the following three conditions required for frost heave:

**Sub-freezing temperatures.** Sub-freezing air temperatures must exist to produce ground temperatures that are sufficiently cold and persistent to freeze the “free” water in the soil and to cause the frost front to penetrate into the ground. The sub-freezing temperature must persist in a moist, frost-susceptible soil long enough for ice lenses to develop (see items below).

**Frost-susceptible soil.** The frost-susceptibility of a soil is classified according to its particle size distribution which, in turn, is related to the ability of the soil to retain moisture while allowing for capillary moisture transport. Silty soils are highly frost-susceptible because they support adequate capillary movement of water to the frost front when the soil is sufficiently moist. Coarse sands and gravels with limited amounts of fines have large particle sizes and do not support the capillary action required for ice lens formation and growth. Clayey soils have very fine soil particles and are generally only slightly frost-susceptible because they tend to block the capillary movement of water. Mixed soils will have varying degrees of frost-susceptibility depending on their composition. The classification of non-frost-susceptible soils is addressed in Section C4.2 of this commentary.

**Availability of soil water.** When sufficient soil moisture is available in a frost-susceptible soil, water may be transported to the frost front from underlying moist, unfrozen soil by capillary action. This phenomenon causes the development of ice layers or ice lenses in the soil at the location of the frost front. These lenses may range in thickness from approximately 1 mm

in soils that are not frost-susceptible to as much as 150 mm in highly susceptible soil types (Rathmayer, 1994). Simple expansion of the soil water due to the freezing process produces only a relatively small amount of heaving. Water in soil voids can expand as much as 10%, but considering the void ratio of most soils, the soil expansion will be substantially less than 10%.

Extending the foundation below the design frost depth avoids sub-freezing temperatures by placing the footing below a locally prescribed frost depth. However, this traditional approach does not necessarily prevent frost heave that is caused by “ad-freezing” or “side grip.” Building on solid rock or on non-frost-susceptible soils prevents frost heave, although the temperature of the soil may be well below freezing and contain frozen water (Section 4.2). Foundations on well-drained soils also prevent frost heave by eliminating water required for frost heave to occur. In other strategies, sub-freezing temperatures can be avoided by supplying heat to the soil by electric-resistance cables, hydronic-heating pipes, or warm-air ducts.

Frost-protected shallow foundations designed in accordance with this Standard will reduce the possibility of sub-freezing ground temperatures adjacent to and beneath the foundations by using thermal insulation. The insulation helps conserve heat from buildings and from geothermal heat sources (Section 4.3), but will not necessarily eliminate frost-susceptible soil or water beneath the foundation. Other strategies for frost protection may be based on sound engineering analysis and accepted design practice. Site-specific analysis may result in more economical design, particularly if effects of the building on frost penetration are considered in the analysis. Methods of analysis, such as finite element computer models, are commercially available and may be used for thermal design of frost protection on building foundations. The accuracy of an analysis using such computer models is dependent on a number of factors, including judgment of the user, characterization of input data, and selected analytical methods. A full discussion is beyond the scope of this commentary.

#### C4.1.1 Bearing Capacity

Since the bearing capacity of soils and fill materials is a concern with any foundation design, this section is included in the Standard to ensure proper consideration. To prevent settlement, a FPSF must be placed on soils capable of supporting the imposed foundation loads, regardless of the requirements for frost protection. The minimum depth requirements of the Standard may be superseded by requirements to provide proper bearing for foundation loads in certain situations.

Polystyrene insulation may be used to support foundation bearing loads when properly specified as shown by its common use in Scandinavia for this purpose. Insulation-bearing capacities, as well as limitations related to creep, were considered in selection of insulation types and allowable bearing values that the Standard permits (Table A1).

Gravel, coarse sand, or crushed stone may also be used to support loads from foundation walls, grade beams, and footings. These materials are commonly used under roads, in railroad beds, and under various types of building foundations. One example of a building foundation application is the permanent wood foundation that is frequently used to support light-frame structures (Southern Pine Council, 1998). For other conditions, engineering analysis may also demonstrate that concrete spread footings are not required, depending on the axial loads, thickness of the gravel, coarse sand, or crushed stone, and the bearing capacity of the soil underlying the foundation. Determination of the thickness and width of granular footings necessary to adequately spread the load from the foundation wall or grade beam to the supporting soil typically assumes an angle of 30 degrees from vertical at each edge of the foundation wall or grade beam.

#### **C4.1.2 Drainage**

Since adequate drainage is a concern with any foundation design, this section is included in the Standard to ensure proper consideration. The removal of soil moisture will prevent the occurrence of frost damage, but is not necessary if the foundation is properly insulated to keep the temperature of soil under the foundation above freezing. Drainage of the granular layer under horizontal wing insulation will tend to improve long-term performance of below-grade insulation, but the insulation type and effective thermal resistivity are intended to apply to long-term exposure to moist, below-ground conditions (Table A1).

#### **C4.1.3 Compaction**

Adequate compaction of soils used for fill or back-fill, in relatively thin layers, is important to reduce consolidation and settlement. Since this structural concern is present with any foundation design using fills, it is included in the Standard to ensure proper consideration following accepted design or construction practice.

#### **C4.1.4 Insulation Protection**

Durable, opaque, weather-resistant coverings or coatings are required on exposed vertical foundation insulation to protect the insulation from ultraviolet radiation, physical damage, and other sources of deterio-

ration. The protective covering is required to extend from the top of the foundation to six inches below grade. Examples of protective finishes used for this purpose include, but are not limited to:

- preservative-treated plywood, foundation grade, often painted above grade
- two- or three-coat stucco over mechanically attached wire mesh
- elastomeric stucco with or without fiberglass reinforcement
- brush-on elastomeric coatings
- fiberglass-reinforced panels
- vinyl siding or panels
- non-corrosive metal coil stock
- cementitious sheets (cement board)

Finishes with low damage resistance should only be installed in areas not susceptible to severe physical abuse (e.g., lawn mowers), such as behind shrubbery or flower beds. Durable coverings or coatings are also required above horizontal wing insulation placed outside the foundation at a depth of 12 inches or less below grade, and on any portion extending outward more than 24 inches from the foundation at any depth, to protect the insulation from possible landscape excavations. The minimum 12-inch depth of horizontal insulation is adequate for small plantings typically located immediately adjacent to a building. Beyond 24 inches from the foundation, protection must be provided at any depth because at this distance, shrubs and other large plantings are more likely. When required to protect the horizontal insulation, coverings may be concrete or asphalt pavement (sidewalks and driveways), cementitious board, foundation-grade preservative-treated plywood, or an equivalent. Minor discontinuities in wing insulation will not significantly affect the performance of the FPSF design, but they should be minimized or avoided.

#### **C4.1.5 Termite Protection**

Wood frame buildings in geographical areas subject to termite infestation must be protected according to locally approved methods, or for federally-assisted housing, the local HUD Field Office. These methods include using chemical soil treatment, physical barriers such as termite shields, or other approved methods. The concern is that termites will tunnel through or behind slab edge insulation from the ground to the wood framing members. When required, physical barriers (e.g., aluminum flashing) should be placed between the foundation and the above-grade structure and extend the full thickness of the foundation, so that termite shelter tubes built around the barrier can be visually in-

spected. Structures constructed entirely of preservative-treated wood, naturally termite-resistant wood, steel, concrete, or other materials not susceptible to termite damage may be considered protected against termites. In some highly susceptible termite regions, local codes may prohibit use of foundation insulation.

#### **C4.2 FOUNDATIONS ON NON-FROST-SUSCEPTIBLE GROUND OR FILL MATERIALS**

The primary means of frost protection for FPSFs is keeping the soil under the foundations above the freezing temperature by conserving heat from a building and/or geothermal heat. Undisturbed non-frost-susceptible soils and properly compacted non-frost-susceptible fill materials can be used to achieve the foundation depths required by the Standard. To be classified as non-frost-susceptible, no more than 6% of the mass of undisturbed soils or fill material must pass through a #200 mesh sieve in accordance with ASTM D422. This criteria is based on a survey of requirements for classifying non-frost-susceptible soils (Chamberlain, et al, 1984) and the judgment of the committee. It is not intended to preclude the use of other non-frost-susceptible materials that have performed successfully as a matter of accepted practice. A soils or geotechnical engineer should determine the frost susceptibility of undisturbed soils or fills, unless otherwise approved.

#### **C4.3 FOUNDATIONS WITH INSULATION TO PREVENT GROUND FREEZING**

The provisions in the Standard for design and construction of FPSFs is considered comprehensive. However, supplemental design and construction guidance, details, and design examples may be found in the *Design Guide for Frost-Protected Shallow Foundations* (NAHB Research Center, 1996). Foundations should not be constructed on frozen soil. FPSFs not completed before the time of first ground freezing should be protected during the winter by methods typically used in cold weather construction (e.g., straw, insulation blankets, and insulation placed beneath the slab). Shallow crawlspace foundations should be protected by insulating foundation walls and suspended floors, and covering the ground with a weather barrier. In addition, during winter, builders in the United States and Scandinavia have constructed FPSFs for years by placing temporary heat in the building while construction is completed. Given the use of the 100-year mean re-

turn period AFI in FPSF design, there is relatively little chance of exposure to long-term ground freezing risk during the short construction phase, compared to exposure during the life of the structure.

#### **C5. SIMPLIFIED FPSF DESIGN METHOD FOR HEATED BUILDINGS**

In consolidating the design steps for the simplified method, R-values for the vertical insulation were established so that the performance level of various conditions, including slab surface temperatures, were conservatively accommodated. Therefore, more economical construction costs may be obtained when the detailed design procedure is followed. The simplified approach is currently found in *International Residential Code* (ICC, 2000), *International One- and Two-Family Dwelling Code* (ICC, 1998), and *One and Two Family Dwelling Code* (CABO, 1995). The simplified approach only applies to the design of heated buildings. It does not apply to unheated buildings or unheated portions of otherwise heated buildings (e.g., an unheated attached garage).

#### **C6. FPSF DESIGN METHOD FOR HEATED BUILDINGS**

In practice, there are many different combinations of vertical and horizontal insulation details, R-values, and footing depths that can be used in an FPSF. The detailed design approach is a flexible approach that allows the designer to use experience and select the preferred method of construction for a given site. For example, the designer may opt to provide vertical wall insulation only, wing insulation only at the corners, or wing insulation around the entire building. However, since more heat loss occurs at exterior building corners than through mid-wall sections of heated buildings, additional frost protection in the form of horizontal wing insulation or a deeper foundation is required at exterior foundation corners for more severe climates ( $F_{100} > 2,250^{\circ}\text{F-days}$ ).

The designer has the flexibility to step footings to increase foundation depths, add wing insulation to reduce required foundation depths, or select the width of wing insulation to meet the minimum design requirements. The design approach for crawlspace foundations is similar to the approach used for slab-on-ground buildings. Vertical insulation may be placed on the outside edge of slab or perimeter grade beam, within a permanent wood foundation or structural insulated

panel, or on the interior and exterior of a perimeter grade beam (e.g., insulating concrete form system), provided there are no cold bridges between interior of building and exterior of foundation wall.

In terms of thermal efficiency, the most effective location for the vertical foundation insulation is on the exterior of the foundation wall. The largest gains in terms of improved energy efficiency of an FPSF can be realized by increasing the amount or thickness of the vertical insulation on the perimeter of the foundation beyond that required for frost protection (Labs K., et al, 1988). It should be noted that the amount of vertical perimeter insulation is dependent on the amount of floor or sub-slab insulation specified to meet or exceed minimum energy code requirements or for improved comfort and floor slab surface temperatures at the perimeter of the building.

## C7. FPSF DESIGN METHOD FOR UNHEATED BUILDINGS

The design of unheated foundations relies on geothermal heat stores. For this reason, a mat of insulation is placed on the ground below the entire foundation. A layer of non-frost-susceptible material is also placed above or below the ground insulation and is integral to the performance of the ground insulation layer. Exterior vertical wall insulation is not needed in buildings considered to be unheated. The designer has the flexibility to increase foundation depths to reduce ground insulation requirements.

## C8. SPECIAL DESIGN CONDITIONS

No commentary is required for Section 8 of the Standard.

### C.A. APPENDIX A

#### C.A.1 Purpose

No commentary necessary.

Thermal conductivity (unfrozen) . . . . .	10.4 Btu-in/h-ft <sup>2</sup> – °F	(1.5 W/m – °K)
Thermal conductivity (frozen) . . . . .	17.3 Btu-in/h-ft <sup>2</sup> – °F	(2.5 W/m – °K)
Heat capacity per unit volume (unfrozen) . . . . .	44.7 Btu/ft <sup>3</sup> – °F	(3 × 10 <sup>6</sup> J/m <sup>3</sup> -°K)
Heat capacity per unit volume (frozen) . . . . .	28.3 Btu/ft <sup>3</sup> – °F	(1.9 × 10 <sup>6</sup> J/m <sup>3</sup> -°K)
Latent heat of freezing per unit volume . . . . .	4.0 × 10 <sup>4</sup> Btu/ft <sup>3</sup>	(1.5 × 10 <sup>8</sup> J/m <sup>3</sup> )
Dry density . . . . .	84.3 lbs/ft <sup>3</sup>	(1,350 kg/m <sup>3</sup> )
Water content (saturation degree = 90%) . . . . .	28.1 lbs/ft <sup>3</sup>	(450 kg/m <sup>3</sup> )

### C.A.2 Material Properties

#### C.A.2.1 Soil Properties

The FPSF insulation requirements in this Standard are based on homogenous ground consisting of frost-susceptible soil with the following properties:

Although other soils at in situ moisture conditions may be more sensitive to frost penetration and heave, this soil was chosen as representative of a worst-case situation in combination with other worst-case factors (i.e., 100-year mean return period AFI, no ground cover, and so on). These soil characteristics were used to determine foundation insulation requirements in Appendix A. Also, the soil is considered to be fully frozen when the temperature of the soil reaches 30.2°F (–1°C). Foundation insulation requirements have been shown to be relatively insensitive to variations in soil condition within the range of frost-susceptible soil types and moisture contents (Adamson, et al, 1973; Torgerson, 1975). This simplification has worked well in practice and in full-scale verification studies (NAHB Research Center, 1994a). Insulation requirements in the Standard are primarily based on *Building Foundations—Thermal Design to Avoid Frost Heave* (CEN, 1996).

#### C.A.2.2 Insulation Materials

Insulation materials approved for use in the Standard are extruded or molded polystyrene foams with adequate densities. These materials have exhibited successful performance in moist, below-ground applications. Effective R-values per inch and densities by insulation type are based on a survey of numerous studies of below-ground performance of polystyrene insulation materials. The values reported in Table A1 reflect the consensus judgment of the committee in reviewing the available data and the European practice. Some of the key published studies are found in Section C2, References (ASTM, 1994; Ojanen and Kokko, date unknown; Ovstaas, et al, 1983; Sandberg, 1986; Greeley, 1997). The effective thermal resistivity values (i.e., R-value per inch) apply to long-term use in moist, below-ground conditions. Insulation should not be used unless the Type (per ASTM C 578) is clearly printed on the insulation or



on a separate certification provided by the manufacturer. This identification is necessary so that builders, building officials, and owners know that the insulation being used has the properties required for the particular FPSF application.

### ***C.A.2.3 Nominal Thermal Properties for Common Building Materials***

The thermal resistivity values provided in Table A2 for various construction materials are provided primarily as a resource for determining floor insulation values based on dry thermal resistance. The floor insulation value,  $R_f$ , will affect the amount of vertical perimeter insulation required by Table A4 in FPSF design of a heated or semi-heated building.

### **C.A.3 Climate Data**

Development of 100-year mean return period AFI,  $F_{100}$ , and a US map by the National Climatic Data Center (NCDC), US National Oceanic and Atmospheric Administration (NOAA) was a necessary part of development of the FPSF design method (Steurer, 1989). Derivation of the AFI was also compared to methods used in Scandinavia to ensure compatibility (Steurer and Crandell, 1995). The AFI is a measure of how cold a climate is with respect to ground freezing potential. It is the cumulative departure of the mean daily temperature above and below 0°C (32°F) between highest and lowest points on a cumulative degree-day time curve for a complete freezing season. This index is commonly referred to in the United

States as freezing degree days (FDD). Thirty years of data (1951–1980) from 3,110 weather stations were used to calculate indexes and various return period estimates (Steurer, 1989; Steurer and Crandell, 1995). A 100-year mean return period was chosen to provide a high level of protection for the FPSF system.

Earlier indexes used for frost protection in the United States were based upon the average of the AFI for the three coldest winters from a 30-year period of record. Scandinavian design methods used either a 50-year or 100-year mean return period for design purposes. A 2-year mean return period for buildings under construction, and a 10-year mean return period for free-standing garages and other similar ancillary buildings, are also used in Scandinavia.

Site-specific AFI data for many US weather stations may be obtained from the National Climatic Data Center (NCDC), US National Oceanic and Atmospheric Administration (NOAA), 151 Patton Avenue, Asheville, NC 28801-5001 or by email at [orders@ncdc.noaa.gov](mailto:orders@ncdc.noaa.gov). Request TD9712D for digital data or request a hard copy printout for one or more stations or states. Local AFI and climate data may also be accessed directly from the website, [www.ncdc.noaa.gov/fpsf.html](http://www.ncdc.noaa.gov/fpsf.html).

### **C.A.4 Foundation Insulation Design Data**

Design tables are based on several references: CEN, 1996; NBI, 1988; NAHB Research Center, 1996.

# INDEX

- air-freezing index (AFI) 1, 26
- approved 1
  
- barriers to termites 3, 31–32
- basements 8, 9, 26, 28
- bearing capacity 3, 7, 11, 15; commentary 30–31
- building classifications 1
  
- cementitious board 3, 31
- chemical soil treatment 3, 31
- classification of buildings 1
- clay soils 28
- climate data 17–20, 22–23, 26; commentary 34
- cold-bridges 5, 6, 8, 14, 33; definition 1
- column foundations 11
- commentary 25–34
- compaction 3; commentary 31
- compressive loads. See bearing capacity
- computer models 30
- continuous foundation walls 11, 25–26, 28
- conventional foundation schematic 25
- corners: heated buildings 7, 32; semi-heated buildings 11; unheated buildings 9; wing insulation 24
- crawlspaces: unvented 7–8, 25–26, 32; vented 11, 25–26, 28
  
- definitions 1–3
- design air-freezing index ( $F_{100}$ ): contour map 18–20; definition 1; selecting 4, 6, 9; select locations 17
- design frost depth 1, 28
- design principles 3–4; commentary 30–32
- drainage 3; commentary 31
  
- effective thermal resistance ( $R_{\text{eff}}$ ) 1
- effective thermal resistivity ( $r_{\text{eff}}$ ) 1
  
- $F_{100}$ . See design air-freezing index ( $F_{100}$ )
- fill materials 3, 4. See also non-frost-susceptible fill
- foundation depth 3; selecting 7; semi-heated buildings 11; small unheated areas 11; without wing insulation 21
- foundation insulation design 21, 24; commentary 33
- FPSF. See frost-protected shallow foundation (FPSF)
- freezing degree days 1, 26
- frost depth 26, 27
- frost heave 26, 27, 30; definition 2
- frost-protected shallow foundation (FPSF): applicability 25; definition 2; materials 25; schematic 25; use 1, 26
- frost-susceptible soil 30
  
- garages 4, 28
- ground insulation: definition 2; placement 9; R-value (thermal resistance) 9, 24; selecting 9, 11; small unheated areas 11; unheated buildings 24
- ground protection, temporary 4, 32
  
- heated buildings: design method 6–8, 28, 32–33; FPSF schematic 25; indoor air temperature 1, 28; large unheated areas 12, 13; simplified design method 4–6, 28, 32; small unheated areas 11, 12
- heat exchange process 26, 27
- horizontal insulation. See wing insulation
  
- insulation materials 15; commentary 33
- insulation protection 3; commentary 31
- insulation requirements, minimum 4
  
- large unheated areas 12, 13
  
- MAT. See mean annual air temperature (MAT)
- material properties 15–16; commentary 33–34
- mean annual air temperature (MAT): contour map 22–23; definition 2; selecting 9; select locations 17
- mean return period air-freezing index 2
- mean return period (mean recurrence interval) 2
  
- non-frost-susceptible fill 4; commentary 32, 33; small unheated areas 11
- non-frost-susceptible soil 4; commentary 32; definition 2; layer 9
  
- permafrost 1, 28; definition 3
- physical barriers to termites 3, 31–32
- pier foundations 11
- plywood 3, 31
- polystyrene insulation 3, 15, 33; commentary 31
  
- references 1, 28–30
- $R_{\text{eff}}$  (effective thermal resistance) 1
- $r_{\text{eff}}$  (effective thermal resistivity) 1
- R-value (thermal resistance) 4–5; commentary 33; definition 3; floor slab 6–7; ground insulation 9, 24; vertical insulation 7, 21; wing insulation 21, 24
  
- scope and limitations 1; commentary 27–28
- semi-heated buildings 6, 8, 12, 14; indoor air temperature 1, 28; simplified design method 4–6, 28, 32
- slab-on-ground foundations 1, 25, 28; heated buildings 6–7, 32; simplified design method 4–6, 28, 32; unheated buildings 8–11

## INDEX

- small unheated areas 7, 11, 12
- soil moisture 30
- soil properties 4, 15; commentary 33
- soils 3, 26; chemical treatment 3, 31; clay 28
- sub-floor insulation 28
- sub-freezing temperatures 30
- suspended floors 1, 4, 28; definition 3
- symbols and units 1, 2
  
- temporary ground protection 4, 32
- temporary heating of internal space 4, 32
- termite protection 3; commentary 31–32
- thermal properties of building materials 16; commentary 34
- thermal resistance. See R-value (thermal resistance)
- thermal resistivity: commentary 33, 34; definition 3
  
- underground foam insulation 3
- unheated areas 4; insulation strategy 25, 26. See also large unheated areas; small unheated areas
  
- unheated buildings 4, 7, 28; design method 8–11, 33; ground insulation 24; indoor air temperature 1; insulation strategy 25, 26
- unit conversions 2
- unvented crawlspaces 7–8, 25–26, 32
  
- vented crawlspaces 11, 25–26, 28
- vertical insulation 3, 4–5, 32–33; basements 8; definition 3; protective covering 31; R-value (thermal resistance) 21; selecting 7; small unheated areas 11
  
- walk-out basements 8, 9, 26, 28
- walls: heated buildings 7; semi-heated buildings 11; unheated buildings 9, 10; vertical insulation 21
- wing insulation 3, 4–5, 32; basements 8; corners 24, 32; definition 3; illustration 6; protective covering 31; R-value (thermal resistance) 21, 24; selecting 7; small unheated areas 11
- worst-case conditions 26–27