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Design and Construction of Frost-Protected Shallow Foundations



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Design and Construction of Frost-Protected Shallow Foundations

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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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STANDARDS

In April 1980, the Board of Direction approved ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by the Society. All such standards are developed by a consensus standards process managed by the Management Group F (MGF), Codes and Standards. The consensus process includes balloting by the balanced standards committee made up of Society members and nonmembers, balloting by the membership of ASCE as a whole, and balloting by the public. All standards are updated or reaffirmed by the same process at intervals not exceeding 5 years.

The following Standards have been issued.

- ANSI/ASCE 1-82 N-725 Guideline for Design and Analysis of Nuclear Safety Related Earth Structures
- ANSI/ASCE 2-91 Measurement of Oxygen Transfer in Clean Water
- 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
- ASCE 14-93 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
- ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
- ASCE 16-95 Standard for Load and Resistance Factor Design (LRFD) of Engineered Wood Construction
- ASCE 17-96 Air-Supported Structures
- ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
- ASCE 19-96 Structural Applications of Steel Cables for Buildings
- ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations
- ASCE 21-96 Automated People Mover Standards—Part 1
- ASCE 21-98 Automated People Mover Standards—Part 2
- SEI/ASCE 23-97 Specification for Structural Steel Beams with Web Openings
- SEI/ASCE 24-98 Flood Resistant Design and Construction
- 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
- EWRI/ASCE 34-01 Standard Guidelines for Artificial Recharge of Ground Water



FOREWORD

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of the standard began in 1995 and incorporates information from several sources, as noted in the document.

This Standard was prepared through a consensus standards process by balloting in compliance with procedures of the ASCE Structural Engineering Institute. Those individuals who serve on the Frost-Protected Shallow Foundations Standard Committee are:

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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 ≥ 63° F (17° C)	Heated
41° F(5° C) < T < 63°F (17° C)	Semi-heated
T ≤ 41° 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 (F₁₀₀): 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_{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_{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_h	Width of horizontal wing insulation along walls	m	ft or in
D_{hc}	Width of horizontal wing insulation at corners	m	ft or in
D_g	Width of ground insulation beyond the perimeter of an unheated building	m	ft or in
F_{100}	100-year mean return period AFI	$^{\circ}\text{C}\cdot\text{hr}$	$^{\circ}\text{F}\cdot\text{days}$
h	Floor height above finished grade	m	ft or in
h_f, h_{fc}	Foundation depth along walls or at corners	m	ft or in
h_v	Depth of vertical wall insulation into ground (minimum footing depth)	m	ft or in
L_1, L_2, L_3	Length of unheated portion of otherwise heated building	m	ft or in
L_c	Length (along a wall) of corner insulation	m	ft or in
MAT	Mean annual air temperature	$^{\circ}\text{C}$	$^{\circ}\text{F}$
R_f	R-value of floor/slab construction or assembly	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_v	Required R-value of vertical wall insulation	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_h	Required R-value of horizontal wing insulation	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_{hc}	Required R-value of horizontal wing insulation at corner	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_g	Required R-value of ground insulation for unheated buildings	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_{eff}	Effective R-value (thermal resistance) of an insulation material in service conditions	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
r_{eff}	Effective resistivity (R_{eff} per inch) of an insulation material in service conditions	$\text{m}\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}\cdot\text{in}$

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 ² = 10,000 cm ² = 10.8 ft ² = 1550 in ²
Volume	1 m ³ = 1 × 10 ⁶ cm ³ = 35.3 ft ³ = 6.1 × 10 ⁴ in ³
Density	1 kg/m ³ = 0.0624 lbm/ft ³ (pcf)
Pressure	1 kPa = 0.145 lbf/in ² (psi) = 20.8 lbf/ft ² (psf)
Temperature	$^{\circ}\text{F} = 1.8 (^{\circ}\text{C} + 32)$
Freezing index	1 $^{\circ}\text{C}\cdot\text{hr} = 0.075 ^{\circ}\text{F}\cdot\text{days}$
Thermal properties:	
• resistance	1 m ² · $^{\circ}\text{K}/\text{W}$ = 5.68 hr · ft ² · $^{\circ}\text{F}/\text{Btu}$ {R-value}
• resistivity	1 m· $^{\circ}\text{K}/\text{W}$ = 0.144 hr · ft ² · $^{\circ}\text{F}/(\text{Btu} \cdot \text{in})$ {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 Buildings¹

Air-Freezing Index, F ₁₀₀ (° F-days)	Vertical Insulation R-value, R _v	Horizontal Insulation R-value, R _h (hr · ft ² · ° F/Btu)		Horizontal Insulation Dimensions per Figure 1 (in)			Minimum Footing Depth (in)
		Along Walls	At Corners	D _h	D _{hc}	L _c	h _v
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

¹ 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_{eff} , in accordance with Table A1 of Appendix A. The insulation material thickness of individual panels shall

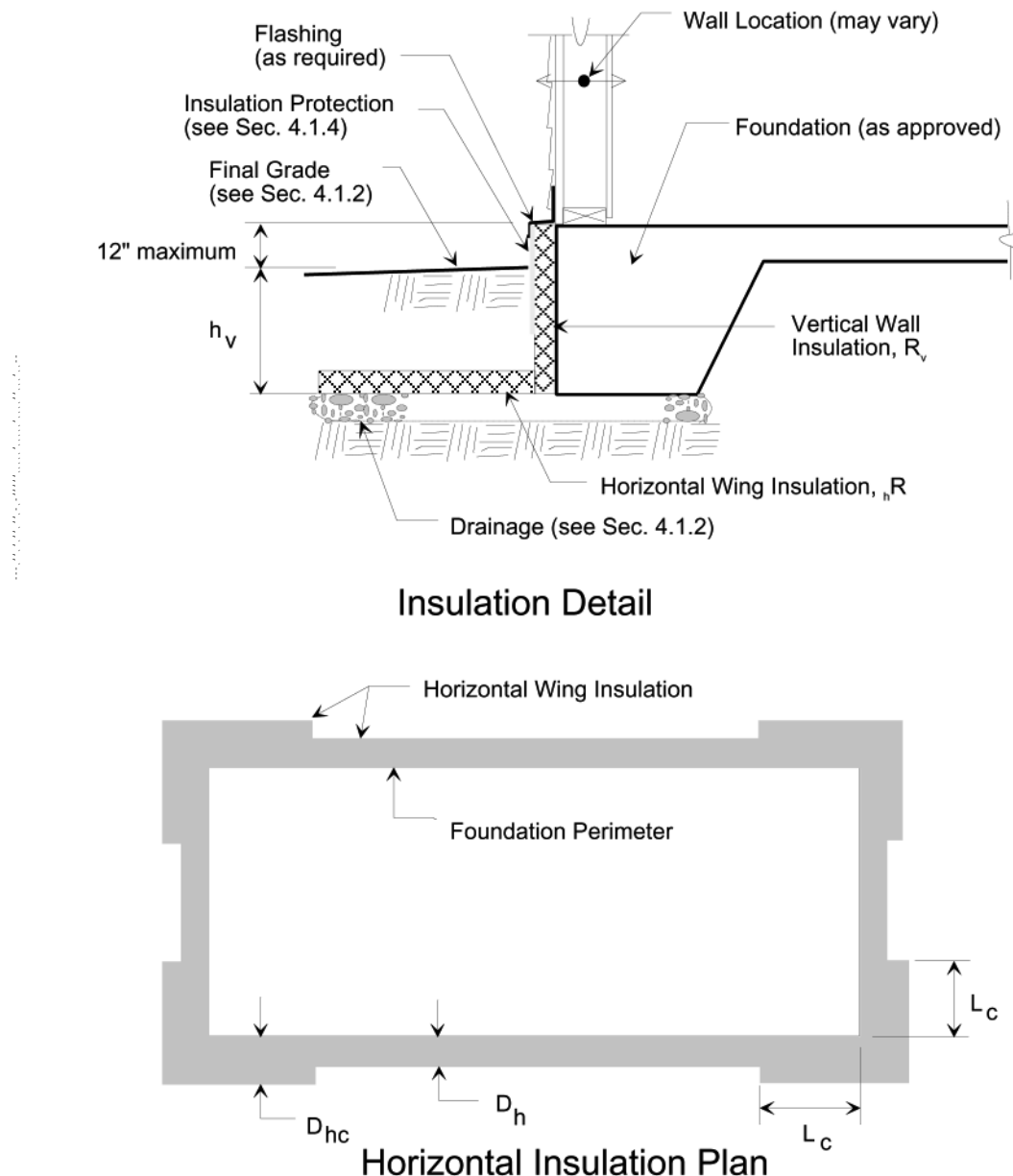


FIGURE 1. FPSF Design Parameters for Heated Buildings Using the Simplified Design Procedure

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

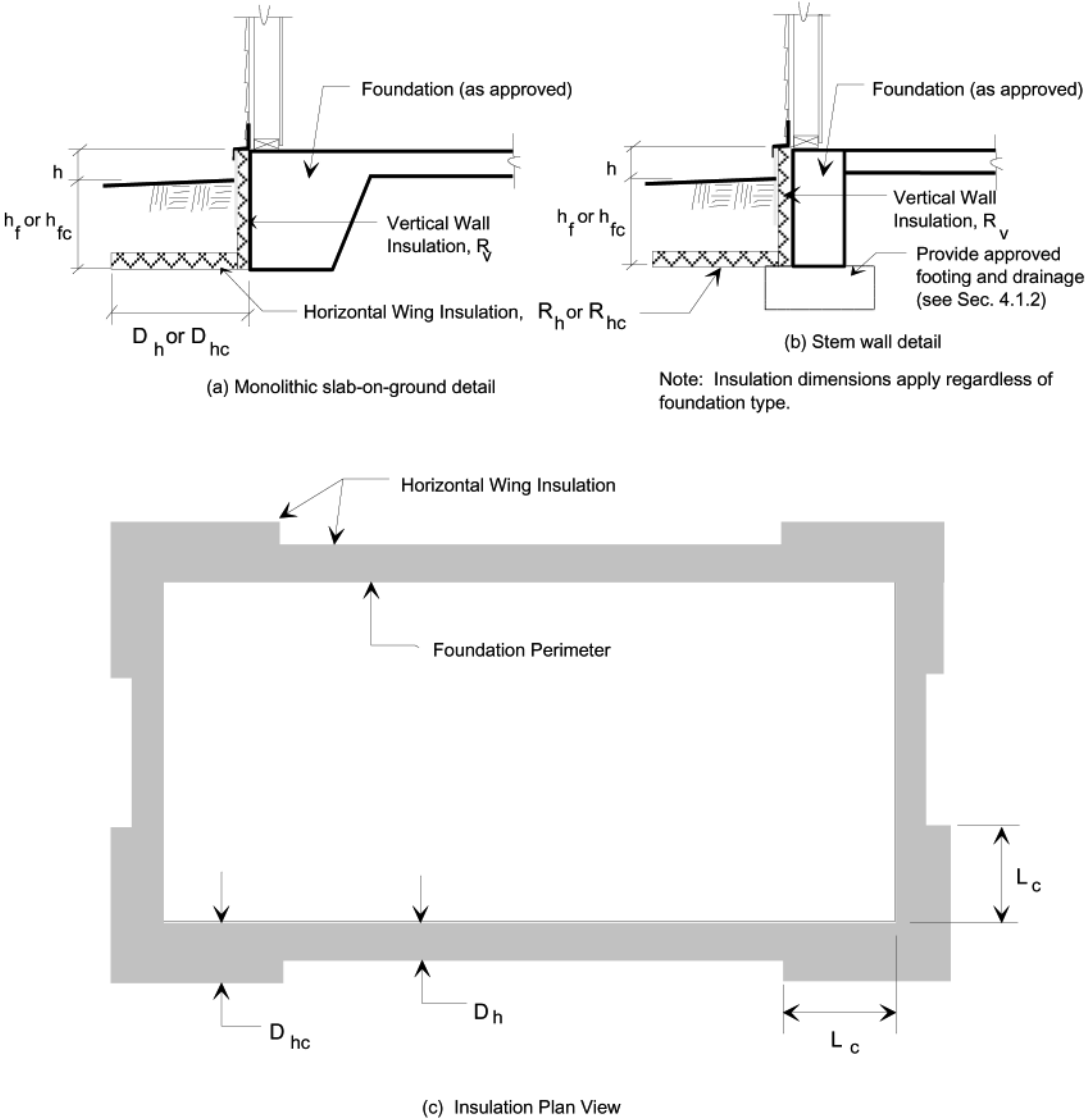


FIGURE 2. Slab-on-Ground Foundation for Heated Buildings