Anchorage Foundation Insulation Study

Interim Report

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Executive Summary

Homebuilders in Southcentral Alaska including the Municipality of Anchorage have raised concerns about a foundation wall insulation strategy recommended by home energy raters. The strategy, intended to increase energy efficiency of the building envelope, involves using R-38 fiberglass batts to insulate from the rim joist, down the foundation wall and four feet horizontally inward along the crawlspace floor (illustrated in Figure 1). This insulation strategy is substantially different from (and may conflict with) those employed to protect foundations from frost heave. Because heat loss from the building foundation contributes to protecting the foundation from frost heave damage, this new insulation strategy may allow the freezing front (or frost line) to penetrate below the foundation footer. Thermal insulation used on and around foundations requires careful consideration to ensure that goals for energy efficiency and frost protection are met. While these topics have been studied extensively, the information and recommendations on best construction practices may not be sufficient or specific enough to prevent potentially risky insulation strategies from being used. Therefore, CCHRC has examined the insulation strategy illustrated in Figure 1 to simulate the freezing front in the soil adjacent to the foundation for Anchorage climatic and soil conditions. The primary question in this study is whether the freeze front can reach the depth of the footer-bearing surface when this insulation strategy is employed.

Figure 1. Proposed insulation retrofit strategy that initiated study.

A thermal modeling program, Temp/W (Geo-Slope International), was selected to perform the analysis. The software permits two-dimensional modeling of various configurations for soil, insulation,

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1 The freezing front is the boundary between frozen and unfrozen materials, such as soil, concrete, or insulation. This boundary is sometimes referred to as the frost line.
and building geometries while accounting for properties such as the latent heat of soil, unfrozen water content of soil, and variability of ground thermal conductivity as a function of temperature.

Modifications to the illustrated insulation strategy were studied to compare the relative change in frost protection and heat loss. The variables studied include:

- Soil type and soil moisture content;
- Exterior ground surface conditions;
- Relative amount (e.g. R-19 versus R-38) of foundation wall insulation;
- Presence of interior “wing” insulation adjacent to the foundation wall.

Models were designed to evaluate the freezing front (frost line) penetration and heat loss through the crawlspace ground and foundation stem wall for each modeled scenario. An example of one model pictorial result is shown in Figure ii. The dashed blue line represents the simulated freezing front. Over 80 different scenarios were modeled that compared varying ground surface conditions, soil types, soil moisture content, exterior insulation strategies and five different interior insulation strategies. The results of this work will be used to propose insulation strategies that best meet the goals of frost protection and energy savings.
Figure ii. Representative model result showing foundation and subsurface cross sections with temperature gradient vectors overlain showing freezing front (isotherm) in subsurface.
Several scenarios provided the potential for ground freezing under the foundation wall. Presence of interior wing insulation was the most significant determination of whether the freezing front penetrates to the footer-bearing surface. Other major factors that contributed to soil freezing at the footer-bearing surface included low soil moisture content, simulated ground conditions that represent low snow coverage, and the presence of sand/gravel soil adjacent to the stem wall.

In most cases, an insulation strategy involving interior R-19 or R-38 insulation installed vertically along the stem wall reduces heat loss through the foundation while offering foundation freeze protection. Exceptions to this were cases when cleared ground conditions were simulated and when sand/gravel soil conditions were modeled. The difference in heat loss due to upgrading from R-19 to R-38 in the same vertical configuration is slight: only 1.3-2.9%. Adopting this insulation strategy will save approximately 25-62% heat loss through the crawlspace when compared to the heat loss through an uninsulated crawlspace. Out of the 12 scenarios with turf ground conditions (with each scenario simulating five different insulation strategies), the addition of the vertical insulation strategy caused the 32°F (freezing) isotherm to penetrate to below the footer bearing surface in one scenario with R-19 insulation, and in two scenarios with R-38 insulation; all three of these scenarios involved a sand/gravel soil type.

The reduction in heat loss through the defined envelope due to increasing insulation from R-19 vertically down the stem wall to R-38 vertically down the stem wall with the interior wing insulation is more significant, however: 10.9-18.0%. Adopting this insulation strategy will save approximately 30-80% heat loss through the crawlspace when compared to no insulation at all; however, this strategy subjects the foundation to risk of damage due to frost heaving. Out of the 12 scenarios with turf ground conditions (with each scenario simulating five different insulation strategies), the addition of the interior wing insulation caused the 32°F isotherm to penetrate to within proximity to or below the footer bearing surface in seven of those scenarios.

Additionally, in every scenario modeled, the simulated freezing front penetrated the concrete foundation to the interior insulation along the stem wall. When the freezing front penetrates the interior insulation during the cold season, the condensation/freezing point would occur at the interface of the concrete stem wall and the fiberglass insulation. If the point of condensation is wood, such as for the rim joist in Figure 1, mold may be able to grow, thereby causing health or structural issues.

The next phase of the study will include physical monitoring of various sites. Geotechnical analyses, moisture content analyses, and temperature and moisture content data collected during this phase will provide an opportunity to calibrate and validate the existing model and expand scenarios to sites with varying climate and soil conditions. The results of this work will ultimately be used to propose insulation strategies that best meet the goals of frost protection and energy savings for both new construction and retrofit construction across Alaska.
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Introduction

Homebuilders in Southcentral Alaska including the Municipality of Anchorage have raised concerns about a foundation wall insulation strategy recommended by home energy raters. The home retrofit insulation strategy, intended to increase energy efficiency of the building envelope, involves using R-38 fiberglass batts to insulate from the rim joist down the foundation wall and four feet horizontally inward along the crawlspace floor (illustrated in Figure 1). This insulation strategy is substantially different than those employed to protect foundations from frost, and could potentially allow for the formation of frozen ground under the foundation footer.

![Figure 1. Proposed insulation strategy that initiated study.](image)

Thermal insulation used on and around foundations requires careful consideration to ensure that goals for energy efficiency and frost protection are simultaneously met. While these topics have been studied extensively, the information and recommendations on best construction practices may not be sufficient or specific enough to prevent potentially risky insulation strategies from being used. Therefore, CCHRC has examined the insulation strategy illustrated in Figure 1 to simulate the freezing front in the soil adjacent to the foundation for Anchorage climatic and soil conditions. The primary question for this study is whether frozen ground can reach the depth of the footer bearing surface when this insulation strategy is employed.

Modifications to this insulation strategy were also studied to compare the relative change in frost protection and heat loss. The most important variables include:

- Soil type and soil moisture content;
- Exterior ground surface conditions;
- Relative amount (e.g. R-19 versus R-38) of foundation wall insulation;
Presence of “wing” insulation adjacent to the foundation wall.

The results of this work will be used to propose insulation strategies that best meet the goals of frost protection and energy savings.

**Project Background**

The Municipality of Anchorage (MOA) has made amendments to the 2006 International Residential Code that are relevant to this study (Municipality of Anchorage, 2006). They state that the minimum frost line depth is 42 inches for warm foundations (i.e. bearing soils are maintained above freezing), and 60 inches for cold foundations (i.e. bearing soils are subjected to freezing). Footings must be below frost depth to prevent the possibility of damage to the structure due to frost heaving (Lstiburek, April 2010). Because the MOA’s minimum crawlspace wall R-value requirement is R-19, doubling the R-value to R-38 may possibly result in a cold foundation that has the footer placement of a warm foundation. The amendments also state that "minimum footing depths may not be adequate for frost susceptible soils" and "provisions shall be made to resist uplift forces due to frost jacking [heaving] on the side of cold foundations" (Municipality of Anchorage, 2006). The industry standard in Anchorage and Southcentral Alaska is to insulate the length of the foundation wall with R-19 or 21 fiberglass batts. According to Southcentral Alaska homebuilders (A. Spinelli, personal communication, March 25, 2011), the recent strategy in question is installing R-38 fiberglass insulation with an additional length inward along the crawlspace floor. This method of insulating crawl spaces is not being suggested for new construction, rather for retrofit improvements of existing homes.

**Key Findings and Relevance of Literature Review**

**Frost Heaving, Adfreezing, & Insulation**

The primary concern over this retrofit insulation strategy is the possibility of frost heaving under the foundation footer-bearing surface. Frost heaving can only occur under the structure foundation if three conditions are met: soil must have a source of water, sufficiently fine-grained to allow wicking\(^2\), and able to reach freezing temperatures.

Figure 2 describes the frost heaving process: water available from unfrozen subgrade materials permeates through a thin transition layer of frozen and unfrozen soil until it meets the interface with the frozen soil. As water collects at the boundary and begins to freeze, an ice lens begins to form, thereby producing uplifting forces on the soil above it. Additionally, the volumetric expansion of the in situ pore water during freezing produces uplifting forces on the soil above it. During this process by which water flowing by capillary action to the freezing front and feeding the growth of the ice lens, these wet soils can expand up to many times their original volume\(^3\) (Swinton, et al., 1999), thereby

\(^2\) "Frost susceptible" soil must be sufficiently porous to allow wicking (or capillary action), yet not so porous as to break capillary continuity.

\(^3\) For example, for one cubic foot of coarse-grained soil with a porosity of 30% that is saturated with water, the void volume is 30% of the total volume. Therefore, 0.3 cubic feet per cubic foot of soil is filled with water. If this water freezes, it expands about 9%; 9% expansion of 0.3 cubic feet would yield 0.27 inches of heave for this
causing significant structural damage to any foundation constructed above the ice lenses. Andersland and Anderson (1978) indicate that the magnitude of the upward pressures on footings due to the freezing of frost susceptible soils “may vary between 20 kPa (417 psf) for a sand soil to 300 kPa (6,265 psf) for a silt soil when ice lenses form at the freezing front and when there is no water migration in the frozen soil” (p. 346).

Unheated basements and crawlspace face the greatest risk of damage through the upward heaving or adfreezing of soil to the crawlspace wall (Lstiburek, April 2010). Adfreezing is the process by which a strong bond is formed at the interface of soil and another subterranean object when freezing conditions exist. During the frost heaving process, the soil could adfreeze to the foundation, subsequently lifting the foundation.

Fidley and Snodgrass (1984) suggest that, in shallow basement constructions (top of footing less than 6 feet from the surface), very high levels of wall and floor insulation can result in potentially harmful frost penetration to footer depths. They also suggest that an uninsulated concrete floor slab would likely be sufficient to prevent frost penetration to the footing depth. A relevant finding in their volume of soil. Coarse-grained soils generally do not support the capillary flow of water to the freezing front and therefore no formation of ice lens.

For a fine grained soil (for instance, silt with clay) with freezing temperatures and a source of water, ice lenses will typically form, resulting in much greater amounts of heave. Even expansions of 20% of 10 inches of soil yields 2 inches of heave which will likely result in foundation damage, especially when the heave is non-uniform. (J. Zarling, personal communication, August 17, 2011)
study is that the depth of frost penetration is strongly dependent on thermal conductivity and volumetric heat capacity of soil, both of which depend on many variables, primarily water content.

**Moisture Concerns**

Water content of soils can vary greatly as a function of depth, depending on the grading of the soil; if the ground near the structure is graded well, water will drain away from the house and reduce moisture in the soils closest to the foundation. In frost susceptible soils, the presence of water in the soil below the footer could be the deciding factor as to whether or not frost heaving occurs (assuming the freezing front penetrates below the footer).

Water vapor has the potential to condense at a predicted dew-point location, but then migrates to a colder-vapor impermeable interface where moisture begins to accumulate. The condensing point of interest in a wall is against the sheathing, however in a vented crawlspace, the condensing points of interest are the underside cavity of insulation in rim joists and at the top surface of the ground (Lstiburek, December 2010). Where moisture is sustained against concrete and concrete masonry unit (CMU) foundations, mold is much less a cause for concern; however, if moisture is sustained against wood (for instance, where fiberglass insulation is installed against a rim joist), the conditions could sustain mold growth. If fiberglass is placed against concrete, then there is a risk of condensation occurring at the interface and moisture and/or frost forming within the insulation.

**Study Methods and Model Objectives**

A thermal modeling program, Temp/W (Geo-Slope International), was selected to model the scenario under study. The software permits two-dimensional modeling of various configurations for soil, insulation, and building geometries while accounting for complex considerations of properties such as the latent heat of soil, unfrozen water content of soil, and variability of ground thermal conductivity as a function of temperature.

For this study, a representative two-dimensional foundation model similar to the sketch in Figure 1 was created for each scenario with different variables. John Zarling, Ph.D. provided initial guidance for the basis of the model construction and some pertinent model inputs. The models were designed to evaluate the freezing front (32°F isotherm) penetration and heat loss through the crawlspace ground and foundation stem wall using variables such as:

- Soil type and soil moisture content;
- Exterior ground surface conditions;
- Relative amount (e.g. R-19 versus R-38) of foundation wall insulation;
- Presence of interior “wing” insulation adjacent to the foundation wall.

The primary metric in this study is determining the freezing front (shown as the 32°F isotherm in the model results) would reach the bearing surface of the footer. An example of one model pictorial result is shown in Figure 3. The dashed blue line represents the simulated freezing front, or *isotherm*; color variations on either side of the 32°F isotherm represent the temperature gradients (“warmer

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4 The freezing isotherm is the curve on a plot that connects points of equal temperature, specifically, 32°F. For the purposes of this report, the term 32°F *isotherm* will be used when referencing a simulated freezing front.
“Warmer colors” indicate temperatures warmer than 32°F, while “cooler colors” indicate temperatures colder than 32°F).

Figure 3. Representative model result showing foundation and subsurface cross sections with temperature gradient vectors overlain showing freezing front (isotherm) in subsurface.
Model Construction

Temperature Data

The air temperature data for this model was obtained for Anchorage International Airport through the National Climatic Data Center (2011). The daily average temperatures for one year were used in the analysis. Every year of analysis reflected on this one year (from May 1, 1994 through April 30, 1995) of average temperature data for as long as the model ran. Figure 4 depicts the air temperatures used for the model.

Figure 4. Average air temperature used in model (for Anchorage conditions).

Crawlspace Temperatures

The assumption was made that the crawlspace was heated only by heat loss through the floor and duct losses (from the furnace) running under the floor. Lstiburek (2010, December) suggests that a reasonable estimate for crawlspace ground surface temperatures is to use the average annual ambient air temperature for that location. The crawlspace surface temperature was modeled to be constant at 36.5°F, the yearly average annual ambient air temperature for Anchorage.

Ground Surface Temperatures

Thermal modifiers (also known as N-factors) were applied at the ground surface to account for factors such as snow, freezing, and thawing. These modifiers relate ground surface temperature to air temperature. As the depths of seasonal thawing and freezing are strongly affected by the surface conditions, N-factors\(^5\) for various surface conditions have been calculated based on numerous field studies. Ground surface temperatures are influenced mainly by solar radiation in the summer and insulating effects of snow cover in the winter; however, other factors such as precipitation, snowmelt, condensation, long wave radiation, and convection also affect ground surface temperatures. Typical values for N-factors, which account for the varying environmental conditions based on the surface type,

\(^5\) the ratio of the surface index to the air-temperature index
have been suggested by Goodrich and Gold (1981). The N-factors used in the model under study are summarized in Table 1.

Table 1
N-Factors Used in Model

<table>
<thead>
<tr>
<th>Condition</th>
<th>Turf</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freezing</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Thawing</td>
<td>1.1</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Material Properties and Soil Parameters

The baseline soil profile was chosen based on the recommendations of homebuilders in the Anchorage area (A. Spinelli, personal communication, March 25, 2011) and findings in the Soil Profile for Anchorage, Alaska (United States Department of Agriculture). The web soil survey provides soil data and information produced by the National Cooperative Survey. Two uniform layers were assumed for the soil in Anchorage. These layers are shown in Figure 5. For the baseline study, the first layer is silt assumed to be 0.5 feet thick. Beneath this is a layer of sand/gravel that extends to depths well below the foundation footer-bearing surface. The soil compositions and moisture contents were varied throughout the course of the modeling and analysis. Table 2 describes the various properties of materials and soil types used in the model.

The volumetric moisture content, \( \Theta \) (ft\(^3\)/ft\(^3\)), was calculated using

\[
\Theta = W \times \frac{\rho_{\text{ds}}}{\rho_{\text{H2O}}}
\]

Where \( W \) is the gravimetric water content of soil, \( \rho_{\text{ds}} \) is the dry density of soil, and \( \rho_{\text{H2O}} \) is the density of water.

The frozen and unfrozen thermal conductivities of soils were determined based on Kersten’s charts (Kersten, 1948). The thermal conductivities were dependent on dry soil density, soil type, and moisture content. Figures 6-8 describe the average frozen and thawed thermal conductivities for various
soil types and serve as the bases on which the thermal conductivities were used in the models under study. The average dry densities of soils used in the study are: sand/gravel, 125 lb/ft$^3$; silt & clay, 90 lb/ft$^3$; and peat, 20 lb/ft$^3$.

Figure 6. Average thermal conductivity for silt and clay soils, frozen and unfrozen (redrawn from Kersten, 1949). Thermal conductivity, $k$, is expressed in BTU/hr*ft$^2$*°F.
The unfrozen water content for each soil type is based on Figures 9 and 10. The values shown in these figures are in terms of gravimetric percentages. The values were subsequently converted to volumetric percentages and are summarized for each soil type (at 29°F) in Table 2.
The volumetric specific heat of the soil, $C$ (BTU/(ft$^3$·°F)), was calculated using

$$C = \rho_{ds}c_{ds} + \rho_{ds}(W/100)c_{H_2O}$$  
(2)

where $\rho_{ds}$ is the dry density of soil, $c_{ds}$ is the specific heat of dry soil, $W$ is the gravimetric water content of soil (in percent), and $c_{H_2O}$ is the specific heat of water or ice.

Three insulation materials were used for the model. The extruded polystyrene (XPS) used for external insulation scenarios was modeled 2 inches thick for using thermal conductivities listed in Table 2. The R-19 and R-38 batted fiberglass insulation was modeled 4 inches thick using the thermal conductivities listed in Table 2. Since the thickness of the fiberglass insulation materials remained constant in the model, the thermal conductivity of the R-38 insulation was half of the thermal conductivity of the R-19 insulation.
Table 2.
Material Properties Used in Model

<table>
<thead>
<tr>
<th>Material Name</th>
<th>Concrete</th>
<th>Silt</th>
<th>Sand/Gravel</th>
<th>Organic Peat</th>
<th>Clay</th>
<th>XPS Foam Board</th>
<th>R-19 Insulation</th>
<th>R-38 Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric Moisture Content, (? (\text{ft}^3/\text{ft}^3))</td>
<td>0</td>
<td>0.16</td>
<td>0.16</td>
<td>0.32</td>
<td>0.43</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unfrozen Thermal Conductivity, (k_u) (BTU/h(\text{hr})(\text{ft})?(\text{²F}))</td>
<td>0.8</td>
<td>0.6</td>
<td>1.45</td>
<td>0.2</td>
<td>0.6</td>
<td>0.015</td>
<td>0.0175</td>
<td>0.00833</td>
</tr>
<tr>
<td>Frozen Thermal Conductivity, (k_f) (BTU/h(\text{hr})(\text{ft})?(\text{²F}))</td>
<td>0.8</td>
<td>0.6</td>
<td>1.7</td>
<td>0.3</td>
<td>0.6</td>
<td>0.015</td>
<td>0.0175</td>
<td>0.00833</td>
</tr>
<tr>
<td>Unfrozen Water Content at 29°F, (? (\text{ft}^3/\text{ft}^3))</td>
<td>0</td>
<td>0.05</td>
<td>0.07</td>
<td>0.03</td>
<td>0.12</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unfrozen Heat Capacity, (c_u) (BTU/(\text{ft}^3)?(\text{²F}))</td>
<td>25.2</td>
<td>27</td>
<td>31</td>
<td>30</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Frozen Heat Capacity, (c_f) (BTU/(\text{ft}^3)?(\text{²F}))</td>
<td>25.2</td>
<td>22</td>
<td>26.25</td>
<td>20</td>
<td>28.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: (1) Value is dependent upon the moisture content of the soil modeled for the specific scenario. The value shown is used for baseline model.

Other Parameters

A representative foundation and cross section similar to the sketch in Figure 1 was created for each scenario of varying variables. Figure 11 depicts the two-dimensional model area of approximately 20 feet wide by 10 feet elevation under study. The complete approximate soil base size of the model, however, was approximately 50 feet wide by about 55 feet deep to ensure that the temperature and heat calculations for the modeled soil adequately represent the presence of thermally stable earth. The two-dimensional model assumes the model extends 1 foot into the page.

At the bottom of layer 2, a geothermal heat flux boundary condition was applied to represent heat from the center of the earth. The value applied to all models was 0.028 BTU/(hr·ft) (Southern Methodist University, 2004).
Analysis and Results

Determining Initial Conditions and Transient Analysis

In order to determine initial conditions for the transient model, boundary conditions representing the average yearly air temperature were applied to the soil surface and a steady-state thermal solution was performed. These results served as the initial condition for the transient analysis. The transient analysis covered a period of six years. After determining that the model results (temperature and heat flux through defined boundaries) were constant after approximately four to five years (in terms of the model run duration), the results from the sixth year served as a basis for comparison.

Determining Heat Loss through Thermal Boundary

The blue dashed line in the model (see Figure 11) indicate heat flow boundaries where cumulative heat transfer (heat flux) may be calculated over a specified period of time. These sections were used to evaluate heat loss through the foundation. The cumulative heat through the boundary is determined for each time step in the analysis. The cumulative heat flux during the sixth year was determined and subsequently used in the comparative analysis of modeling scenarios.

Modeling Results

Over eighty scenarios were modeled that compared ground surface conditions, soil conditions, soil moisture content, exterior insulation strategies, and five different interior insulation strategies. In each scenario modeled, the analysis was evaluated to determine:

1. if the freezing front reached the foundation wall bearing surface, and
2. the cumulative heat flow across the flux boundary in one year.
For each scenario, the cumulative heat loss through the flux section boundary was calculated for the baseline case in which no interior insulation has been installed; the heat loss was then compared to heat loss in subsequent models with varying amounts of insulation. The percent reduction in heat loss for each case is presented in the results.

Summary of Modeling Results for Turf Ground Conditions

Note. Moisture contents (MC) expressed in the Modeling Results sections are expressed as gravimetric values (i.e. soil moisture content, W, is expressed as the mass of water divided by the mass of the dry soil).

Turf ground surface conditions were simulated as soil types, moisture content, and other factors were varied. This scenario was assumed as the most common case for a typical residence. A general accumulation of snow is assumed present when turf ground conditions are simulated. Table 3 summarizes the modeling results for all scenarios with turf ground surface conditions.
### Table 3. Summary of Modeling Results for All Scenarios with Turf Ground Surface Conditions

<table>
<thead>
<tr>
<th>Ground Conditions</th>
<th>Soil Conditions</th>
<th>Moisture Content (%)</th>
<th>Exterior Insulation</th>
<th>Crawlspace Ground Surface Level</th>
<th>Interior Insulation Strategy</th>
<th>Percent Reduction in Heat Loss</th>
<th>Frost Line Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>10% (Sand/Silt)</td>
<td>8% (Sand/Gravel)</td>
<td>Level with top of footer</td>
<td>None</td>
<td>No Interior Insulation</td>
<td>No Frost Line Penetration at Footer Depth</td>
<td></td>
</tr>
<tr>
<td>Level with bottom of footer</td>
<td>No Interior Insulation</td>
<td>No Frost Line Penetration at Footer Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Exterior Insulation (2&quot; XPS R-10 Foam Board)</td>
<td>Level with top of footer</td>
<td>No Interior Insulation</td>
<td>No Frost Line Penetration at Footer Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Exterior Insulation with Horizontal Wing (2&quot; XPS R-10 Foam Board, 38° Total)</td>
<td>Level with top of footer</td>
<td>No Interior Insulation</td>
<td>No Frost Line Penetration at Footer Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
1. Gravimetric Moisture Content (MC)
2. No need to model further. Any additional insulation would cause the 32°F isotherm to reach even further below the footing bearing surface.
3. No need to model further. Modeling insulation conditions between the extreme conditions is not necessary, as intermediate conditions would not indicate 32°F isotherm penetrations below the footing bearing surface.
Comparison of Interior Insulation Strategies to Varying Exterior Insulation Strategies

Scenario A served as the baseline when comparing varying exterior insulation strategies. Two inches of extruded polystyrene (XPS) rigid insulation were modeled: case one with rigid insulation vertically along the stem wall on the exterior surface, stopping at the top of the footer, and case two added a horizontal wing (with a 5% slope) extending outward from the foundation. Figure 12 summarizes the comparisons of analyses.

Key Findings

- The addition of 2-inch XPS exterior insulation (without adding any interior insulation) reduces heat loss to the soil by approximately 20%. Adding R-19 down the stem wall further reduces heat loss by 40-44 % from the base case.
- Although the presence of the 1-foot wide horizontal wing insulation does little to reduce overall heat loss through the thermal envelope, it alters the heat flow enough to prevent the freezing front from reaching the foundation footer-bearing surface as is evident in Figure 13. Figure 13 describes the proximity of each respective 32°F isotherm at the deepest penetration depth for each exterior insulation strategy; the graphics within the figure show the effect the wing insulation has on the freezing front profile with respect to the foundation. Although this strategy is expensive and often impractical to implement for a home retrofit, the frost protection value of this exterior insulation strategy is emphasized in this analysis.
- The use of R-19 or R-38 insulation down the foundation stem wall does not cause the 32°F isotherm to reach the footer-bearing surface depth. Upgrading from R-19 to R-38 insulation down the stem wall results in a marginal overall heat loss reduction.
- The use of R-19 or R-38 insulation down the foundation stem wall with a 4-foot inward wing permits the 32°F isotherm to reach the "caution" zone of the footer bearing surface for Scenarios A and C.
Figure 12. Comparison of interior insulation strategies to varying exterior insulation strategies.

### Constants
- **Surface conditions:** Turf
- **Temperature Profile:** Anchorage, AK
- **Average Crawlspace Temperature:** 36.5°F

### Soil Composition:
- **First six inches:** Silt Soil, 10% MC
- **Remaining soil base:** Sand/Gravel Soil, 8% MC

### Exterior Insulation Strategy: No Exterior Insulation
- **Heat Loss (BTU/lin ft/yr):** 85,429
- **Reduction in Heat Loss:** --

### Scenario A
- **Heat Loss (BTU/lin ft/yr):** 67,670
- **Reduction in Heat Loss:** --
  - **Reduction:** 20.8%

### Scenario B
- **Heat Loss (BTU/lin ft/yr):** 50,710
- **Reduction in Heat Loss:** 25.1%
- **Reduction in Heat Loss:** 40.6%

### Scenario C
- **Heat Loss (BTU/lin ft/yr):** 49,450
- **Reduction in Heat Loss:** 26.9%
- **Reduction in Heat Loss:** 42.1%

### Scenario D
- **Heat Loss (BTU/lin ft/yr):** 65,190
- **Reduction in Heat Loss:** --
  - **Reduction:** 23.7%

### Notes:
1. Gravimetric Moisture Content (MC)
2. Percent reduction in heat loss with respect to this scenario with no insulation.
3. Percent reduction in heat loss with respect to baseline condition with no exterior or interior insulation (Scenario A).

- **Safe Zone**
  - Green shading indicates that the model predicts the frost line to be well above the footer bearing surface depth.
- **Caution Zone**
  - Yellow shading indicates that the model predicts the frost line to be within proximity to the footer bearing surface depth. Small variations in model input parameters may cause the model to simulate frost line penetration to deeper or shallower depths.
- **Danger Zone**
  - Red shading indicates that the model predicts the frost line to penetrate below the footer bearing surface depth. If frost susceptible soils and a sufficient water source are present, frost heaving could occur.
<table>
<thead>
<tr>
<th>Constants</th>
<th>Scenario A</th>
<th>Scenario C</th>
<th>Scenario D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface conditions: Turf</td>
<td>No Exterior Insulation</td>
<td>Vertical Exterior Insulation (2” XPS R-10 Foam Board)</td>
<td>Vertical Exterior Insulation with Horizontal Wing (2” XPS R-10 Foam Board, 48” Total Length)</td>
</tr>
<tr>
<td>Temperature Profile: Anchorage, AK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Crawlspace Temperature: 36.5°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil composition:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First six inches: Silt Soil, 20% MC(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remaining soil base: Sand/Gravel Soil, 8% MC(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior Insulation Strategy:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-38 Fiberglass Down Stem Wall, 4 ft Wing Inward</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior Insulation Strategy:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
(1) Gravimetric Moisture Content (MC)

Figure 13. Freeze depth penetration contours showing worst-case 32°F isotherm penetration.
Comparison of Interior Insulation Strategies to Varying Soil Compositions

Scenario A served as the overall baseline when compared to the cases where the two soil layers were the same. In Scenario A, the first 6 inches were composed of silt (10% MC) while the remaining soil was sand/gravel (8% MC). In Scenario G, both soil layers were comprised of sand/gravel (8% MC), while in Scenario K, both soil layers were comprised of silt (10% MC). Figure 15 summarizes the comparisons of analyses.

Key Findings

- When comparing Scenario A to Scenario G, the top 6-inch layer of silt (10% MC) offers a level of freeze protection to the foundation; its acts a thermal buffer between the surface and the more thermally-responsive sand/gravel soil layer beneath. The presence of this top layer shifts the possibility of using R-19 or R-38 insulation down stem wall from the danger category (as evident in Scenario G) to the caution category (as evident in Scenario A).
- The 32°F isotherm comes within 2 inches of the footer bearing surface when any configuration of interior insulation wing strategies were employed.
- When comparing Scenario G to Scenario K, the apparent insulating effect of the silt (10% MC) is evident; the overall heat loss through the ground and foundation is approximately halved when compared to sand/gravel (8% MC).
**Anchorage Foundation Insulation Study**

**Cold Climate Housing Research Center**

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**Figure 14. Comparison of interior insulation strategies to varying soil compositions.**

<table>
<thead>
<tr>
<th>Interior Insulation Strategy</th>
<th>Scenario A</th>
<th>Scenario G</th>
<th>Scenario K</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Interior Insulation</td>
<td>85,420</td>
<td>91,840</td>
<td>55,440</td>
</tr>
<tr>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>52,140</td>
<td>52,560</td>
<td>52,980</td>
</tr>
<tr>
<td>R-48 Down Stem Wall</td>
<td>50,500</td>
<td>50,920</td>
<td>51,340</td>
</tr>
<tr>
<td>R-38 Down Stem Wall, 4 ft Inward Wing</td>
<td>39,040</td>
<td>38,650</td>
<td>39,260</td>
</tr>
</tbody>
</table>

**Notes:**

1. Gravimetric Moisture Content (MC)
2. Percent reduction in heat loss with respect to this scenario with no insulation.
3. Percent reduction in heat loss with respect to baseline condition with no exterior or interior insulation (Scenario A).

- **Safe Zone:** Green shading indicates that the model predicts the frost line to be well above the footer bearing surface depth.
- **Caution Zone:** Yellow shading indicates that the model predicts the frost line to be within proximity to the footer bearing surface depth. Small variations in model input parameters may cause the model to simulate frost line penetration to deeper or shallower depths.
- **Danger Zone:** Red shading indicates that the model predicts the frost line to penetrate below the footer bearing surface depth. If frost susceptible soils and a sufficient water source are present, frost heaving could occur.
Comparison of Insulation Strategies with Regard to Varying Soil Types

Scenario A served as the overall baseline when compared to the cases where the two soil layers were the same and varied from sand/gravel, silt, clay, and peat. A mid-range moisture content was chosen for each soil type. Figure 15 summarizes the comparisons of analyses.

Key Findings

- When the soil layers are sand/gravel (8% MC), the 32°F isotherm penetrates to below the footer bearing surface when the interior wing insulation strategy is employed. As long as the sand/gravel is considered to be non-frost susceptible fill\(^6\), then the presence alone of the freezing front below the footer-bearing surface does not give rise to concern of frost heaving. The most important factor, however, is to ensure that the sand/gravel is NFS material. If this cannot be verified, then the addition of interior wing insulation should be avoided to prevent penetration of the freezing front to the footer-bearing surface.

- When only silt (10% MC) is modeled, the 32°F isotherm penetrates to within approximately 2 to 4 inches of the footer-bearing surface when the interior wing insulation strategy is employed. If the critical soil moisture content (approximately 28% MC for 90 lb/ft\(^3\) frozen silt, per Figure 6) is not present, then frost heaving cannot occur. Once again, if this cannot be verified, then the addition of interior wing insulation should be avoided to prevent penetration of the freezing front to the footer-bearing surface.

- This comparison emphasizes the importance of knowing the site condition and soil composition.

---

\(^6\) NFS material can act as a capillary break to prevent the transmission of water to create ice lenses. It is defined by the amount of particles passing a no. 200 sieve.
### Anchorage Foundation Insulation Study

**Figure 15. Comparison of insulation strategies with regard to varying soil types.**

<table>
<thead>
<tr>
<th>Soil Composition for First 6 Inches of Soil:</th>
<th>Scenario A</th>
<th>Scenario G</th>
<th>Scenario K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand/Gravel, 8% MC</td>
<td>Heat Loss (BTU/lin ft/yr)</td>
<td>Reduction in Heat Loss (BTU/lin ft/yr)</td>
<td>Reduction in Heat Loss (BTU/lin ft/yr)</td>
</tr>
<tr>
<td>No Interior Insulation</td>
<td>55,400</td>
<td>-</td>
<td>55,400</td>
</tr>
<tr>
<td>R-19 Down Stem Wall</td>
<td>50,560</td>
<td>9.6%</td>
<td>50,660</td>
</tr>
<tr>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>41,400</td>
<td>31.3%</td>
<td>40,600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Composition for Remaining Soil Base:</th>
<th>Scenario L</th>
<th>Scenario M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat, 100% MC</td>
<td>Heat Loss (BTU/lin ft/yr)</td>
<td>Reduction in Heat Loss (BTU/lin ft/yr)</td>
</tr>
<tr>
<td>No Interior Insulation</td>
<td>56,710</td>
<td>-</td>
</tr>
<tr>
<td>R-19 Down Stem Wall</td>
<td>32,720</td>
<td>42.3%</td>
</tr>
<tr>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>(4)</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No Interior Insulation</td>
<td>24,080</td>
<td>-</td>
<td>24,080</td>
</tr>
<tr>
<td>R-19 Down Stem Wall</td>
<td>17,718</td>
<td>79.6%</td>
<td>19,160</td>
</tr>
</tbody>
</table>

**Notes:**

(1) Gravimetric Moisture Content (MC)

(2) Percent reduction in heat loss with respect to this scenario with no insulation.

(3) Percent reduction in heat loss with respect to baseline condition with no exterior or interior insulation (Scenario A).

(4) No need to model further. Modeling insulation conditions between the extreme conditions is not necessary, as in-between conditions would not indicate frost depth penetrations below the footer bearing surface.

- **Safe Zone**: Green shading indicates that the model predicts the frost line to be well above the footer bearing surface depth.
- **Caution Zone**: Yellow shading indicates that the model predicts the frost line to be within proximity to the footer bearing surface depth. Small variations in model input parameters may cause the model to simulate frost line penetration to deeper or shallower depths.
- **Danger Zone**: Red shading indicates that the model predicts the frost line to penetrate below the footer bearing surface depth. If frost susceptible soils and a sufficient water source are present, frost heaving could occur.
Comparison of Insulation Strategies with Regard to Varying Soil Moisture Contents

Although TEMP/W cannot account for water flow into or out of the soil, it can account for various amounts of soil moisture content. A range of moisture contents were compared for silt and sand/gravel soils. Sand/gravel, which generally has a moisture content of 2-15%, was evaluated at each extreme moisture condition as well as at 8% for a mid-range condition. Silt, which generally has a moisture content of 5-40%, was evaluated at each extreme moisture condition as well as 10% for a low mid-range condition. Figure 16 summarizes the comparisons of analyses.

Key Findings

- In low moisture content sand/gravel conditions, any amount of insulation on the stem wall or along the crawlspace ground would contribute to the 32°F isotherm penetrating to the footer-bearing surface. However, 2% moisture content sand/gravel is not sufficient to cause heaving; the saturation limit of sand/gravel (which can be determined by evaluating Figure 7) occurs when the moisture content approaches approximately 12%-13% for sand/gravel with an assumed density of 125 lb/ft.

- As the moisture content of the sand/gravel soil increases, the 32°F isotherm tends to penetrate less under the footer-bearing surface. As evident in Scenario H (2% MC Sand/Gravel), the 32°F isotherm penetrates to the footer bearing surface when any amount of interior insulation is added to the scenario. The risk of the 32°F isotherm reaching the footer bearing is reduced as moisture content of the soil increases. The insulating effect of the wet soil does not necessarily justify its use for frost protection; if the soil is not NFS material, the risk of frost heaving increases if freezing conditions are present.

- As moisture content of the silt increases, the 32°F isotherm tends to penetrate less under the footer-bearing surface. As evident in Scenario P (5% MC Silt), the 32°F isotherm penetrates to the footer bearing surface (the “danger zone”) when insulation on the stem wall and along the crawlspace ground is added to the scenario. When evaluating Scenario K (10% MC) with insulation on the stem wall and along the crawlspace ground, the 32°F isotherm penetrates to the “caution zone” of the footer-bearing surface (meaning the isotherm comes within approximately 0.5 feet of the footer bearing surface). When compared to Scenario J (40% MC), the 32°F isotherm does not reach the footer-bearing surface.

- The use of R-19 or R-38 insulation down the foundation stem wall with a 4-foot inward wing permits the simulated 32°F isotherm to reach the “caution zone” of the footer-bearing surface for Scenarios G, H, and I (sand/gravel soil types with varying moisture contents).

- As moisture content increases for the sand/gravel and silt soil types, the heat loss to the ground increases.

- Ground conditions that provide inadequate moisture drainage because of such factors as soil quality, ground slope conditions, or lack of rain gutters will affect the potential for the 32°F isotherm to reach the footer bearing surface. Although the higher moisture content soils tend to

---

7 Frost heaving can only occur under the structure foundation if three conditions are met: soil must be wet, sufficiently porous to allow wicking, and able to reach freezing temperatures.
inhibit the 32°F isotherm from penetrating to the footer-bearing surface, the worst-case scenario is when the 32°F isotherm reaches the footer-bearing surface in frost-susceptible soils that have access to enough moisture to cause heaving.
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**Figure 16. Comparison of insulation strategies with regard to varying soil moisture contents.**

- **Constants**  
  Surface conditions: Turf  
  Temperature Profile: Anchorage, AK  
  Average Crawlspace Temperature: 36.5°F  
  Exterior Insulation: None

<table>
<thead>
<tr>
<th>Soil Composition for First 6 Inches of Soil:</th>
<th>Sand/Gravel, 2% MC</th>
<th>Sand/Gravel, 8% MC</th>
<th>Sand/Gravel, 15% MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Interior Insulation</td>
<td>87,660</td>
<td>-</td>
<td>51,840</td>
</tr>
<tr>
<td>R-19 Down Stem Wall</td>
<td>48,400</td>
<td>44.8%</td>
<td>52,380</td>
</tr>
<tr>
<td>R-38 Down Stem Wall</td>
<td>50,600</td>
<td>44.8%</td>
<td>50,600</td>
</tr>
<tr>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>(5)</td>
<td></td>
<td>40,880</td>
</tr>
<tr>
<td>R-38 Down Stem Wall, 4 ft Inward Wing</td>
<td>33,660</td>
<td>57.9%</td>
<td>40,630</td>
</tr>
</tbody>
</table>

### Scenario P  
Soil Composition for First 6 Inches of Soil: Silt, 5% MC  
Soil Composition for Remaining Soil Base:  

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No Interior Insulation</td>
<td>57,170</td>
<td>-</td>
<td>58,440</td>
<td>-</td>
<td>61,200</td>
<td>-</td>
</tr>
<tr>
<td>R-19 Down Stem Wall</td>
<td>27,720</td>
<td>51.5%</td>
<td>28,898</td>
<td>50.6%</td>
<td>31,140</td>
<td>49.1%</td>
</tr>
<tr>
<td>R-38 Down Stem Wall</td>
<td>26,120</td>
<td>54.3%</td>
<td>27,310</td>
<td>53.3%</td>
<td>(4)</td>
<td></td>
</tr>
<tr>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>20,879</td>
<td>63.5%</td>
<td>21,771</td>
<td>62.7%</td>
<td>23,020</td>
<td>63.7%</td>
</tr>
<tr>
<td>R-38 Down Stem Wall, 4 ft Inward Wing</td>
<td>18,685</td>
<td>67.4%</td>
<td>19,511</td>
<td>66.6%</td>
<td>21,020</td>
<td>65.7%</td>
</tr>
</tbody>
</table>

### Scenario K  
Soil Composition for First 6 Inches of Soil: Silt, 10% MC  
Soil Composition for Remaining Soil Base:  

### Scenario J  
Soil Composition for First 6 Inches of Soil: Silt, 40% MC  
Soil Composition for Remaining Soil Base:  

**Notes:**  
(1) Gravimetric Moisture Content (MC)  
(2) Percent reduction in heat loss with respect to this scenario with no insulation.  
(4) No need to model further. Modeling insulation conditions between the extreme conditions is not necessary, as in-between conditions would not indicate frost depth penetrations below the footing bearing surface.  
(5) No need to model further. Any additional insulation would cause the frost line to reach even further below the footing bearing surface.

- **Safe Zone**  
  - Green shading indicates that the model predicts the frost line to be well above the footing bearing surface depth.

- **Caution Zone**  
  - Yellow shading indicates that the model predicts the frost line to be within proximity to the footing bearing surface depth. Small variations in model input parameters may cause the model to simulate frost line penetration to deeper or shallower depths.

- **Danger Zone**  
  - Red shading indicates that the model predicts the frost line to penetrate below the footing bearing surface depth. If frost susceptible soils and a sufficient water source are present, frost heaving could occur.
Comparison of Interior Insulation Strategies against Crawlspace Ground Levels

A request by an Anchorage homebuilder was made to study the effects of insulation on foundations where the soil is at the bottom of the footing (as opposed to the top of the footing), as shown in the graphic in Figure 17. This homebuilder indicated that situations occur when interior insulation is installed down the foundation stem wall with a 4-foot inward wing; however a portion of the footer may be exposed, also depicted in the graphic in Figure 17. Figure 17 summarizes the comparisons of analyses.

Key Findings

- The overall heat loss of Scenario B is approximately 5% more than Scenario A for all insulation strategies. The exposure of the footer seems to provide enough heat loss to shifts the possibility of using R-19 or R-38 Insulation down stem wall and horizontally along the ground from the "caution" category to "safe" category.
### Figure 17. Comparison of interior insulation strategies against crawlspace ground levels.

<table>
<thead>
<tr>
<th>Soil Base Level</th>
<th>To Top of Footer</th>
<th>To Base of Footer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Interior Insulation</td>
<td>85,420</td>
<td>25.0%</td>
</tr>
<tr>
<td>R-19 Down Stem Wall</td>
<td>52,140</td>
<td>39.0%</td>
</tr>
<tr>
<td>R-38 Down Stem Wall</td>
<td>50,560</td>
<td>40.8%</td>
</tr>
<tr>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>41,400</td>
<td>51.5%</td>
</tr>
<tr>
<td>R-38 Down Stem Wall, 4 ft Inward Wing</td>
<td>39,040</td>
<td>54.3%</td>
</tr>
</tbody>
</table>

**Notes:**

1. Gravimetric Moisture Content (MC)
2. Percent reduction in heat loss with respect to this scenario with no insulation.
3. Percent reduction in heat loss with respect to baseline condition with no exterior or interior insulation (Scenario A).

**Legend:**

- **Safe Zone**: Green shading indicates that the model predicts the frost line to be well above the footer bearing surface depth.
- **Caution Zone**: Yellow shading indicates that the model predicts the frost line to be within proximity to the footer bearing surface depth. Small variations in model input parameters may cause the model to simulate frost line penetration to deeper or shallower depths.
- **Danger Zone**: Red shading indicates that the model predicts the frost line to penetrate below the footer bearing surface depth. If frost susceptible soils and a sufficient water source are present, frost heaving could occur.
Summary of Modeling Results for Cleared Ground Conditions

Worst-case freezing front penetration conditions were simulated by creating a cleared ground surface condition (modeled as “asphalt” conditions). This modeling scenario most closely simulates the condition when snow levels are generally low due to snow removal, the insulating properties of snow are thereby mitigated, and the freezing front is most likely to penetrate the deepest. Actual scenarios that this condition may simulate include homes and businesses that have entry door slabs, sidewalks, asphalt, bare ground, and parking pads that are adjacent to crawlspace walls. Table 4 summarizes the modeling results for all scenarios with cleared ground surface conditions.

Table 4.
Summary of Modeling Results for All Scenarios with Cleared Ground Surface Conditions

<table>
<thead>
<tr>
<th>Ground Conditions</th>
<th>Soil Conditions</th>
<th>Moisture Content</th>
<th>Exterior Insulation</th>
<th>Crawlspace Ground Surface Level</th>
<th>Interior Insulation Strategy</th>
<th>Percent Reduction in Heat Loss</th>
<th>Frost Line Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>Silt</td>
<td>8%</td>
<td>Vertical Exterior Insulation with Horizontal Wing (2” XPS R-10 Foam Board, 48” Total)</td>
<td>None</td>
<td>No Interior Insulation</td>
<td>No Frost Line Penetration at Footer Depth</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30%</td>
<td></td>
<td></td>
<td>R-19 Down Stem Wall</td>
<td>46.8%</td>
<td>Frost Line Penetration at or below Footer Depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td></td>
<td></td>
<td>R-38 Down Stem Wall</td>
<td>42.8%</td>
<td>Frost Line Penetration at or below Footer Depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50%</td>
<td></td>
<td></td>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>50.8%</td>
<td>Frost Line Penetration at or below Footer Depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60%</td>
<td></td>
<td></td>
<td>R-38 Down Stem Wall, 4 ft Inward Wing</td>
<td>56.5%</td>
<td>Frost Line Penetration at or below Footer Depth</td>
</tr>
</tbody>
</table>

Notes:
1. Gravimetric Moisture Content (MC)
2. No need to model further. Any additional insulation would cause the 32°F isotherm to reach even further below the footing bearing surface.
3. No need to model further. Modeling insulation conditions between the extreme conditions is not necessary, as intermediate conditions would not indicate 32°F isotherm penetrations below the footing bearing surface.

Comparison of Interior Insulation Strategies against an Exterior Insulation Strategy in Cleared (Worst-Case) Surface Conditions

Scenario E served as the overall baseline when comparing varying exterior insulation strategies with cleared surface conditions. Two inches of extruded polystyrene XPS rigid insulation were modeled...
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vertically along the stem wall on the exterior surface with a horizontal wing (on a 5% slope) extending outward from the foundation, as shown in Figure 18. Figure 18 summarizes the comparisons of analyses.

Key Findings

- Although the presence of the exterior horizontal wing insulation reduces the overall heat loss through the thermal envelope by only approximately 25%, its presence shifts the possibility of using R-19 or R-38 Insulation down stem wall (without the interior wing) from "danger" category to "caution" category.
- The 32°F isotherm reaches the footer-bearing surface depth in Scenario E when any of the insulation strategies under study are implemented.
### Constants
- **Surface conditions:** Asphalt
- **Temperature Profile:** Anchorage, AK
- **Average Crawlspace Temperature:** 36.5°F

**Soil composition:**
- First six inches: Silt Soil, 10% MC^{[1]}
- Remaining soil base: Sand/Gravel Soil, 8% MC^{[2]}

### Exterior Insulation Strategy

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No Interior Insulation</td>
<td>256,400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-19 Down Stem Wall</td>
<td>151,670</td>
<td>40.8%</td>
<td>26.8%</td>
<td>45.1%</td>
</tr>
<tr>
<td>R-38 Down Stem Wall</td>
<td>146,720</td>
<td>42.8%</td>
<td>28.8%</td>
<td>46.6%</td>
</tr>
<tr>
<td>R-19 Down Stem Wall, 4 ft Inward Wing</td>
<td>118,300</td>
<td>53.9%</td>
<td>41.2%</td>
<td>53.9%</td>
</tr>
<tr>
<td>R-38 Down Stem Wall, 4 ft Inward Wing</td>
<td>111,650</td>
<td>56.5%</td>
<td>44.1%</td>
<td>58.1%</td>
</tr>
</tbody>
</table>

### Notes:
- **(1)** Gravimetric Moisture Content (MC)
- **(2)** Percent reduction in heat loss with respect to this scenario with no insulation.
- **(3)** Percent reduction in heat loss with respect to Asphalt condition with no exterior or interior insulation (Scenario F).

#### Diagram

- **Safe Zone**
  - Green shading indicates that the model predicts the frost line to be well above the footer bearing surface depth.
- **Caution Zone**
  - Yellow shading indicates that the model predicts the frost line to be within proximity to the footer bearing surface depth. Small variations in model input parameters may cause the model to simulate frost line penetration to deeper or shallower depths.
- **Danger Zone**
  - Red shading indicates that the model predicts the frost line to penetrate below the footer bearing surface depth. If frost susceptible soils and a sufficient water source are present, frost heaving could occur.

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**Figure 18.** Comparison of interior insulation strategies against an exterior insulation strategy in cleared (worst-case) surface conditions.
Comparison of Interior Insulation Strategies against Various Soil Types and Moisture Conditions in Cleared (Worst-Case) Surface Conditions

Scenario E served as the overall baseline when compared to the cases where the two soil layers were the same and moisture contents varied. In Scenario E, the first 6 inches composed of silt (10% MC) while the remaining soil was sand/gravel (8% MC). In Scenario Q, both soil layers comprised of silt (5% MC), while in Scenario N, both soil layers were comprised of silt (40% MC). In Scenario O, both layers were comprised of clay (30% MC).

In section entitled *Comparison of Interior Insulation Strategies to Varying Soil Compositions*, Scenario A served as the overall baseline when compared to the cases where the two soil layers were the same. In Scenario A, the first 6 inches composed of silt (10% MC) while the remaining soil was sand/gravel (8% MC), just as is shown in Scenario E. In Scenario G, both soil layers comprised of sand/gravel (8% MC), while in Scenario K, both soil layers comprised of silt (10% MC). In this analysis, silt (10% MC) seemed to offer a better degree of frost protection than a sand/gravel layer (8% MC). Using asphalt in the model to represent cleared surface conditions, a similar comparison was made between Scenarios E, Q, N, and O. Figure 19 summarizes the comparisons of analyses.

**Key Findings**

- When low moisture content silt (5% MC) is modeled under cleared surface conditions, the 32°F isotherm penetrates to the footer-bearing surface depth with any amount of interior insulation strategy under study. However, when high moisture content silt (40% MC) is modeled under cleared conditions, the 32°F isotherm does not reach the footer-bearing surface depth with any amount of interior insulation strategy under study. This comparison highlights the insulating properties of the water in the soil.

- This analysis demonstrates that, in areas where worst-case conditions may occur, foundation freeze protection can only be offered where no interior insulation strategy is employed.
Figure 19. Comparison of interior insulation strategies against various soil types and moisture conditions in cleared (worst-case) surface conditions.
Conclusion

Overall Key Findings

As determining the potential of frost heaving caused by retrofit insulation strategies is a primary concern in this study, understanding the requirements for frost heaving to occur is an important baseline in interpreting the results of the study. Frost heaving can only occur under the structure foundation if three conditions are met: soil must have a source of water, sufficiently fine-grained to allow wicking, and able to reach freezing temperatures. This study focuses primarily on determining the presence of the freezing conditions in the soil below the foundation footer; however, the moisture content and frost susceptibility of the soils are also addressed in the analysis of the findings. A key concern at the inception of this study is that, because the MOA's minimum crawlspace wall R-value requirement is R-19, doubling the R-value to R-38 and adding an inward wing of insulation on the crawlspace floor may result in a cold foundation that has the footer placement of a warm foundation.

In most cases, an insulation strategy involving interior R-19 or R-38 insulation installed vertically along the stem wall alone reduces heat loss while offering foundation freeze protection; however, the difference in heat loss due to upgrading from R-19 to R-38 in the same vertical configuration is slight: only 1.3-2.9%. Adopting this R-19 insulation strategy alone will save approximately 25-62% heat loss through the crawlspace when compared to using no insulation at all. Out of the 12 scenarios with turf ground conditions (with each scenario simulating five different insulation strategies), the addition of the vertical insulation strategy caused the 32°F isotherm to penetrate to below the footer bearing surface in one scenario with R-19 insulation, and in two scenarios with R-38 insulation; all three of these scenarios involved a sand/gravel soil type.

The reduction in heat loss is increased when the interior insulation strategy includes the interior wing. The difference in heat loss through the defined envelope due to increasing insulation from R-19 vertically down the stem wall to R-38 vertically down the stem wall with the interior wing insulation is more significant, however: 10.9-18%. According to the modeling results, adopting this insulation strategy will save approximately 30-80% heat loss through the crawlspace when compared to no insulation at all; however, this strategy increases the risk of damage due to frost heaving. Out of the 12 scenarios with turf ground conditions (with each scenario simulating five different insulation strategies), the addition of the interior the wing insulation caused the 32°F isotherm to penetrate to within proximity to or below the footer bearing surface in seven of those scenarios.

Of the four soil types modeled, the 32°F isotherm tended to penetrate to the footer-bearing surface for sand/gravel soils. Additionally, when comparing moisture content across identical soil types, the 32°F isotherm tended to reach the footer-bearing surface in soils with lower moisture content. The results seem to imply that silt, peat, and clay soils with higher moisture content inhibit the penetration of the 32°F isotherm to the bearing-foundation surface. These results emphasize the importance of evaluating the soil composition. Understanding the soil provides insight to justifying certain interior insulation strategies; for instance, as the soil moisture content increases, the heat loss to the ground increases. Remembering the requirements for frost heaving (soil must have a source of water, sufficiently fine-grained to allow wicking, and able to reach freezing temperatures), soils such as silt may have a high moisture content are generally sufficiently “wet” and fine-grained enough to allow wicking,
though the apparent latent heat insulating effect of the moisture may inhibit freezing temperatures at foundation footer depths. Choosing silt to be used as a form of foundation frost protection is a highly risky strategy since silt has a high frost heaving potential. Likewise, using low moisture content sand/gravel allows for freezing front penetration to reach the foundation-footer bearing surface, however its risk for frost heaving potential is low since the soil may not be sufficiently wet or porous.

Additionally, in every scenario modeled, the 32°F isotherm penetrated the concrete foundation to some point within the interior insulation along the stem wall. Despite the 32°F isotherm occurring within the insulation during the cold season, the condensation/freezing point would occur at the point of interest (in the modeled scenarios, the point of interest would be the interface of the concrete stem wall and the fiberglass insulation). The general concern is that, if the surface at the point of interest is wood, mold may be able to grow, thereby causing health or structural issues. If the conditions do not exist long enough for mold to grow, the issue is moot. When the point of interest is the concrete or concrete masonry unit (CMU) foundation, the surface generally has the ability to allow the moisture to permeate through the material and mold is no longer an issue.

Further Research

Most of the research effort in this phase of the study is through finite element modeling. Basic uncertainties were assumed during the modeling effort that may affect the outcome of the actual heat loss and freezing front penetration. Significant uncertainties include crawlspace temperatures, heterogeneity of soil types, and moisture contents. Despite these uncertainties, the modeling provides a more comprehensive understanding of the effect of varying factors (such as insulation values, soil composition, soil moisture content, etc.) and provides an avenue for future research. The next phase of this project may now be pursued with a more defined process and goal than could be achieved without prior modeling.

During the proposed second phase of this study, site measurements may be made to calibrate and validate the model. Instrumentation used in this phase may include temperature and moisture sensors at various locations in the soil as well as temperature sensors in the crawlspace. The soil measurements may be used to track the freezing front in the soil adjacent to the foundation, which could be used for model validation and calibration. One homebuilder explained that in the post-improvement energy ratings he has completed, homes with R-30 or higher on the foundation wall tend to create a warmer floor and crawlspace (J. Herring, personal communication, March 25, 2011). As no documentation was found regarding the correlation of crawlspace temperatures before and after the installation of interior insulation, making such measurements may prove fruitful for better fine-tuning the model. The current model was somewhat conservative since it did not account for this increase in crawlspace temperature, which would increase the heat loss through the foundation and offer additional frost protection.

8 Calibration is verifying that the model yields comparable results to a numerical analysis and to site measurements from an individual site.
9 Validation is verifying that the model yields comparable results to site measurements from sites with differing conditions.
An additional uncertainty of this modeling process is the accuracy in the characterization of the subsurface. Geotechnical analyses of multiple soil samples from sites in this next phase may prove useful in developing a better understanding of the sites and correlation to the model. Moisture content analyses may also be included such an analysis.

While the current modeling effort focused on assumed generic and extreme case ground surface conditions, additional modeling that includes a more comprehensive focus on ground surface conditions may be a worthwhile future research effort. Evaluating the results over a spectrum of ground surface conditions (by varying N-factors) may provide further insight in understanding the interrelationship between ground surface conditions and varying insulation strategies. Additionally, the heat loss at the exterior corners of the foundation cannot be modeled using the two-dimensional analysis of TEMP/W, however the next phase of this study will include an analysis of such heat loss.

Although the initial focus on this study was based on the Anchorage and Southcentral Alaska area, this insulation strategy has also been suggested in other areas across Alaska. Later phases of this study may include studying these insulation strategies in various Alaskan climates, including the Fairbanks area. The results of this work will ultimately be used to propose insulation strategies that best meet the goals of frost protection and energy savings for both new construction and retrofit construction across Alaska.
REFERENCES


**Disclaimer:** The research conducted or products tested used the methodologies described in this report. CCHRC cautions that different results might be obtained using different test methodologies. CCHRC suggests caution in drawing inferences regarding the research or products beyond the circumstances described in this report.