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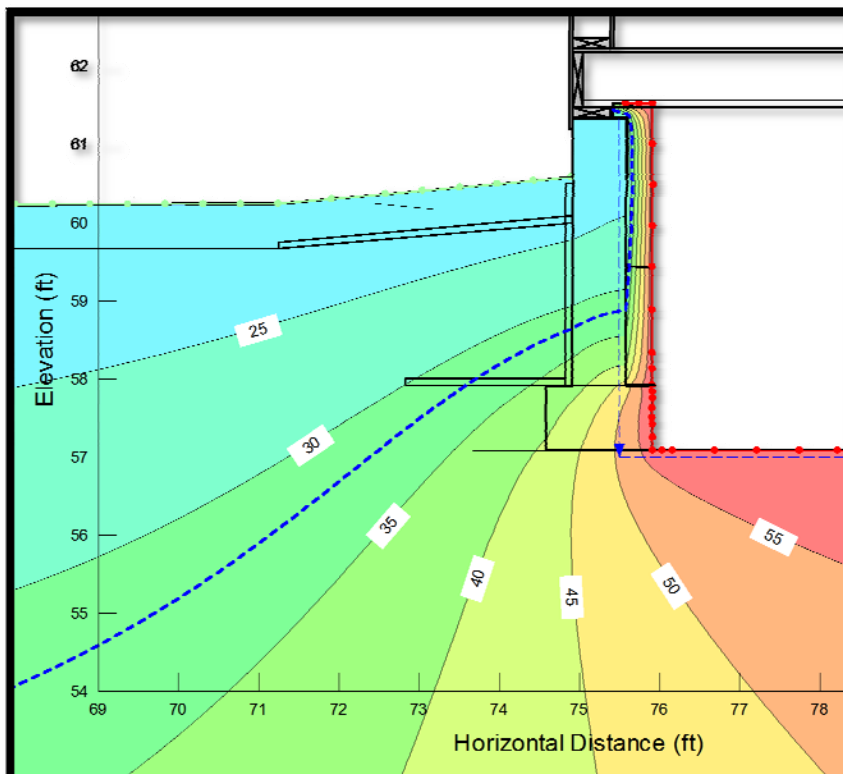**CCHRC**

Anchorage Foundation Insulation Study

**Final Report to
AFHC**

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Executive Summary

Introduction

Homebuilders in Southcentral Alaska and the Municipality of Anchorage have raised concerns about a foundation wall insulation strategy recommended by home energy raters. The strategy 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 *i*). 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 frostline*) to penetrate below the foundation footing. Thermal insulation used on and around foundations requires careful consideration to ensure that goals for energy efficiency and frost protection are met. Therefore, CCHRC has examined the insulation strategy illustrated in Figure *i* to simulate the freezing front[1] 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 footing-bearing surface when this insulation strategy is employed.
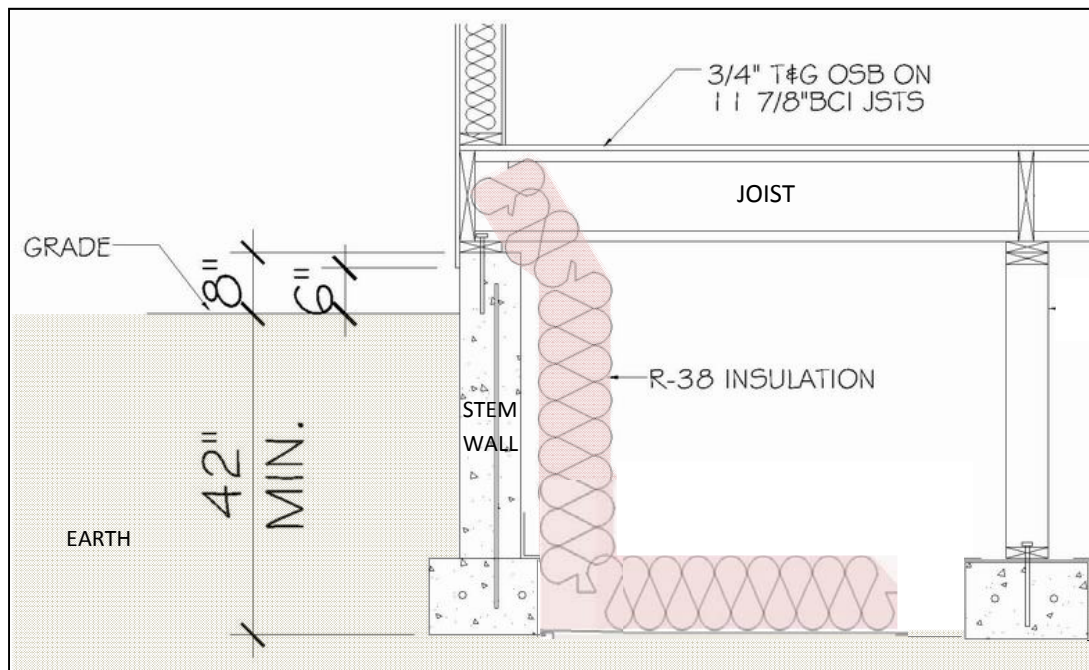

Figure i. Proposed insulation retrofit strategy that initiated the study

Method

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, 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;

[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 *frostline*.

exterior ground surface conditions; relative amount of foundation wall insulation (e.g. R-19 versus R-38); presence of interior "wing" insulation adjacent to the foundation wall; crawlspace temperatures; exterior climate conditions; and implementation of exterior insulation frost protection strategies.

Models were designed to evaluate the freezing front (frostline) 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.
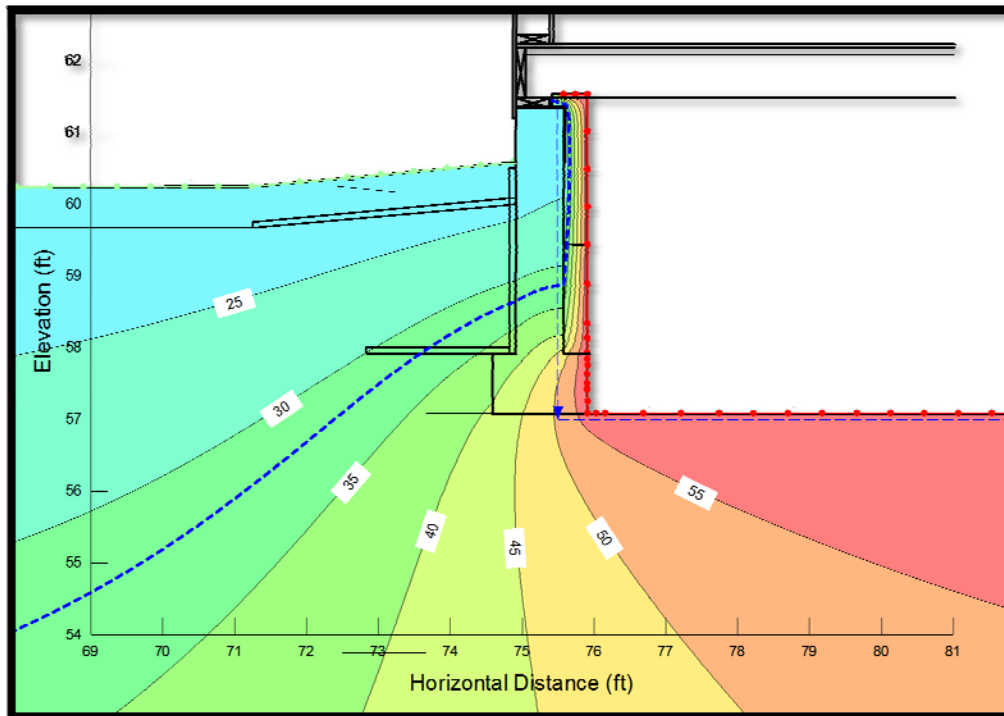

Figure ii. Representative model result showing foundation and subsurface cross sections showing freezing front (isotherm) in subsurface.

The study includes geotechnical, crawlspace and ground temperature data collected at several sites in Southcentral Alaska, which were used to calibrate the thermal models.

Eighteen house sites with crawlspaces across Anchorage and Southcentral Alaska were selected to characterize year-round crawlspace temperature regimes. The ambient air temperatures of the crawlspaces were monitored at each site for one year.

Four house sites were chosen to collect soil temperature and geotechnical data. At each of these sites, a geotechnical analysis of the soil adjacent to the foundation was performed by a consulting firm to characterize the soil properties. A string of temperature sensors were installed adjacent to the foundation wall at varying depths down to six feet deep. An additional temperature sensor measured the outdoor air temperature at each site. The data from these sites were collected after one year of monitoring.

Results

The analysis suggests that the addition of any amount of ground insulation causes the frostline depth to be closer to the foundation footing. However, for the conditions studied representing the Anchorage area, an R-38 stem wall and ground insulation (up to 4 feet in from the stem wall) appears unlikely to cause the frostline to reach the footing as long as the crawlspace maintains an annual average temperature of 59.5°F and snow cover around the foundation wall is not cleared. Notably, as the frostline depth increases at colder locations, this strategy is very likely to cause frozen footings in places like Fairbanks.

The crawlspace air temperature had a direct effect on the proximity of the frostline to the foundation footing. Variations of crawlspace temperatures to the model reveal a freezing potential at the foundation footing when the average annual crawlspace temperature was between 45°F and 50°F. Additional analysis revealed that any amount of insulation on the stem wall (assuming none on the ground) will not enable the frostline to reach the footing when the average crawlspace temperature remained above 40°F.

The simulated ground surface conditions were varied to understand how ground conditions affect the frostline depth. Regardless of the modeled crawlspace temperatures, the frostline reached the footing in both cases where the ground was cleared of snow in the winter. The presence of snow clearly acts as an insulating blanket on the ground when the air temperatures drop significantly below freezing.

Conclusions

The primary conclusion is that, for the range of conditions selected to represent the Anchorage area, an R-38 stem wall and ground insulation (up to 4 feet in from the stem wall) will not pose an unreasonable risk of the frostline approaching the foundation as long as the crawlspace maintains an average annual temperature of at least 57.1°F and snow covers the ground near the foundation. Changing ground surface conditions, such as removing snow from the general surrounding area (due to driveways or decks) increases the chance of freezing the footing. Additionally, as the frostline penetrates deeper in colder climates, this strategy is very likely to enable footing freezing in places like Fairbanks.

In response to scenarios involving R-38 stem wall and ground insulation for an area that involves snow removal, an exterior insulation strategy was analyzed to reduce freezing potential: a 42-inch long, 4-inch thick XPS foam board (R-20) was simulated as approximately 6 inches below the ground surface. When the stem wall and ground insulation values were varied, the result was a larger thaw bulb area beneath the foundation. This insulation strategy mitigated frostline penetration toward the foundation footing. The modeling results indicate that it may provide a potential solution for the Anchorage area homeowner who would like to implement the R-38 stem wall and ground insulation strategy described by Figure i, yet who has a driveway or deck adjacent to their crawlspace.

Findings from this study validate the concern about potential frost heave in locations colder than Anchorage or in situations in Anchorage where adjacent parking areas (or other places where snow is removed during the winter) are situated against the crawlspace foundation. Consequently, the modification or restriction of this insulation strategy in AKWarm may merit consideration.

These findings are intended to make homebuilders, homeowners, energy auditors, and other members of the building community aware of the effect of crawlspace insulation strategies in the Southcentral area as well as other parts of Alaska. These findings may initiate a statewide conversation among the building community regarding the best crawlspace insulation strategies to recommend in other parts of the state, such as Fairbanks.

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Introduction

Homebuilders in Southcentral Alaska and the Municipality of Anchorage have raised concerns about a foundation wall insulation strategy recommended by home energy raters. The home 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 footing.
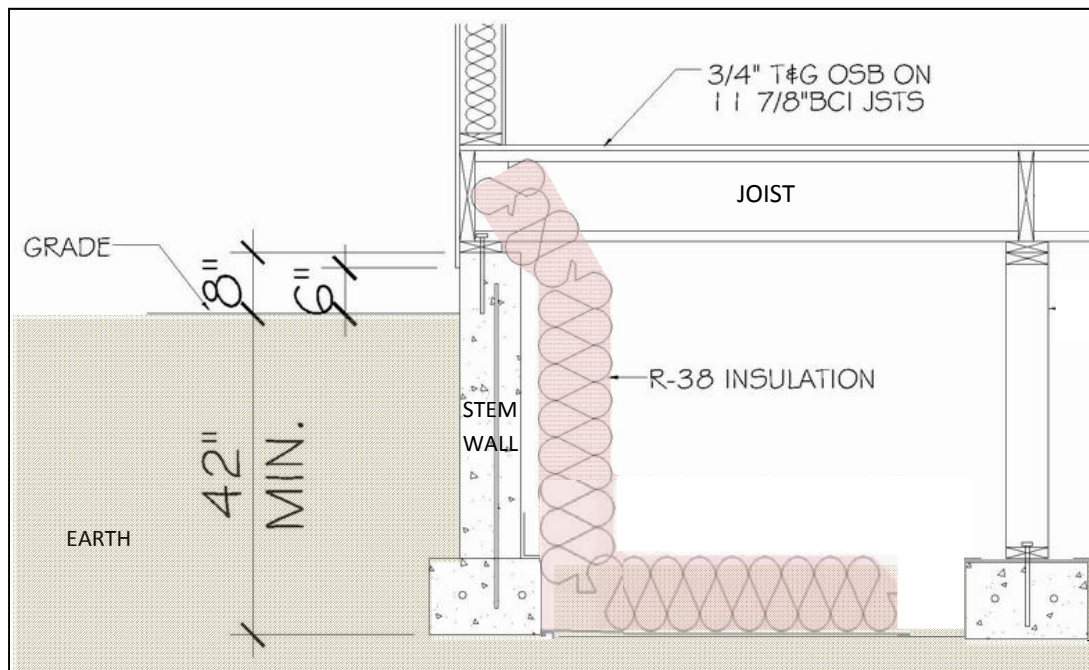
Figure 1. Proposed insulation strategy that initiated study

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 evaluate 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 footing bearing surface when this insulation strategy is employed.

Modifications to the illustrated insulation strategy were studied to compare the relative change in frost protection and heat loss. The variables include:
- Soil type and soil moisture content;
- Exterior ground surface conditions (i.e. snow-covered turf, bare asphalt, or bare gravel);
- Relative amount of foundation wall insulation (e.g. R-19 versus R-38);

- Presence of interior "wing" insulation adjacent to the foundation wall;
- Crawlspace temperatures;
- Exterior climate conditions;
- Presence of exterior insulation frost protection strategies.

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 frostline 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.

The industry standard in Anchorage and Southcentral Alaska is to insulate the length of the foundation wall with R-19 or R-21 fiberglass batts. 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 being used for both new construction and for retrofit improvements of existing homes. Because the MOA's minimum crawlspace wall R-value requirement is R-19, doubling the R-value to R-38 could result in a cold foundation that has the footing placement of a warm foundation.

Key Findings of Interim Study

CCHRC conducted a preliminary study of this topic, which is summarized in an interim report (Grunau 2011). The initial efforts focused on a literature review of the topic and thermal modeling of foundations with varying insulation configurations and soil properties. More than 80 scenarios were modeled that compared ground surface conditions, soil conditions, soil moisture content, exterior insulation strategies, and interior insulation strategies. In each scenario, the analysis was evaluated to determine if the freezing front reached the foundation wall bearing surface and the annual cumulative heat flow through the foundation wall and floor.

In most cases, an insulation strategy involving interior R-19 or R-38 insulation installed vertically along the stem wall alone (without the inward wing) reduces heat loss while maintaining foundation freeze protection. Of the 12 modeled scenarios with turf ground conditions (representative of typical lawns that are snow covered during the winter), the addition of the vertical insulation strategy caused the freezing front to penetrate below the footing bearing surface in only one scenario using R-19 insulation, and in two scenarios using R-38 insulation; all three scenarios involved a sand/gravel soil type. Additional investigation revealed that a warmer crawlspace temperature may mitigate this problem.

Heat loss is reduced when interior wing is added in addition to stem wall insulation. Out of the 12 scenarios with turf ground conditions, the addition of interior wing insulation caused the freezing front to reach the footing bearing surface in seven of those 12 scenarios.

Of the four soil types modeled, the freezing front tended to reach the footing-bearing surface for sand/gravel soils. Additionally, when comparing moisture content across identical soil types, the

freezing front tended to reach the footing-bearing surface in soils with lower moisture content. Interestingly, the results seem to imply that silt, peat, and clay soils with higher moisture content inhibit the penetration of the freezing front to the bearing-foundation surface. In other words, dry, sandy/gravel soils (non-frost susceptible soils) are actually the worst-case condition, in terms of frostline penetration depth.

The results from this initial study are considered highly conservative due, however, to the cold crawlspace temperatures assumed (38°F year-round). Significant uncertainties in the modeling include crawlspace temperatures, variability of soil types, and ground surface conditions. In order to address these uncertainties, the findings from this initial study were used to advance the work by guiding the placement and type of physical monitoring of various sites in Southcentral Alaska. Geotechnical analyses, moisture content analyses, and temperature and moisture content data collected during the next phase of the project were used to calibrate and validate the existing model.

Overview of this Study

This study includes data collected from several sites in Southcentral Alaska to calibrate a numerical thermal model for evaluating the frost-heave potential of several crawlspace insulation scenarios. Eighteen house sites with crawlspaces across Anchorage and Southcentral Alaska were selected to characterize year-round crawlspace temperature regimes. Data loggers measuring crawlspace air temperature were installed at each site and the resulting data were collected after one year of monitoring.

Four house sites were chosen to collect soil temperature and geotechnical data. At each site, an analysis of the soil adjacent to the foundation was performed by a geotechnical consulting firm to characterize the physical soil properties. A string of temperature sensors were installed adjacent to the foundation wall at varying depths down to six feet deep. An additional temperature sensor measured the ambient outdoor air temperature at each site. The data from these sites were collected after one year of monitoring in order to perform a complete temperature analysis and provide further refinement of the model.

A thermal modeling program, Temp/W (Geo-Slope International), was used to model the scenarios. 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. 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 previously described, such as exterior ground surface conditions, relative amount of foundation wall insulation, crawlspace temperatures, etc.

The primary determinant in evaluating each scenario is whether the freezing front (shown as the 32°F isotherm in the model results) would reach the bearing surface of the footing. An example of one model pictorial result is shown in Figure 2. The dashed blue line represents the simulated freezing front,

or *isotherm*[2]; color variations on either side of the 32°F isotherm represent the temperature gradients ("warmer colors" indicate temperatures warmer than 32°F, while "cooler colors" indicate temperatures colder than 32°F).
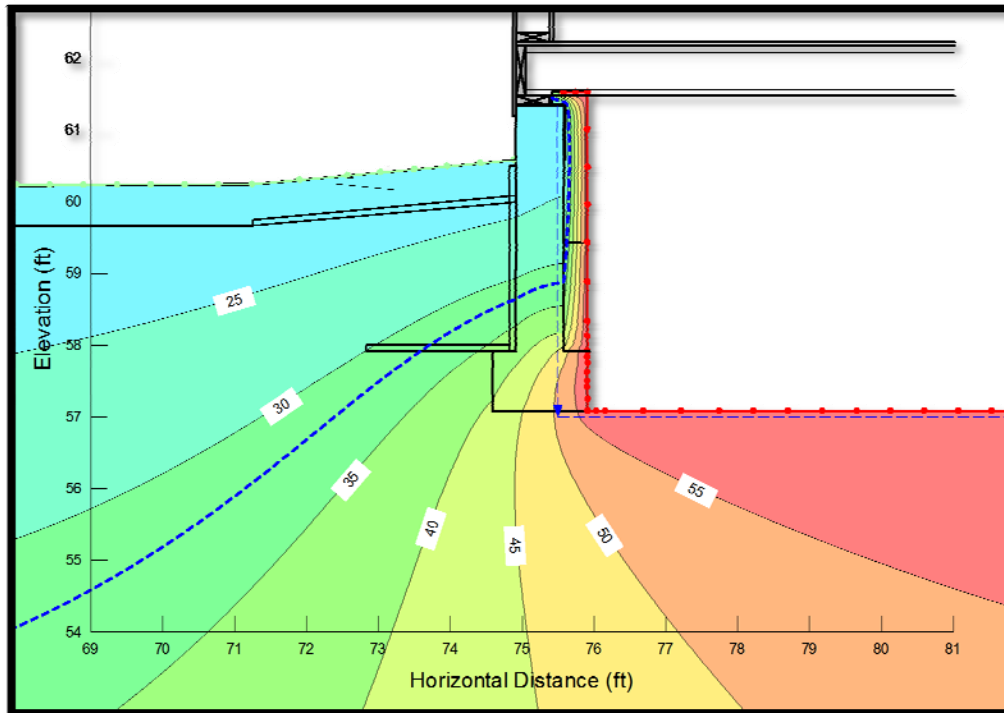
Figure 2. Representative model result showing foundation and subsurface cross sections with temperature gradient vectors overlain showing freezing front (isotherm) in subsurface.

The results of a steady-state analysis of the model served as the initial conditions used for the transient analysis. The transient analysis evaluated the soil temperatures and heat flows for a period of nine years and served as the basis for evaluating the varying soil and environmental thermal conditions and insulation strategies.

The primary concern of this retrofit insulation strategy is the possibility of frost heaving under the foundation footing-bearing surface. Frost heaving can only occur under the structure foundation if three conditions are met: soil must have a source of water, be sufficiently fine-grained to allow wicking, and be able to reach freezing temperatures. The analyses performed during this study accounts only for the presence of subsurface freezing conditions and does not account for the wicking ability of soils or the presence of water sources.

Scope and Limitations

- The primary concern of this retrofit insulation strategy is the possibility of frost heaving under the foundation footing-bearing surface.
- This study evaluates the freezing conditions of the soil only and does not account for the wicking ability of soils or the presence of water.

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[2] The freezing front 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.

- All models assumed a 42" subsurface footing depth.
- Since silty, sandy, and gravely soils were the primary soil types encountered during the geotechnical evaluation, these soils types were the only ones analyzed in this study.
- The focus of the study includes the Anchorage and Southcentral Alaska area only and does not apply to other regions of Alaska.
- Findings in this study do not apply to foundations built on permafrost soils.

Method

Crawlspace Study

Temperature sensors were installed in the crawlspaces of 18 homes located in Anchorage, Palmer and Wasilla. The sites were selected based on willing homeowners who responded to a request for study participants. Most of the respondents were friends, family members, or acquaintances of members of the Southcentral building community. The crawlspace conditions ranged from uninsulated/poorly insulated and unmaintained spaces with no ground vapor retarder to well-insulated, well-maintained spaces with tightly installed ground vapor retarders. Examples of various crawlspaces encountered in the study are shown in Figure 3.

Instrumentation

The instrumentation used was a battery-operated integrated temperature and relative humidity sensor and data logger (HOBO U10-003), an example of which is shown in Figure 4. Each temperature logger sampled and recorded the ambient air temperature on an hourly basis from November 2011 through November 2012. The data was downloaded directly from each logger and includes a time stamp and measured temperature point (units in °F). The sensors were located as close to the foundation wall as could be reasonably placed. Figure 5 shows several typical installations of the temperature loggers in crawlspaces involved in the study. Figure 6 and Figure 7 describe the approximate locations of the homes that were included in the crawlspace study.

Data Analysis Procedure

The recorded temperatures from each logger were evaluated for average daily and yearly temperatures, average maximum and minimum daily temperatures, and absolute maximum and minimum hourly temperatures. For every recorded hour, the measured minimum, maximum, and average temperatures of all 18 loggers were logged. Box-and-whisker plots were created to characterize the temperature measurements at each site.

Figure 3. Typical crawlspaces involved in temperature study ranged from well-insulated to uninsulated conditions. The top left photo is representative of the most commonly encountered crawlspace insulation strategy, which includes one to two inches of rigid foam attached halfway down the stem wall. The top right photo shows an example of the R-38 fiberglass batt insulation draped down the stem wall with the ground insulation (the strategy under study). The bottom left photo shows R-19 fiberglass batt insulation draped down the stem wall. The bottom right photo shows an uninsulated stem wall and poorly insulated floor joists.

Figure 4. Integrated temperature loggers were installed in each crawlspace.

Figure 5. Temperature sensors installed near foundation walls to measure crawlspace air temperatures for one year.
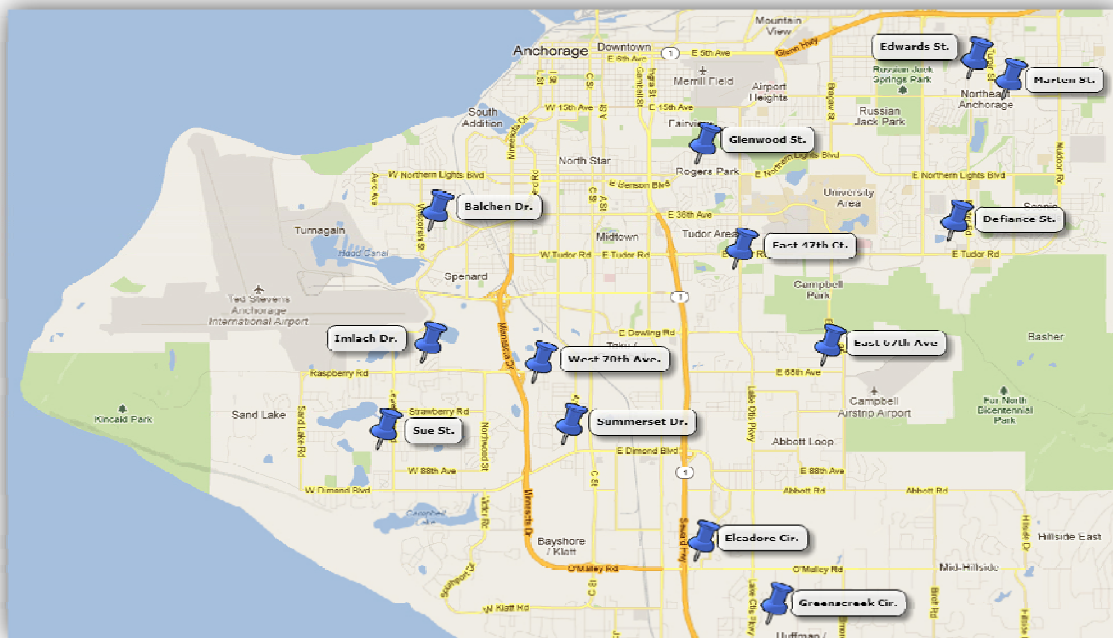
Figure 6. Fifteen home sites across the Anchorage area were included in the survey. (Not shown: Glacier Bay Ct. and Toklat St.)
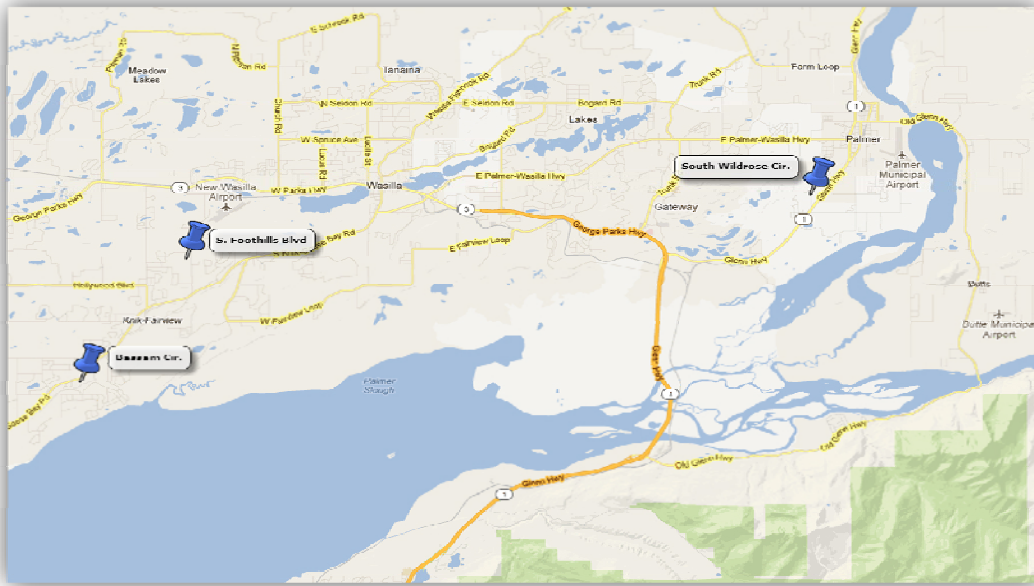
Figure 7. Three home sites in the Palmer-Wasilla area were included in the survey.

Soil and Air Temperature Measurements Study

Four home sites were selected for the soil and air temperature measurement study. These sites were located at Sue St., Glenwood St., Edwards St., and Imlach Dr., as indicated by Figure 8. The insulation strategy of each site was noted and is summarized in Table 1. The crawlspaces at these sites were included in the crawlspace temperature study and the resulting data were used for thermal modeling calibration and validation.
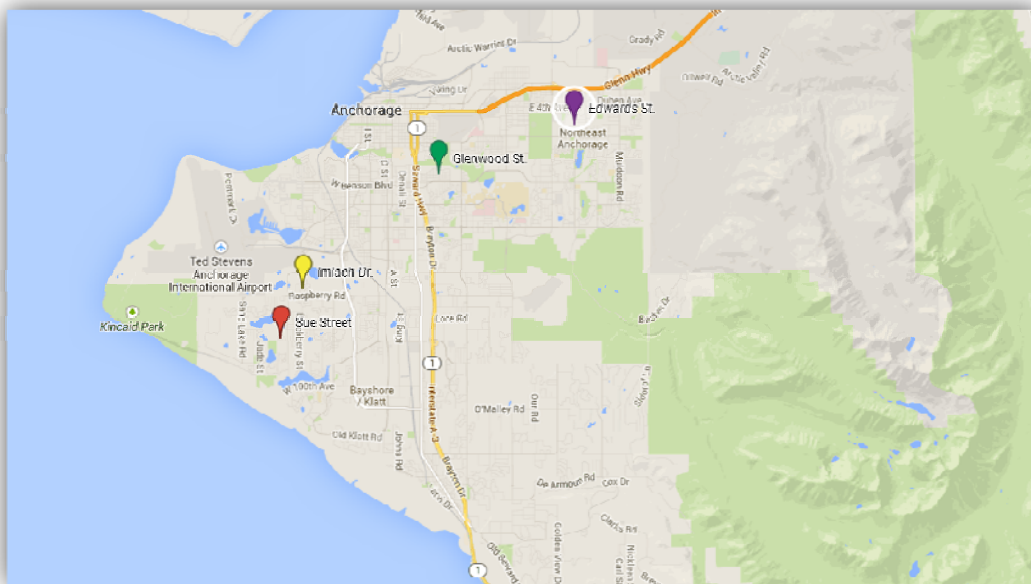
Figure 8. The colored pins mark the locations of the four Anchorage homes included in the soil and air temperature measurement study.

Table 1
Summary of site-specific conditions and crawlspace insulation strategies

Site Location	Placement of Temperature Probe with Respect to Home	Description of Stem Wall Insulation
Sue St., Anchorage, AK	Southwest side of house. 28 inches from house. 7 feet from northwest corner of house.	1" thick expanded polystyrene foam extending from top of stem wall down 2 feet. Space is heated with dedicated hydronic baseboard fintube.
Imlach Dr. , Anchorage, AK	Northeast side of house. 19 inches from house. 4.7 feet from east corner of house	2" thick extruded polystyrene foam extending from top of stem wall down to ground and completely covering the ground surface of the crawlspace. Stem wall finished with gypsum board. Space is used for storage and heated with dedicated hydronic baseboard fintube.
Glenwood St. , Anchorage, AK	West side of house. 28 inches from house, 7 feet from northwest corner of house.	No insulation on stem wall. Space is heated with dedicated hydronic baseboard fintube.
Edwards St. , Anchorage, AK	North side of house. 25 inches from house, 12 feet from northeast corner of house.	1" thick rigid polyisocyanurate board extending from top of stem wall down 2 feet. Space is heated with dedicated hydronic baseboard fintube.

Instrumentation

A temperature probe assembly was created for each of the four sites where soil temperatures were monitored. Each temperature probe assembly was installed approximately 20 - 30 inches away from the foundation stem wall. The probe assemblies were positioned to avoid utilities in the subsurface and other obstacles; additionally, the assemblies were located as close to the center of the length of the wall as practical. The assemblies measured the air temperature approximately 24 inches above the surface of the ground, the ground temperature approximately 1 inch below the surface, and at subsequent depths of 18, 36, 54, and 72 inches.

The temperature probe assembly consisted of 9-foot long PVC pipe with temperature sensors protruding from holes drilled in the sides of the probe. A radiation shield housed the sensor used to measure the air temperature. A plastic housing was affixed to the top of the probe that contained the data loggers. The probes were inserted in the holes drilled by the soil drilling rig used for the geotechnical soil analysis. The annular space between the borehole wall and the casing was backfilled with cuttings produced during the drilling. A photo of a completed assembly is shown in Figure 9.

Each assembly contained two four-channel battery-operated data loggers (HOBO U12-006), an example of which can be seen in Figure 9. Each temperature logger sampled and recorded the ambient air temperature on an hourly basis from November 2011 through November 2012. The data was downloaded directly from each logger and includes a time stamp and measured temperature point (units in °F).

Figure 9. (Clockwise; starting from left) The probe assembly prior to installation; the assembly after installation; one of the two data loggers contained within the housing. The soil temperature probe assembly housed the temperature sensors and data loggers.

Data Analysis Procedure

The recorded data from the loggers at each of the four test sites were evaluated by plotting soil temperature versus depth of sensors over the course of a year to form a set of whiplash curves. Trumpet curves, which characterize typical high and low soil temperatures with respect to soil depth, were derived from the whiplash curves. The whiplash and trumpet curves characterize the soil temperature profile over the course of the year. These curves served as a comparison for the thermal modeling outputs to aid in model calibration and validation.

Geotechnical Analysis of Soil

The geotechnical consulting firm Shannon & Wilson, Inc. was hired to perform subsurface explorations and laboratory testing at each of the four home sites. One geotechnical boring was drilled at each residence to characterize the subsurface soil and groundwater conditions. Soil samples recovered from the borings were tested at their laboratory. A report detailing the subsurface exploration procedures and an interpretation of subsurface conditions was provided.

The borings were drilled to depths of approximately 10 feet below the ground surface and approximately 18 inches from the foundation. A track-mounted GeoProbe drill rig equipped with a hollow-stem auger was used to retrieve the borings and a geologist collected the samples and logged subsurface conditions. These samples were collected at approximately 2.5-foot intervals using Standard Penetration Test (SPT) methods. The soils were visually classified in the field according to the Unified Soils Classification System and later verified through laboratory analysis. The laboratory tests were performed on the collected samples primarily focused on estimating the materials gradation properties and in-situ water content. Summary logs of the borings of this work were provided to CCHRC and are included in Appendix A.

Temp/W Model Construction

Temperature Data

The air temperature data for the models in this study used data from the Western Regional Climate Center (2013) specific to each Alaska location. The 30-year daily temperature data collected from 1971 to 2000 were used to create a time-series temperature function for each analysis. The following procedure describes how this function was derived:

The warmest and coldest daily temperatures, T_{high} and T_{low}, were obtained from the data set for each location. The mean temperature, T_M, was calculated by taking the average of the 365 daily average temperatures. The average phase lag, φ, was determined for each data set to describe the average number of days the coldest and warmest temperatures occur with respect to the first and middle days of the year. These parameters were used to calculate the daily average temperatures using

$$A = \frac{(T_{high} - T_{low})}{2} \tag{1}$$

and

$$T(t) = T_M - A \cos\left(\frac{2\pi(t - \phi)}{365}\right) \tag{2}$$

where t is days measured from January 1.

The annual modeled air temperatures for Anchorage are shown in Figure 10. Every year of analysis reflected on this average temperature data for as long as the model ran. This methodology to calculate annual air temperature was used as a proxy for locations with different air freezing indices (AFI) used later in this study.
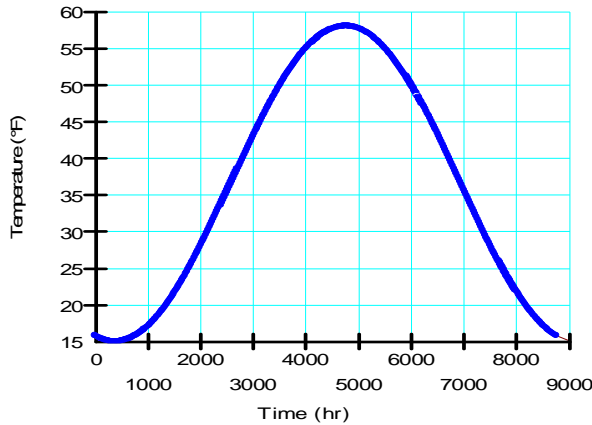
Figure 10. Average air temperature used for baseline model (for Anchorage conditions).

Crawlspace Temperatures

The crawlspace temperatures were based on the results of the crawlspace survey conducted at the 18 residences. The baseline model used temperatures from a data set collected during the survey that represented the coldest average transient crawlspace temperature throughout one year. Various iterations of crawlspace conditions were modeled to examine the effect of crawlspace temperature on ground temperatures.

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 and have been calculated based on numerous field studies. The depths of seasonal thawing and freezing are strongly affected by the surface conditions. 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, were based on suggestions from Goodrich and Gold (1981) and are shown in Table 2. Slight variations of the N-factors were used to calibrate the model. N-factors were modified to examine the effect of ground surface conditions on the freezing front.

Table 2
N-Factors Used in Model

Condition	N-factor Modifier			
	Turf[a]	Asphalt[a]	Sand & Gravel	Model Baseline
Freezing	0.5	0.9	0.9	0.4
Thawing	1.1	1.8	2	1.1

a) Based on Goodrich and Gold (1981)

Material Properties and Soil Parameters

The baseline soil profile was chosen based on anecdotal recommendations of homebuilders in the Anchorage area (A. Spinelli, personal communication, March 25, 2011), findings in the Soil Profile for Anchorage, Alaska (United States Department of Agriculture), and the geotechnical report provided by Shannon & Wilson. Table 3 describes the various properties of materials and soil types used in the baseline model.

Table 3.
Baseline Model Inputs and Material Properties

Parameters	Concrete	40.5% Gravel, 40.5% Sand, 19% Silt	XPS Foam Board	R-19 Insulation	R-38 Insulation
Volumetric Moisture Content, Θ (ft^3/ft^3)	0	0.15	0	0	0
Unfrozen Thermal Conductivity, k_u (BTU/(hr·ft·°F))	0.8	1.34	0.015	0.0175	0.00833
Frozen Thermal Conductivity, k_f (BTU/(hr·ft·°F))	0.8	1.56	0.015	0.0175	0.00833
Unfrozen Water Content at 29°F, (ft^3/ft^3)	0	0.05	0	0	0
Unfrozen Heat Capacity, c_u (BTU/(ft^3·°F))	25.2	34.8	0	0	0
Frozen Heat Capacity, c_f (BTU/(ft^3·°F)))	25.2	27.2	0	0	0
Freezing N-Factor	0.4				
Thawing N-Factor	1.1				
Outside Air Temperature Data Set	Anchorage, AK				

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

$$\Theta = W \times \rho_{ds}/\rho_{H2O} \tag{3}$$

where W is the gravimetric water content of soil, ρ_{ds} is the dry density of soil, and ρ_{H2O} is the density of water.

The thermal conductivity of soils was determined based on Kersten's average frozen and unfrozen thermal conductivity for each soil type (Kersten, 1948). The thermal conductivities were dependent on dry soil density, soil type, and moisture content. 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.

The unfrozen water content for each soil type is based on unfrozen water content values at below-freezing temperatures for clay, silt, and sand, as determined by Frietag & McFadden (1997). The unfrozen water content values used for peat, as determined by Farouki (1981) were also used. The values determined by Frietag & McFadden (1997) and Farouki (1981) were subsequently converted to volumetric percentages and are summarized for each soil type (at 29°F) in Table 3.

The volumetric specific heat of the soil, C [BTU/(ft^3·°F)], was calculated using

$$C = \rho_{ds}c_{ds} + \rho_{ds} (W/100) \ c_{H2O} \tag{4}$$

where ρ_{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_{H2O} 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 3. The R-19 and R-38 fiberglass batt insulation was modeled 4 inches thick using the thermal conductivities listed in Table 3. 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.

The thermal conductivity, water content, and heat capacities of the soils were adjusted based on the results of the log borings produced during the geotechnical analysis. For each site, modeled soil layer material properties were created based on the corresponding soil profile described by the boring. Each site was evaluated for the mix of soil types and grain sizes; for instance, the boring from surface to approximately eight feet below ground that occurred at the Edwards Street monitoring site produced samples that were described as "frozen to medium dense to dense, brown, slightly silty to silty, sandy GRAVEL; moist… 41% Gravel, 40% Sand, 19% Fines."

Thermal properties for such specific soil mixtures have not been developed and therefore must be estimated. In this study, all of the soil types were described as being some form of silt, sand, or gravel; therefore, thermal and moisture properties for sand were applied to "gravel" and "sand" descriptors in the report and thermal and moisture properties for silt were applied to "fines" descriptors. The thermal conductivity, volumetric water content, and heat capacity of the mixed soils were calculated using weighted averages of the soil mixture.

The unfrozen thermal conductivity, K_u [BTU/hr-ft-°F], for the soil was calculated as

$$K_u = p_{sand} (1.45) + p_{silt} (0.6) \tag{5}$$

where p_{sand} is the percentage of combined sand/gravel in the soil (in percent) and p_{silt} is the percentage of fines in the soil (in percent).

The unfrozen thermal conductivity for the example above would be calculated from Equation 5 as: $K_u = (41\%+40\%) \times (1.45) + (19\%) (0.6) = 1.2885$ [BTU/hr-ft-°F]. Similarly, the frozen thermal conductivity, dry density of soils, volumetric water content, frozen and unfrozen heat capacity of each soil mix were also calculated.

The frozen thermal conductivity, K_f [BTU/hr-ft-°F], for the soil was calculated as

$$K_f = p_{sand} (1.70) + p_{silt} (0.6) \tag{6}$$

where p_{sand} is the percentage of combined sand/gravel in the soil (in percent) and p_{silt} is the percentage of fines in the soil (in percent).

The dry density of the soils, ρ_{ds} [lb/ft^3], for the soil was calculated as

$$\rho_{ds} = p_{sand} (125 \text{ lb/ft}^3) + p_{silt} (90 \text{ lb/ft}^3) \tag{7}$$

where p_{sand} is the percentage of combined sand/gravel in the soil (in percent) and p_{silt} is the percentage of fines in the soil (in percent).

The volumetric water content, M_v [%], of the soil was calculated as

$$M_v = M_g \times \rho_{ds} /62.4 \tag{8}$$

where M_g is the gravimetric water content of the soil (in percent), and ρ_{ds} is the dry density of the mixed soils calculated from Equation 7.

The unfrozen heat capacity, C_u [BTU/ ft^3-°F], and frozen heat capacity, C_f [BTU/ ft^3-°F], were calculated using Equations 4 and 7.

Additional Inputs

A representative foundation and cross section similar to the sketch in Figure 1 was created for each scenario. Figure 11 depicts the two-dimensional model area of the area under study, approximately 20 feet wide by 10 feet elevation. 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 soil parameters are assumed to be uniform across the entire model. The two-dimensional model assumes the model extends 1 foot into the page.

At the bottom of the model, 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).
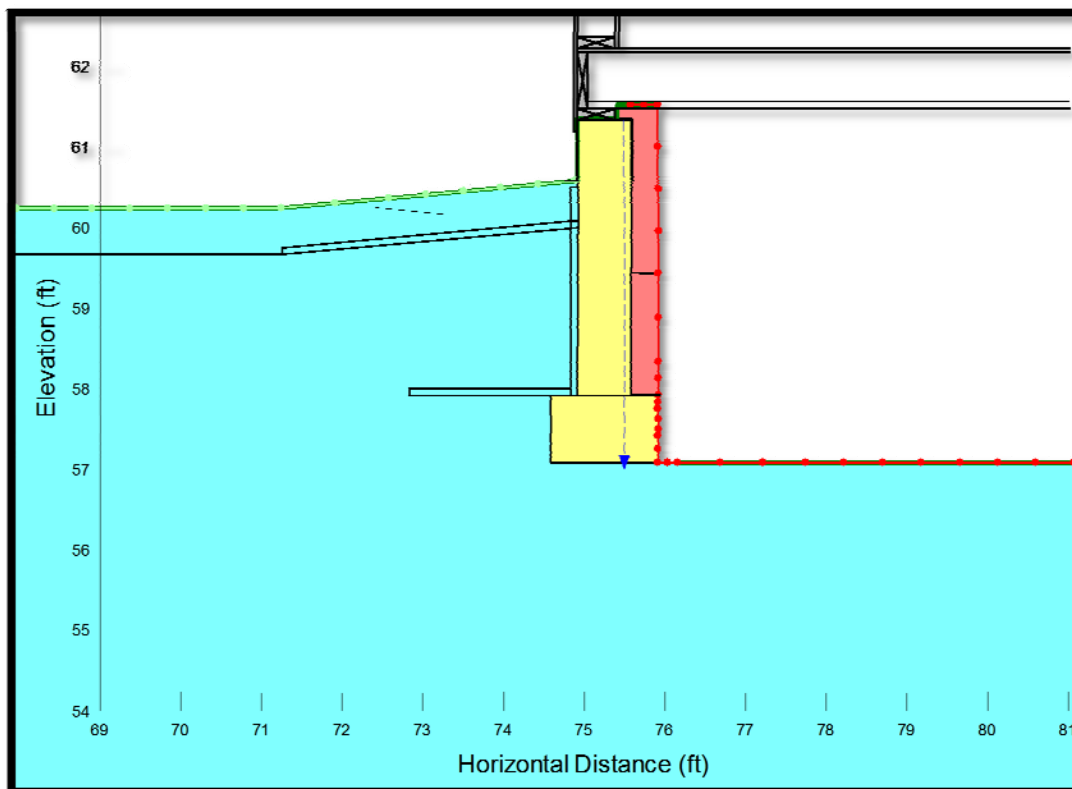
Figure 11. Example of basic model layout used in study.

Temp/W Analysis Procedure

Determining Initial Conditions and Transient Analysis

In order to determine initial conditions for the transient model, boundary conditions representing the average yearly air temperature and yearly crawlspace surface 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 ninth year served as a basis for comparison.

Determining Heat Loss through Thermal Boundary

The blue dashed line in the model (see Figure 11) indicates 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.

Evaluating the (Horizontal and Vertical) Proximity of Freezing Front to Corner of Footing

The minimum proximity of the freezing front to the foundation footing was evaluated by determining the minimum vertical and horizontal distance of the freezing front to the bottom outermost corner. If the freezing front was within a 41" x 30" window centered on the exterior corner of the foundation footing at any point in the modeled year, the horizontal and vertical distances could be determined to the nearest inch. The horizontal proximity was determined if the freezing front was within 15 inches to the exterior of the footing corner or 15 inches to the interior of the footing corner. The vertical proximity was determined if the freezing front was within 26 inches above the footing corner or up to 15 inches below the footing corner. An example of this evaluation can be seen in Figure 12. When the freezing front was within this window, the proximity of the front to the foundation footing could be calculated. Additionally, the maximum frostline depth from the ground surface (directly above the corner of the foundation footing) was evaluated for each modeled scenario.
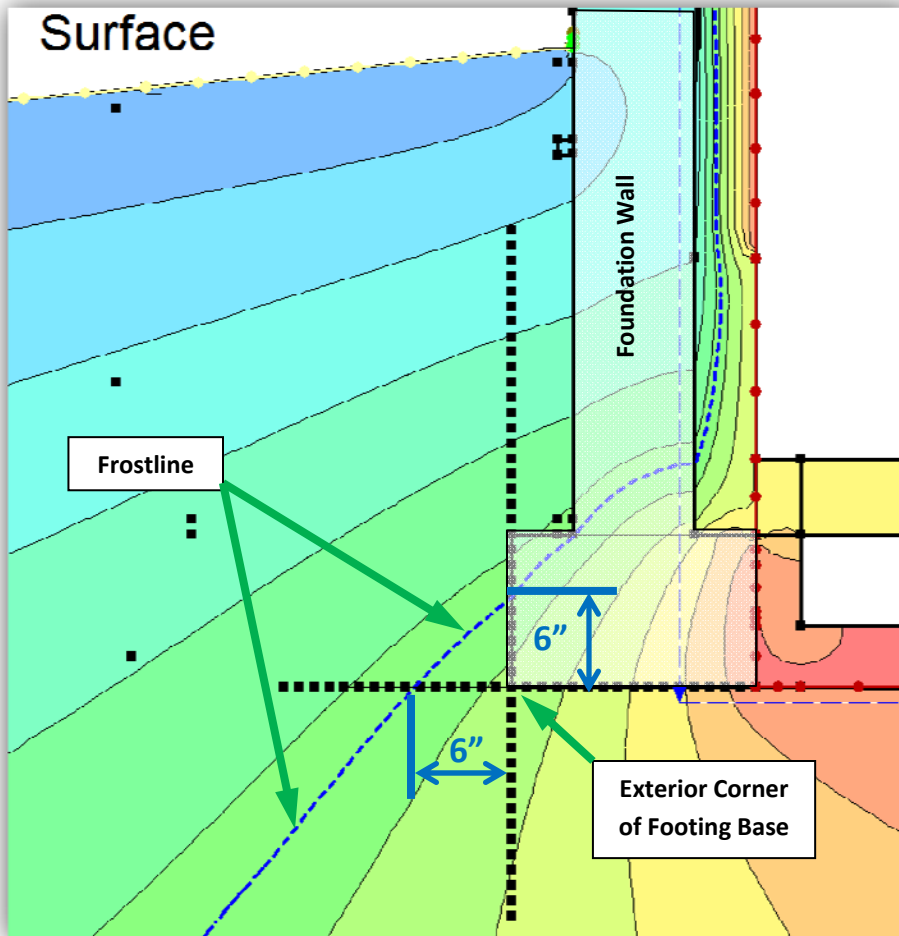
Figure 12. The minimum proximity of the frostline to the foundation footing base was calculated. In this example, the frostline came within 6 horizontal inches and 6 vertical inches of the exterior base corner of the footing; the maximum frostline depth is 36 inches from the surface (since the base of the footing is 42" below the surface).

Results

Due to the complex nature of this study, the results presented in this section include an analysis of measured data, the development and refinement of the model based on these data, and the manipulation of the model inputs to address the effect of variables in determining the model output.

Summary of Findings of Crawlspace Survey

Box-and-whisker temperature plots were created as a graphical representation of the data from each site depicting: the smallest observation (minimum temperature), lower quartile, median, upper quartile, and largest observation (maximum temperature). These plots in Figure 13 allow for the comparison of measured results between the monitored homes; the mean temperatures of the sites ranged from 52.5°F to 71.2°F. Box-and-whisker temperature plots were also created for comparison of results over the course of the year in Figure 14. The mean annual temperature of the 18 sites was found to be 60.3°F.

Crawlspace Temperature Survey Box Plots by Location

Value shown indicates mean temperature
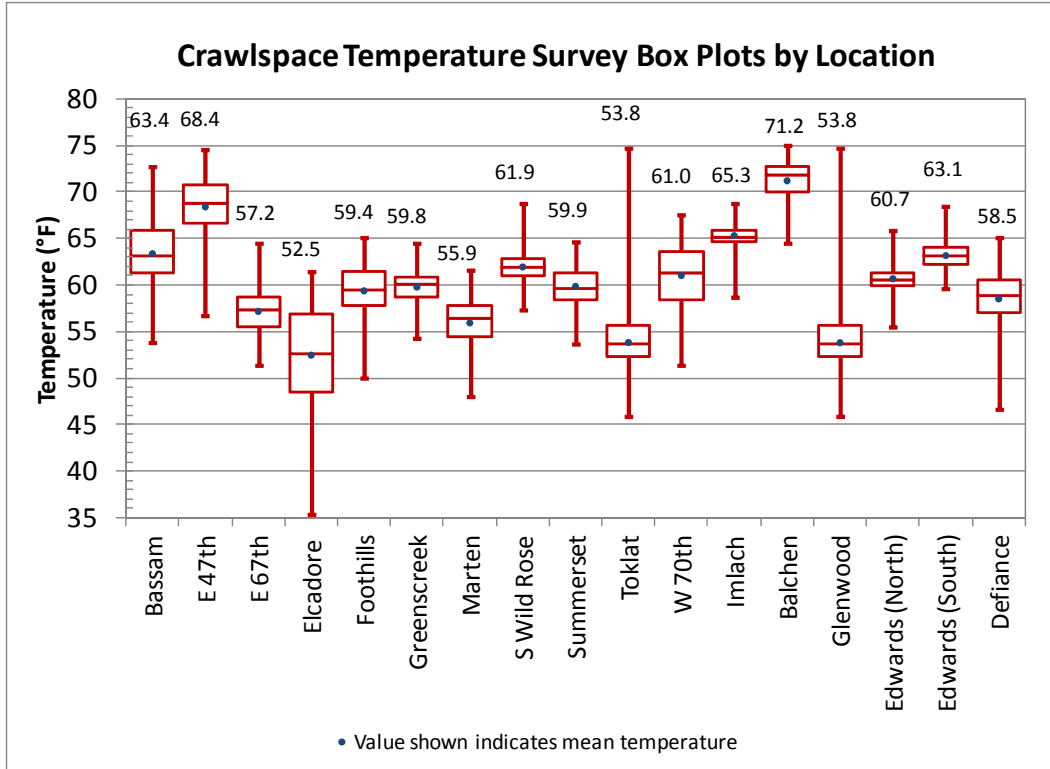
Figure 13. These box-and-whisker plots characterize the temperatures recorded at each site. The 17 sites are identified by their corresponding street name.

Crawlspace Temperature Survey Box Plots by Time

Value shown indicates mean temperature
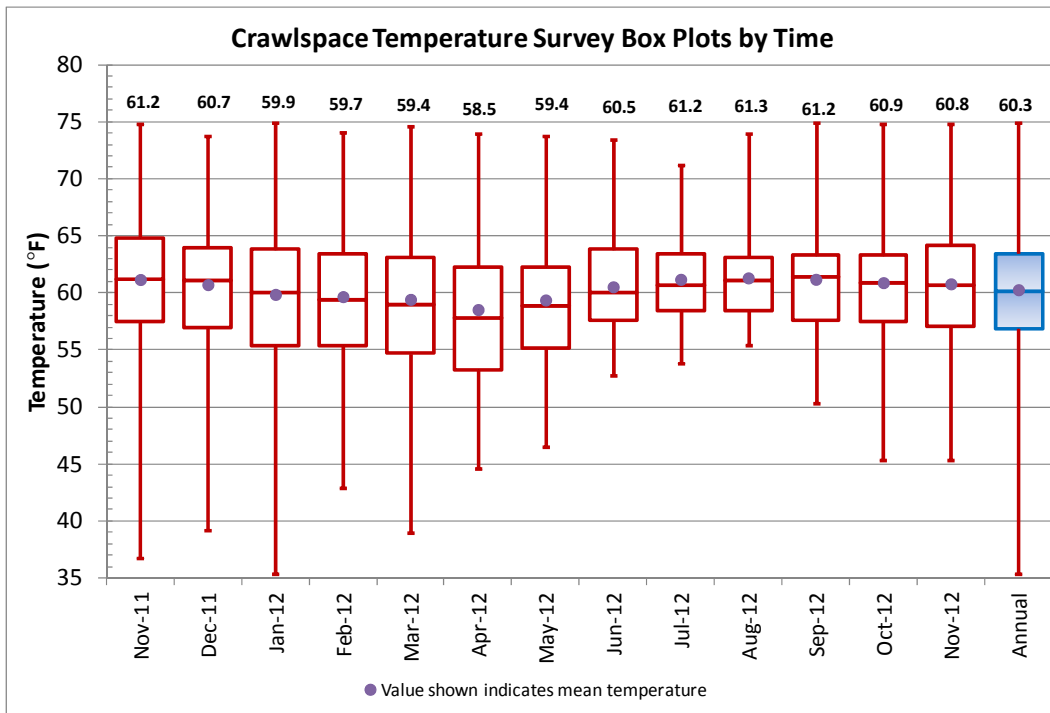
Figure 14. These box-and-whisker plots characterize combined measured temperatures at all sites for each month under study. The box-and-whisker series labeled "annual" characterizes the combined measured temperatures for the entire period.

The comparison of time history temperature plots were created for each site studied. Figure 15 depicts the measured minimum, maximum, and average temperatures of all other crawlspaces in the survey. Based on Figure 14, the Greenscreek Cir. site was selected to represent the mean, the coldest (Elcadore Cir.), and the warmest (Balchen Dr.) representative data sets and were used in the modeling analyses. Time history plots of these sites are also presented in Figure 15.

General Anchorage Crawlspace Temperature Trends

Legend: Min, Max, Average, Greenscreek Cir., Elcadore Cir., Balchen Dr.
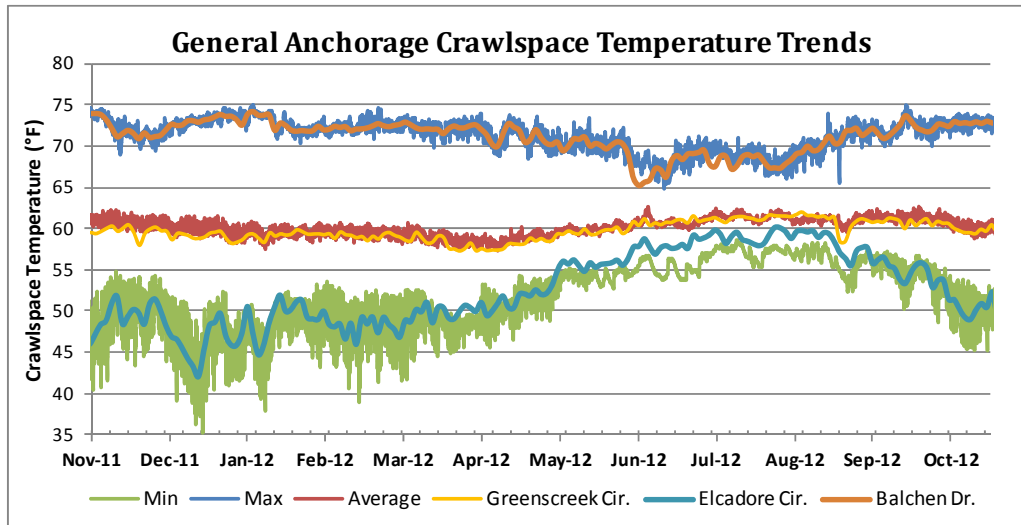
Figure 15. The aggregate minimum, maximum, and average crawlspace temperatures are shown. The time history plots for Greenscreek Cir. (measured median), Elcadore Cir. (measured minimum), and Balchen Dr. (measured maximum) are also shown.

Summary of Findings of Ground and Air Measurements

The outdoor air temperature was measured at four sites: Sue Street, Edwards Street, Imlach Drive, and Glenwood Street. The averaged data from these four sites is shown in the plot in Figure 16. The average outside daily air temperature is compared against the air temperature data used for the modeling that was obtained for Anchorage International Airport through the Western Regional Climate Center (2013).

Figure 17 depicts the box-and-whisker plots created to compare outside air temperatures of each test site. The mean annual temperature of each site was within +/- 0.5°F of the combined annual mean.

The comparison between the average climate data and the measured site data provided confidence in using the WRCC climate data as an appropriate model input.

Average Outdoor Air Temperature in Anchorage, AK
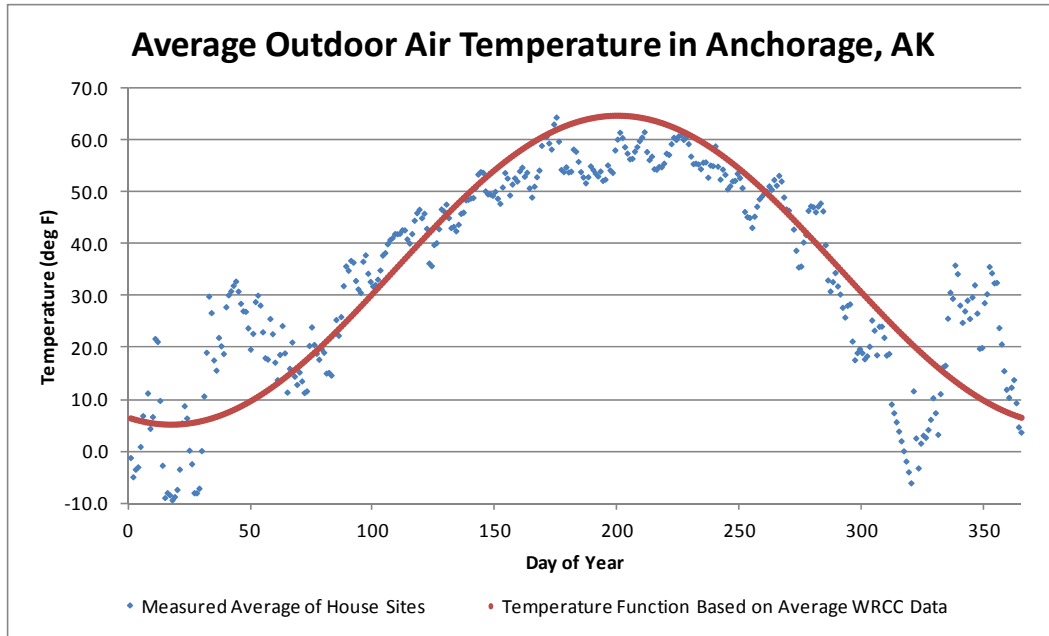
Figure 16. The average daily measured outdoor air temperature is compared against the air temperature data (red line) used for the thermal modeling.

Annual Outside Air Temperature Box Plots by Location
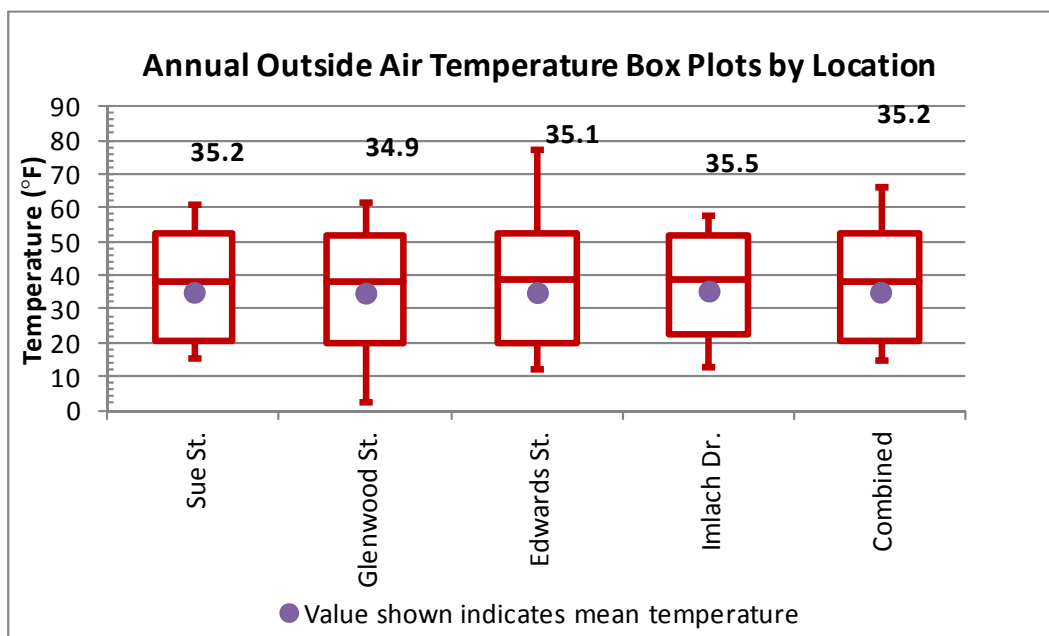
Figure 17. The annual outside air temperature box-and-whisker plots characterize combined measured annual temperatures at all sites. The mean temperature of each site varies only slightly between sites.

Calibration/Validation of Model

Model calibration was conducted by adjusting the input parameters of each model so that the resulting agreement of the output (modeled trumpet curves in Figure 19) with the set of experimental field data (measured trumpet curves in Figure 20) was maximized by visual comparison. Input parameters such as specific heat capacity, moisture content, and thermal conductivity were initially adjusted with only mild effects on the output. Correspondingly, these properties were not treated as

variables but were assigned values based on commonly accepted parameters or the geotechnical analysis to match the material properties at each site. The adjusted N-factors had the greatest effect on the resulting model output and also the greatest uncertainty, and therefore were chosen as the primary model parameter for calibrating the model.

The Sue St. soil profile was selected to define the baseline model soil parameters because its percentage of fines (19%, soil classification) in the first 8 feet was closest to the average percentage of all four sites (31.5%). Findings from the interim report (Grunau, 2011) indicate that sandy soils tend to enable deeper frostline penetration toward the foundation footing. In order to maintain a level of slight conservatism in the modeling, soil properties from the first 8 feet of the Sue St. soil profile were selected for baseline modeling.

Calibration Details

Model calibration was performed for the Edwards and Imlach sites. A transient analysis of each model based on a 9-year simulation was performed and evaluated against the measured ground temperatures. Due to a faulty sensor at the ground surface of the Edwards site, data from this sensor was completely removed. The sensor at 56 inches at the Imlach site was out of range prior to May 31, 2012, due to signal noise; the data prior to this date have been removed from the data sets.

The modeled thermal properties of the soils were derived using the geotechnical analysis results from each site and Equations 3 though 8. Additionally, the average water content for each soil layer (as described by the geotechnical report) was determined from the boring log and from Equations 3 and 7. The measured crawlspace temperature at each site was applied to each model for the entire 9-year modeled duration. The outdoor air temperatures based on the air temperature data obtained for Anchorage International Airport (Western Regional Climate Center, 2013) were applied to years 1 through 8; the measured outdoor air temperatures of the corresponding site were applied to year 9 (the final year). The crawlspace insulation applied to each model corresponded to the stem wall and ground insulation strategies observed at each site.

Nodes were created at approximately 28 inches from the foundation wall at the same corresponding depths as the temperature sensors on the temperature probe assembly: 1 inch below the surface, and at subsequent depths of 18, 36, 54, and 72 inches. Whiplash curves were created from these nodes and were compared to the whiplash and trumpet curves derived from the measured data. The N-factors were modified slightly for all sites until the modeled trumpet curves reasonably approximated the measured trumpet curves. Examples of two such comparisons of whiplash curves are shown in Figure 19. While the modeled whiplash and trumpet curves are approximations of the measured data, the modeled data tended to predict slightly colder annual soil temperatures, therefore resulting in slightly conservative estimates for the purposes of evaluating insulation strategies affecting the freezing of foundation bearing surfaces.

The frozen and unfrozen N-factors modified to fit the models to the Edwards and Imlach site data were averaged and used in subsequent baseline modeling and validation. The baseline N-factors are: N_f = 0.4, N_u = 1.1. Figure 18 describes the baseline model used for validation and subsequent analyses.
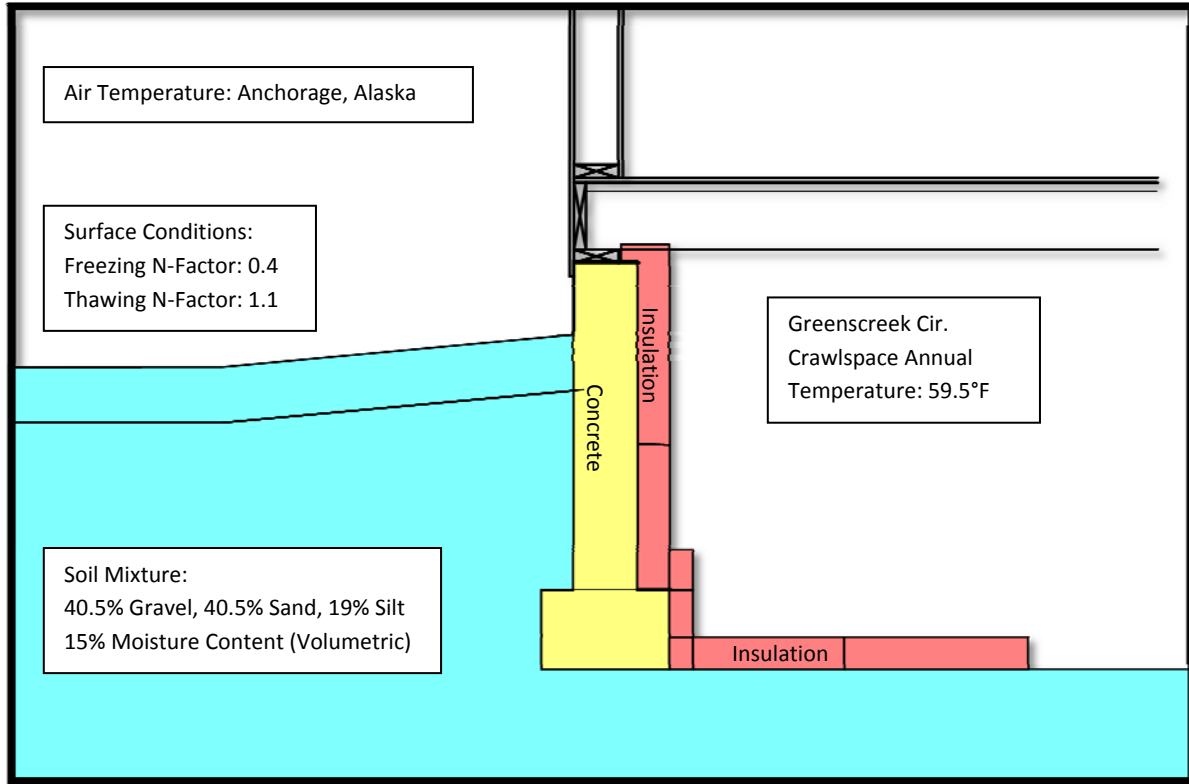
Figure 18. Depiction of baseline model used for model validation and subsequent analyses.

Validation Details

Model validation was performed by basing the inputs (adjusted N-factor) of the previously calibrated models (Imlach and Edwards sites) and applying them to the Sue and Glenwood models. The modeled outputs (whiplash and trumpet curves) were then compared to the whiplash and trumpet curves generated based on measured soil temperatures from these sites, as shown in Figure 19. The crawlspace temperature logger for Sue St. malfunctioned and the data was lost. Because the Edwards St. crawlspace insulation strategy was nearly identical to the Sue St. insulation strategy, the Edwards St. crawlspace temperature set was applied to the Sue St. model.
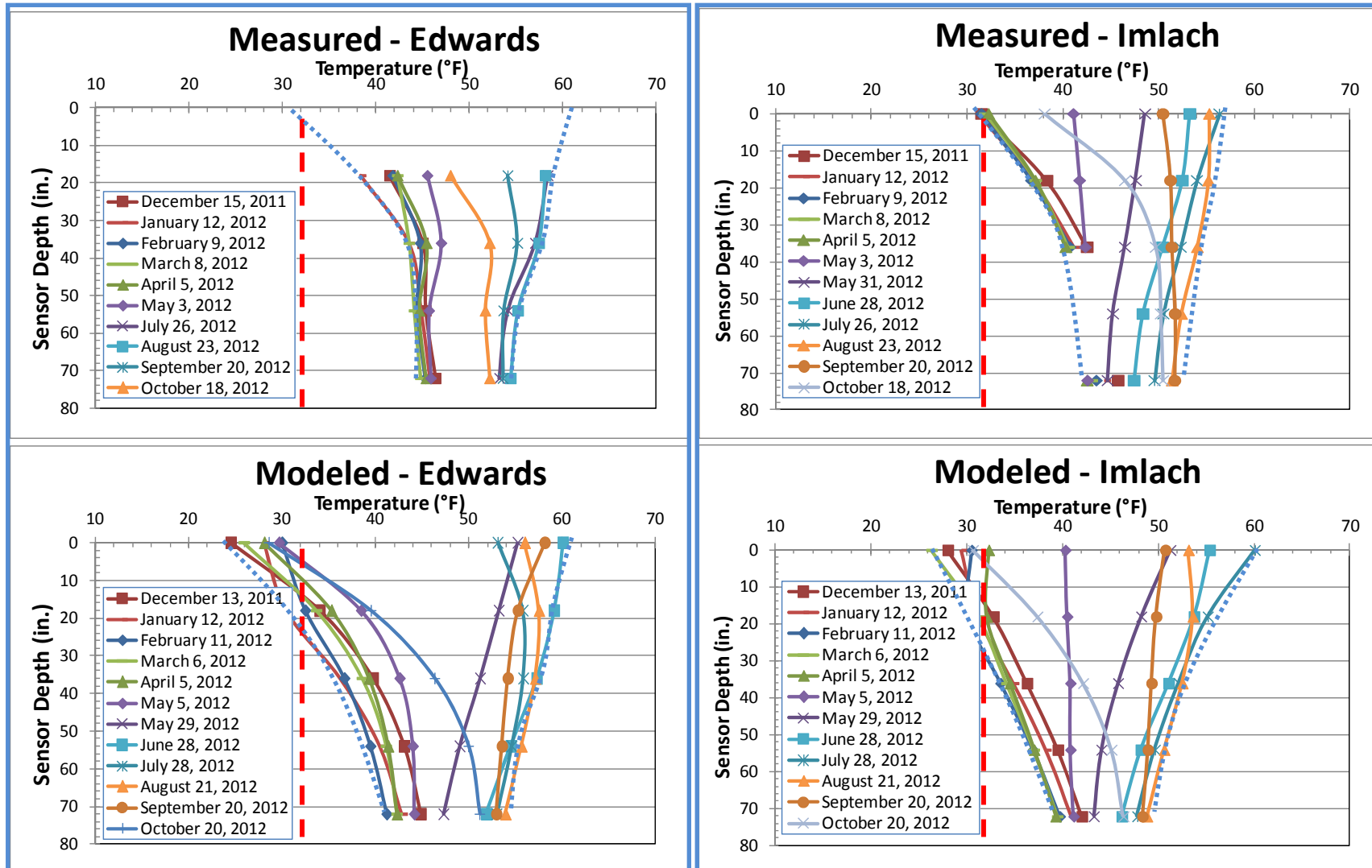
Figure 19. The calibrated modeling output whiplash and trumpet curves for Edwards St. and Imlach Dr. were compared to the corresponding curves based on measured temperature data. The red dashed line indicates the freezing point. The blue dotted line represents the approximate trumpet curve. Erroneous data recording the Edwards site ground surface temperatures and Imlach temperature data at 56 inches depth prior to May 31, 2012 have been removed. Modeled N-factors for Edwards are Nf = 0.5, Nu = 1.2. Modeled N-factors for Imlach are Nf = 0.3, Nu = 1.0.
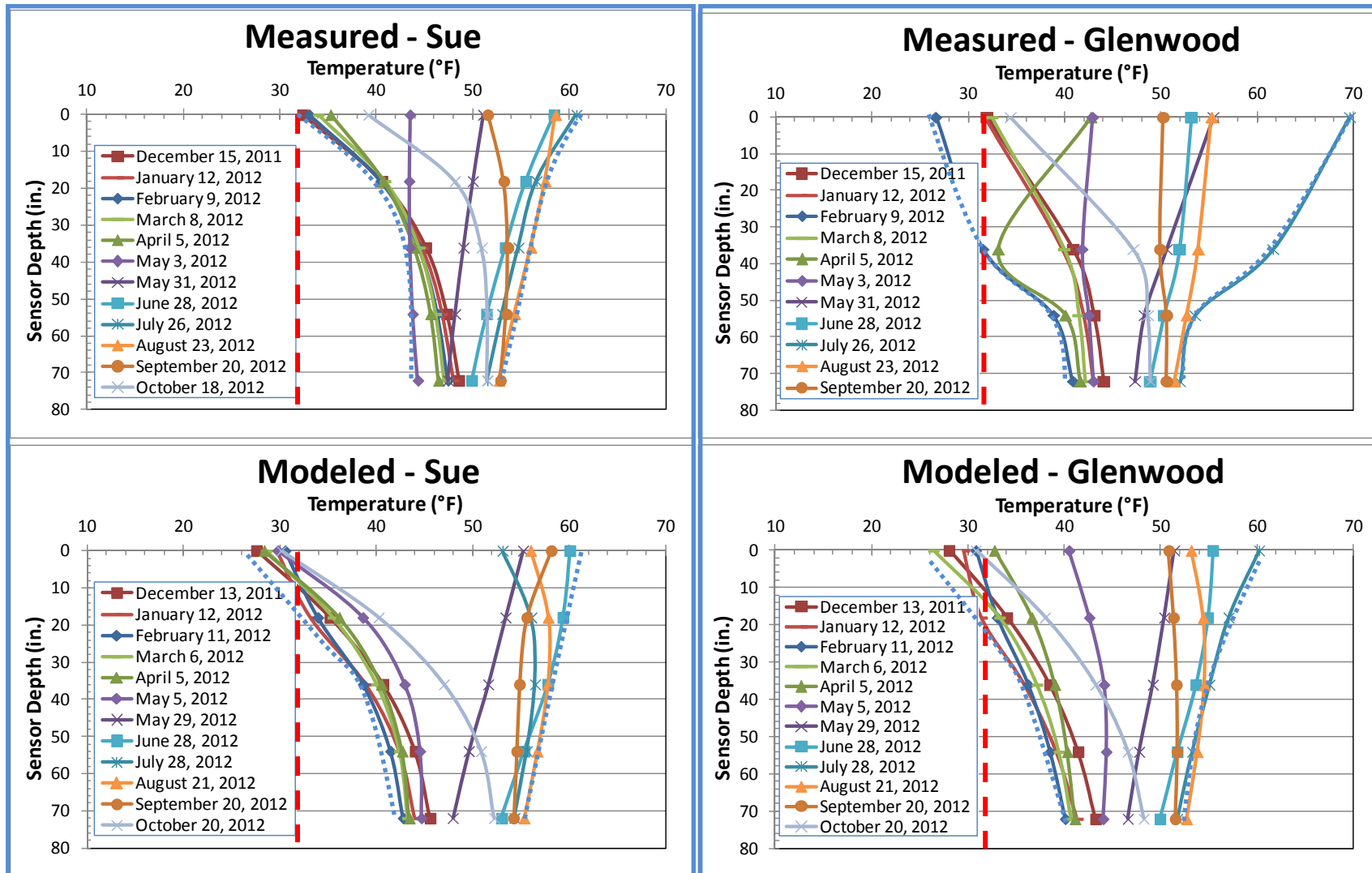
Figure 20. The models for Glenwood St. and Sue St were validated based on input parameters derived from the calibration process and comparing the modeled whiplash and trumpet curves to the corresponding curves based on measured temperature data. The red dashed line indicates the freezing point. The blue dotted line represents the approximate trumpet curve. Modeled N-factors for Sue are N_f = 0.4, N_u = 1.1. Modeled N-factors for Glenwood are N_f = 0.4, N_u = 1.1.

Modeling Results

Over 210 scenarios were modeled that compared varying crawlspace conditions, outdoor air temperatures, ground surface conditions (N-factors), interior crawlspace insulation strategies, soil types, moisture content, and exterior insulation strategies. In each scenario modeled, the analysis was evaluated to determine the minimum proximity of the freezing front to the foundation wall bearing surface.

Stem Wall and Ground Insulation R-values

The stem wall and ground insulation values varied from zero to R-50 and were applied to the baseline model to evaluate the effects of these values on the thermal regime in the ground; these effects are described by Figure 21. The crawlspace data sets for the Elcadore Cir. (the lowest measured temperature set) and Greenscreek Cir. (the baseline temperature set) were also evaluated. These models assume that the stem wall and ground insulation maintain the same R-value.

Insulation Strategy:
Varying Stem Wall &
Ground Insulation Values
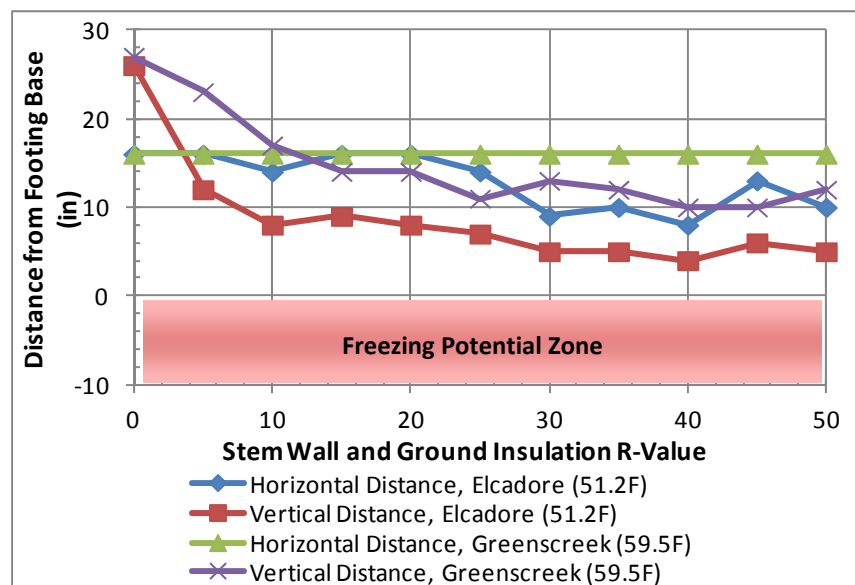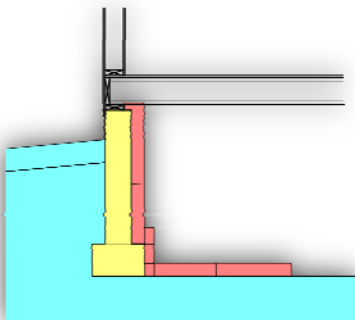
Figure 21. Plot describes the minimum annual horizontal and vertical distance of the frostline to the footing based on stem wall and ground insulation R-value. *Note: The maximum horizontal distance from the footing base that could be calculated was 16 inches; values greater than 16 inches are shown as 16 inches.*

Crawlspace Temperatures

Varying crawlspace temperatures were simulated and applied to the baseline model, which included simulated R-38 stem wall and ground insulation, as shown in Figure 22. Representative crawlspace temperatures were selected from the measured data for evaluating minimum, average, maximum, and at intervals between. Hypothetical crawlspace conditions were modeled to evaluate conditions outside the measured range of temperatures recorded.

Insulation Strategy: R-38 Stem Wall & Ground Insulation
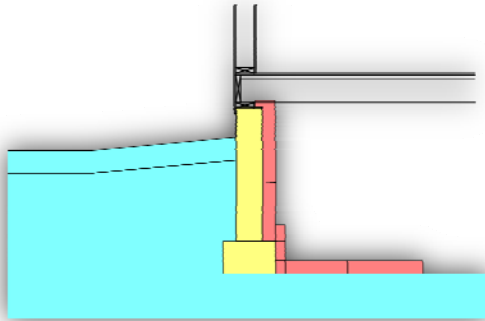
Crawlspace Condition	Average Annual Temperature
Constant year-round (hypothetical) Temperature	35.0
Constant year-round (hypothetical) Temperature	40.0
Constant year-round (hypothetical) Temperature	45.0
Constant year-round (hypothetical) Temperature	50.0
Measured Data from Elcadore Cir.	52.2
Measured Data from Toklat St.	53.8
Measured Data from East 67th Ave.	57.1
Measured Data from Edwards St. (South Unit)	62.6
Measured Data from Imlach Dr.	65.2
Measured Data from Balchen Dr.	71.1
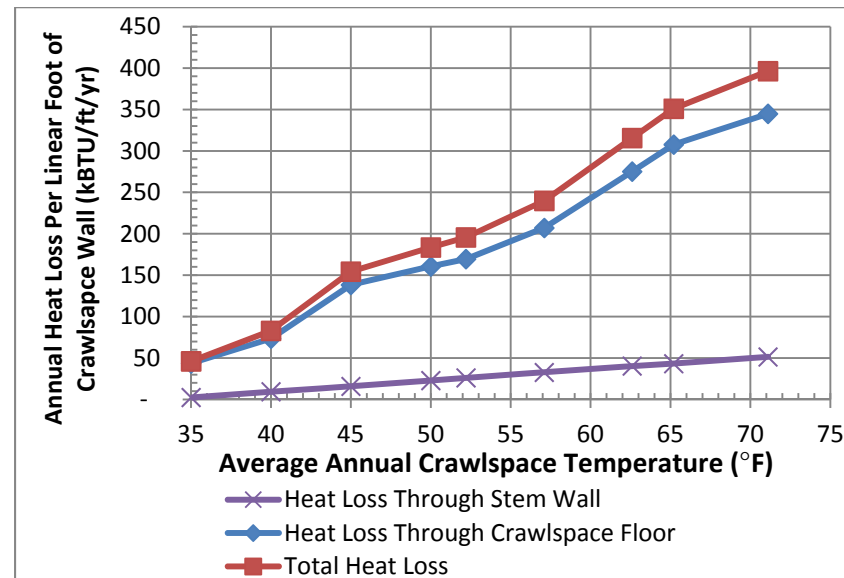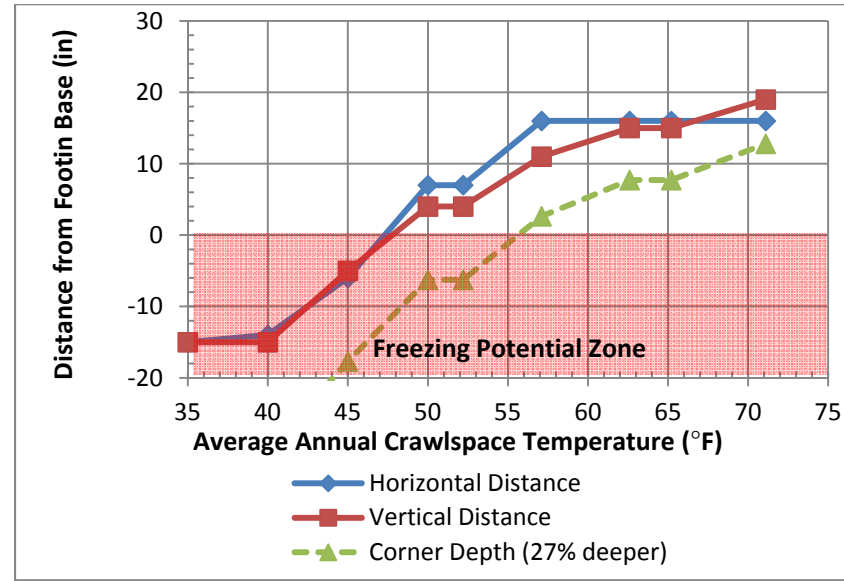
Figure 22. Top left: Diagram of modeled condition with R-38 stem wall and ground insulation. Bottom left: Description of modeled crawlspace conditions with R-38 stem wall and ground insulation. Top right: The effect of the varying crawlspace conditions on the proximity of the frostline to the foundation footing is shown. *Note: The maximum horizontal distance from the footing base that could be calculated was 16 inches; values greater than 16 inches are shown as 16 inches.* **Bottom right: The effect of varying crawlspace conditions on the annual heat loss through the foundation wall and floor per linear foot of foundation wall is described.**

N-Factors

To understand the impact of N-factors on the model output, the freezing and thawing N-factors were varied and applied to the model to evaluate the effects of these values on the thermal regime in the ground; these effects are described by Figure 23. In this case, the model assumes R-19 stem wall insulation with no ground insulation. When evaluating the freezing N-factors, the thawing N-factors were held constant and vice versa. While specific sets of freezing and thawing N-factors are paired to surface conditions such as turf, snow, and gravel, these values were varied individually to understand the effects of each on the thermal regime of the ground. The coldest measured crawlspace temperature data set (Elcadore Cir.) was applied to the model for this analysis.

Insulation Strategy:

R-19 Stem Wall
Only
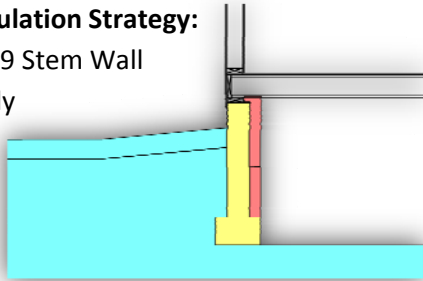
Freezing N-Factor Evaluation		
Freezing N-Factor	Thawing N-Factor	Crawlspace Temperature Data Set
0.3	1.1	
0.4	1.1	
0.5	1.1	
0.6	1.1	Elcadore Cir. (51.2°F avg annual temp)
0.7	1.1	
0.8	1.1	
0.9	1.1	
1.0	1.1	

Thawing N-Factor Evaluation		
Thawing N-Factor	Freezing N-Factor	Crawlspace Temperature Data Set
0.3	0.4	
0.5	0.4	
0.7	0.4	
0.9	0.4	
1.1	0.4	Elcadore Cir. (51.2°F avg annual temp)
1.3	0.4	
1.5	0.4	
1.7	0.4	
1.9	0.4	

Figure 23. Top: Description of each modeled scenario varying the freezing N-factor is shown while holding the thawing N-factor constant. The effect of these changes on the frostline is evident in the corresponding plot to the right. **Bottom:** Description of each modeled scenario varying the thawing N-factor is shown while holding the freezing N-factor constant. *Note: The maximum horizontal distance from the footing base that could be calculated was 16 inches; values greater than 16 inches are shown as 16 inches.*

Surface Conditions

Three varying surface conditions were applied to the baseline model to evaluate the effects of these values on the thermal regime in the ground: turf (snow-covered), sand and gravel (cleared of snow), and asphalt pavement (cleared of snow). The effects are described in Figure 24.

Insulation Strategy:
R-38 Stem Wall & Ground
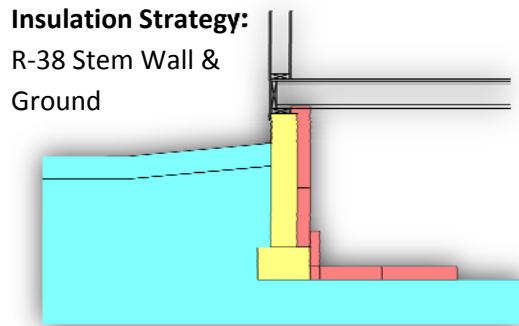
Surface Condition Evaluation			
Surface Condition	Crawlspace Data Set	Freezing N-Factor	Thawing N-Factor
Turf (with snow cover)	Greenscreek Cir. (59.5°F avg annual temp)	0.5	1
Sand and Gravel (clear of snow)		0.9	2
Asphalt Pavement (clear of snow)		0.9	1.8
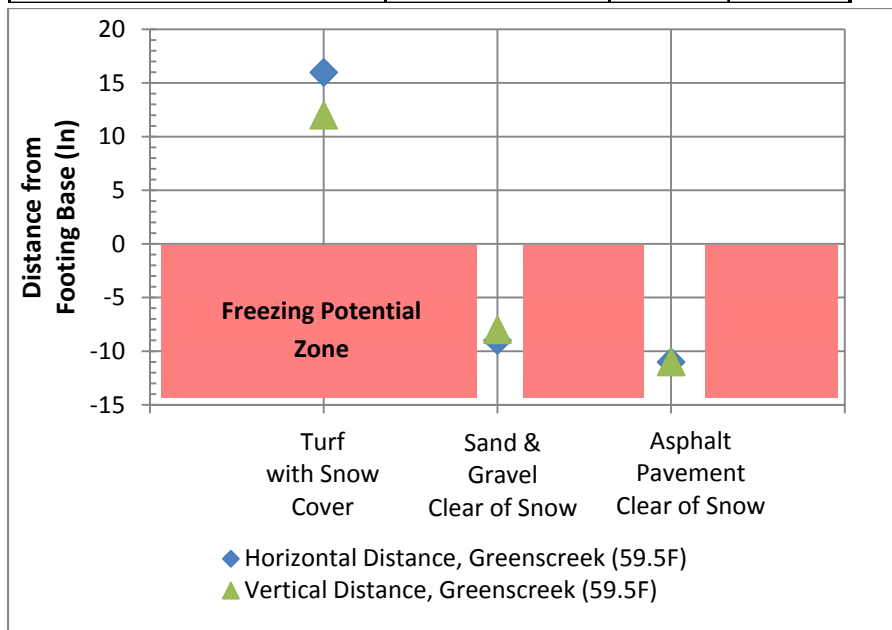
Figure 24. Top: Description of each modeled scenario varying the general ideal surface condition is shown. The effect of these changes on the frostline is evident in the corresponding plot. Bottom: Plot showing how the minimum annual horizontal and vertical distance of the frostline to the footing is based on general ideal surface conditions.

Stem Wall Insulation R-values

The stem wall insulation values varied from zero to R-50 and were applied to the baseline model to evaluate the effects on the thermal regime in the ground; these effects are described in Figure 25. The coldest measured crawlspace temperature data set (Elcadore Cir.) was applied to the model for this analysis. These models assume that no inward horizontal wing ground insulation is present.

Insulation Strategy:

Stem Wall Only
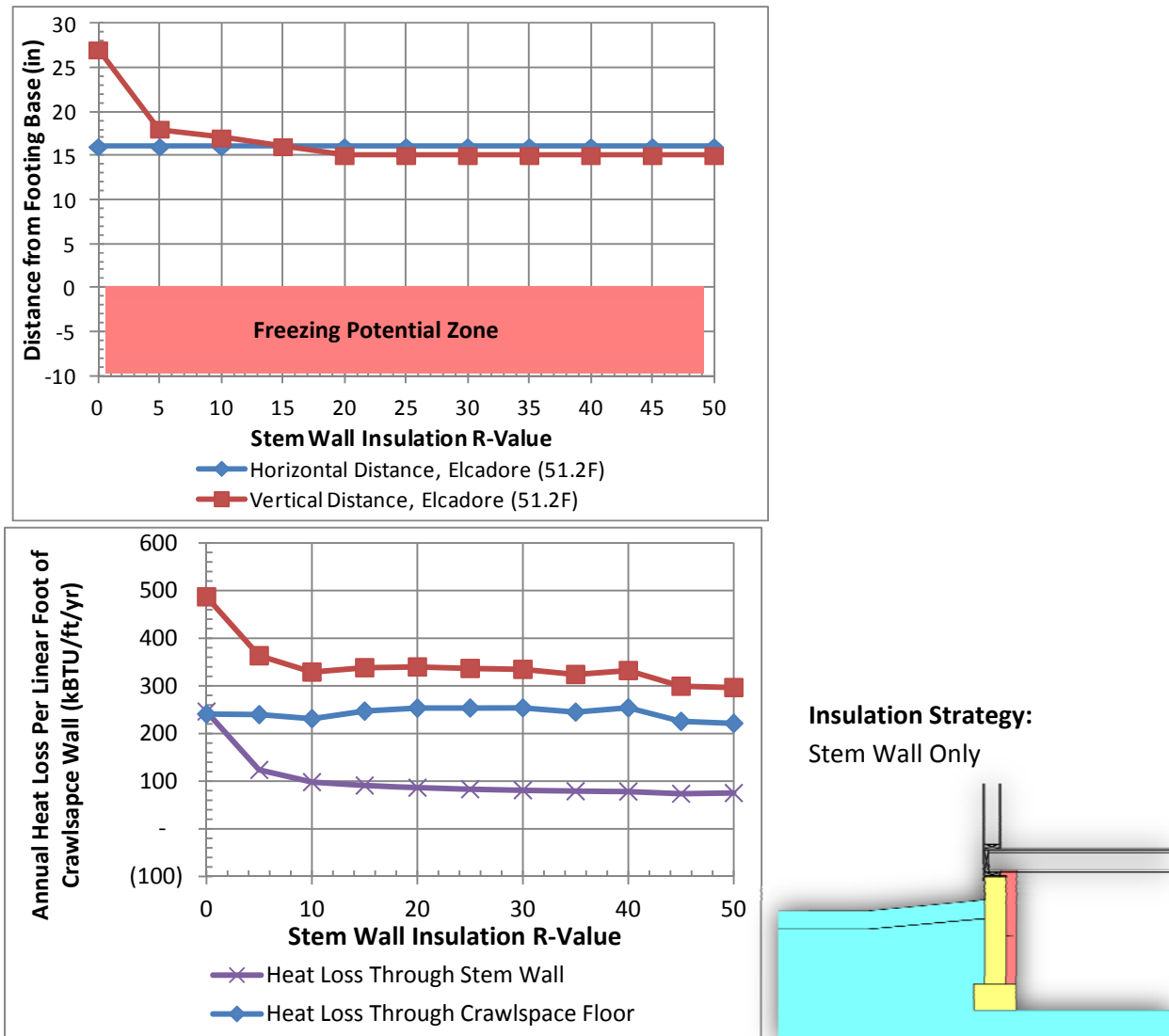
Figure 25. Top: Plot describes how the minimum annual horizontal and vertical proximity of the frostline to the footing is based on stem wall insulation R-value. *Note: The maximum horizontal distance from the footing base that could be calculated was 16 inches; values greater than 16 inches are shown as 16 inches.* **Bottom: The effect of varying stem wall insulation R-values on the annual heat loss through the foundation wall and floor per linear foot of foundation wall is described.**

Soil Moisture Content

The soil conditions were varied and applied to the baseline model to evaluate the effects on the thermal regime in the ground; these effects are described in Figure 26. Because silt and sand soils were encountered during the on-site soil analyses, only silt and sand soil conditions were varied. Additionally, the water content was varied for each soil type. The crawlspace data set for the Greenscreek Cir. (baseline condition) was evaluated. The model assumes R-19 stem wall insulation with no ground insulation.

Insulation Strategy:

Stem Wall Only
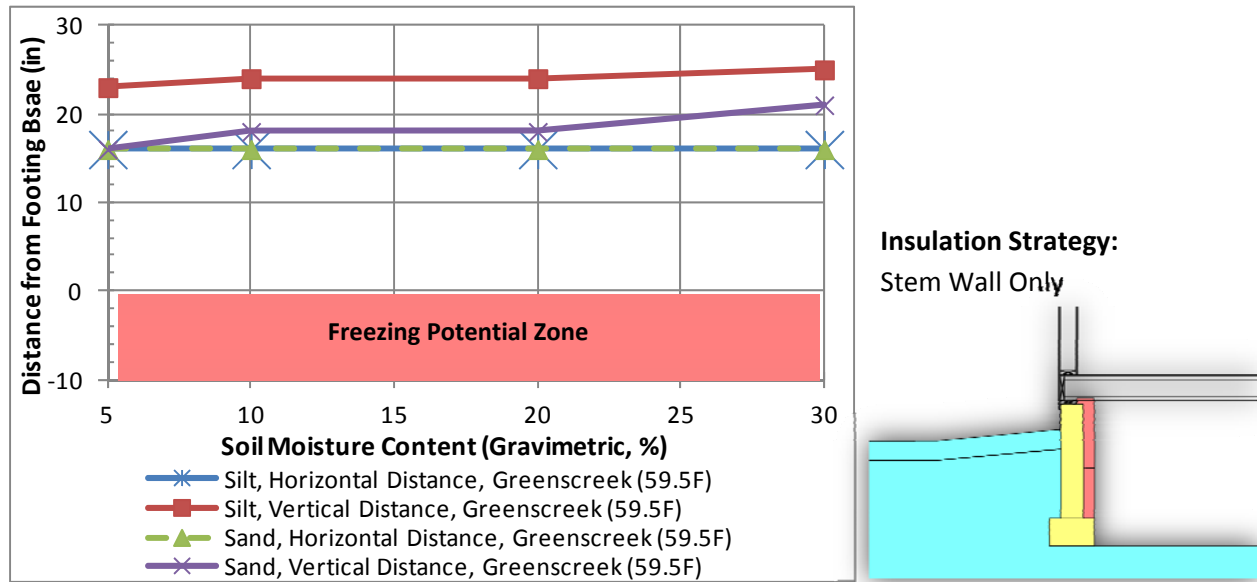
Figure 26. Plot describes the effect of sand and silt soils at varying moisture contents on the minimum annual horizontal and vertical distance of the frostline to the footing. *Note: The maximum horizontal distance from the footing base that could be calculated was 16 inches; values greater than 16 inches are shown as 16 inches.*

Outdoor Air Temperatures for Alaskan Locations

The outside climate conditions were varied according to the air freezing index (AFI) of several communities across the state. Outside annual air temperature data sets were generated for each location based on 30-year climate data for each location obtained through the Western Regional Climate Center (2013) and Equations 1 and 2. These outside air temperatures were applied to the baseline model to evaluate the effect of the climate on the thermal regime in the ground; these effects are described by Figure 27. These results are intended to investigate the relationship of outdoor air temperatures on the baseline model and do not factor in other conditions specific to some of these communities such as the presence of permafrost or other soil types.

Insulation Strategy:

R-38 Stem Wall & Ground

Location	Air Freezing Index	Crawlspace Temperature Data Set
Juneau	2,057	
Anchorage	3,427	
Talkeetna	4,322	
Bethel	5,195	Greenscreek Cir. (59.5°F avg annual temp)
Nome	5,859	
Fairbanks	7,030	
Northway	8,070	
Barrow	10,179	

Figure 27. Description of modeled outdoor air temperature conditions applied to model, in terms of 100 year AFI (base 32°F) for each location. Right: The effect of the varying outdoor air conditions on the proximity of the frostline to the foundation footing is shown using baseline conditions (Greenscreek Cir, 59.5°F average annual crawlspace temperature). *Note: The maximum horizontal distance from the footing base that could be calculated was 16 inches; values greater than 16 inches are shown as 16 inches.*

Insulation Strategy:

R-38 Stem Wall & Ground

Location	Air Freezing Index	Crawlspace Temperature Data Set
Juneau	2,057	
Anchorage	3,427	
Talkeetna	4,322	
Bethel	5,195	Elcadore Cir. (51.2°F avg annual temp)
Nome	5,859	
Fairbanks	7,030	
Northway	8,070	
Barrow	10,179	

Figure 28. Description of modeled outdoor air temperature conditions applied to model, in terms of 100-year AFI (base 32°F) for each location. Right: The effect of the varying outdoor air conditions on the proximity of the frostline to the foundation footing is shown using the coldest measured crawlspace temperature profile (Elcadore Cir., 51.2°F average annual crawlspace temperature). *Note: The maximum horizontal distance from the footing base that could be calculated was 16 inches; values greater than 16 inches are shown as 16 inches.*

Stem Wall and Ground Insulation R-values with Exterior Foam Wing

The baseline model was modified to include the equivalent of 4 inches of rigid foam (R-20) installed 6 inches down the stem wall, and horizontally outward for approximately 42 inches, approximately 6 inches below the ground surface. A diagram of this modified model is shown in Figure 29.
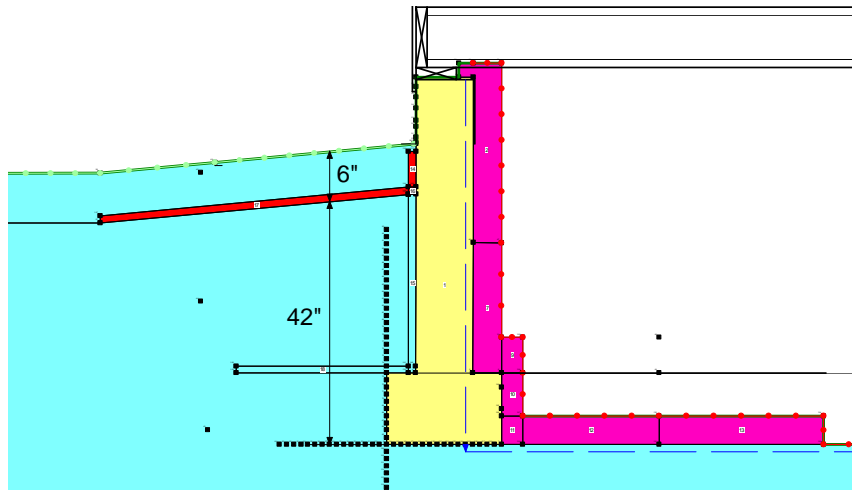
Figure 29. Modified baseline model to show a subsurface exterior insulation wing to mitigate frostline penetration.

Using this modified baseline, the stem wall and ground insulation values varied from zero to R-50 and were applied to evaluate the effects of these values on the thermal regime in the ground; these effects are described in Figure 30. To add an additional level of conservativism to this experimental technique, the coldest measured crawlspace temperature data set (Elcadore Cir.) was applied to the model for this analysis. These models assume that the stem wall and ground insulation maintain the same R-value. Notably, when the same model used R-10 rigid insulation for the shallow exterior wing, the same effect was not observed; while the wing delayed the frost penetration toward the foundation, the proximity to the foundation footing was approximately the same as it would have been without the exterior wing.
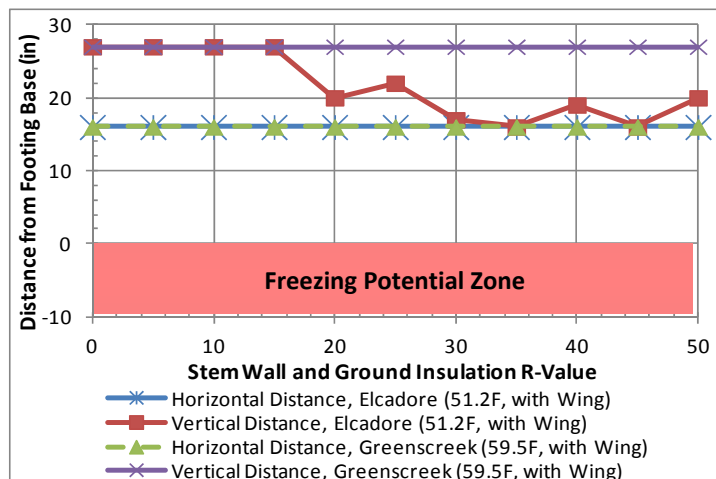
Figure 30. Plot describes how the minimum annual horizontal and vertical distance of the frostline to the footing is based on stem wall and ground insulation R-value. The model assumes an R-20 exterior wing buried 6 inches beneath the surface. *The maximum horizontal distance from the footing base that could be calculated was 16 i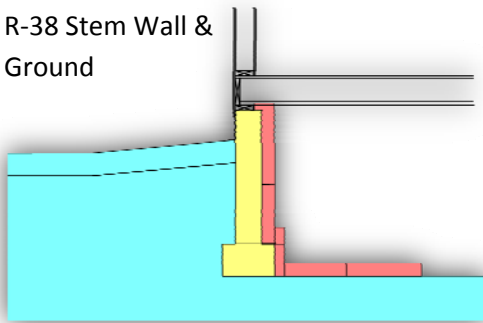nches; values greater than 16 inches are shown as 16 inches. The maximum vertical distance from the footing base that could be calculated was 28 inches; values greater than 28 inches are shown as 28 inches.*

Discussion

While much of the thermal modeling analysis investigates the relevance of variables on the baseline model, the main focus of this study is to evaluate whether the frostline can reach the depth of the footing bearing surface when R-38 insulation is installed from the rim joist down the foundation wall and four feet horizontally inward along the crawlspace floor. The thermal modeling performed for this study was the key determinant of whether the frostline would penetrate the foundation footing. A key parameter that has changed between the initial efforts detailed in the interim report (Grunau, 2011) and the efforts detailed in this report is the crawlspace air temperature; the change in this boundary condition is a significant aspect of the refined modeling work. The models were calibrated and validated based on crawlspace, foundation soil, and air temperature data measured in the Anchorage area. The baseline model created from this information is intended to represent a probable foundation scenario found in the Anchorage area under typical snow conditions and serves as a basis for comparing the effects of insulation strategies and temperature conditions on the frostline penetration toward the foundation footing.

Rim Joist Moisture

While this study does not specifically analyze the thermodynamics of insulating a rim joist, the author would like to emphasize the ramifications of installing unsealed fiberglass batting insulation against the rim joist of the foundation. Moisture from the crawlspace can build up in the fiberglass batting where the dew point occurs. The moisture that accumulates could migrate to the wood rim joists and cause moisture damage on the wood. If fiberglass batting is used at the rim joist, steps must be taken to ensure that no air can penetrate the fiberglass, either by using rigid insulation with sealed edges or by spraying a coat of polyurethane foam over the fiberglass batting in the rim joist area.

Heat Loss at Corners

The thermal modeling analysis is limited to 2-dimensional heat flow through the building envelope; consequently heat loss at foundation corners has not been modeled since it would require a three-dimensional analysis. The 2-dimensional analysis investigates heat flow in the vertical and horizontal axes of the model shown in Figure 2; the heat flow in the third dimension (i.e. the axis that is orthogonal to the vertical-horizontal plane) cannot be evaluated. Hong and Jiang (1981) studied the effect of heat loss through foundation slabs on frostline depth beneath foundations of buildings. Their findings describe the effect of foundation corner heat loss on the frostline depth by two methods. First, Figure 31 shows the measured frostline depth along a wall. Considering the frost depths on the north side only (to avoid the effect of solar heat gain), the maximum frost depth at the corners averaged 177.5 cm and the average minimum near the center of the north wall is 148.8 cm. The 177.5 cm: 148.8 cm frost depth ratio equates to approximately 1.19.
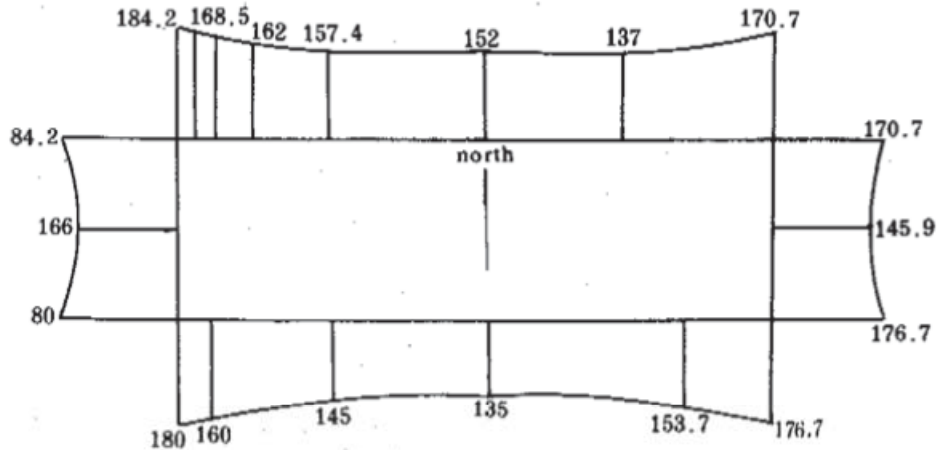
Figure 31. Maximum frostline depth in cm for a test house (Hong and Jiang, 1981) Leftward frost depths shown to the far left edge are presumably an error (sic). The frost depths are at the very edge of the foundation.

The second method introduces a coefficient of heating on frostline depth, M_t:

$$M_t = \frac{H_h}{H_n}$$

(9)

where H_h is the measured frostline depth at the outside of the exterior foundation wall of a building and H_n is the frostline depth of soils nearby the building in natural conditions with a bare surface (no snow or vegetation).

Accordingly, Hong and Jiang (1981) suggest M_t values of 0.84 at the corner and 0.64 mid-wall. The ratio of these values (0.84:0.64) is equal to 1.35. Based on the two methods presented by these researchers, frostline depths at corners are 19% to 35% deeper at foundation corners. The average of these two values is 27%. The foundations studied by Hong and Jiang (1981) involved subterranean footings with outside ground and interior floor approximately on the same plane; heat loss to the ground is transferred through the floor and foundation and subsequently to soils exterior to the foundation. Due to the differences in heat loss, the author of this report assumes that the 27% increased frostline depth at corners is a conservative estimate and the actual frostline depth may be less than 27%, but this number has not been quantified. For the purposes of this paper, however, the evaluation of modeling scenarios of frostlines at foundation corners assume an additional 27% greater frostline depth than indicated by the modeling.

Synopsis of Findings

Ground Insulation

As described in Figure 21, the addition of any amount of ground insulation causes the frostline depth to be closer to the foundation footing of the baseline model. However, for Anchorage conditions with turf ground conditions and average yearly crawlspaces at least as warm as the Elcadore Cir. profile (51.2°F), no amount of modeled stem wall and ground insulation caused the frostline to penetrate to the footing depth. The modeled stem wall and ground insulation ranged from zero to R-50. As shown in Figure 21, the frostline penetrated to within 4 inches of the foundation footing at R-40 insulation and with the colder crawlspace condition (Elcadore Cir., average 51.2°F). However, with the average

crawlspace condition (Greenscreek Cir., average 59.5°F), the frostline only penetrated to within 10 inches of the foundation footing with R-40 insulation. When considering the effect of heat loss at the corners, however, the difference of 10 inches and 4 inches may be the difference between freezing and not freezing the footing. If the 27% rule were applied to the model with Greenscreek Cir. Crawlspace conditions, then the resulting frostline depth is 40 inches—almost the depth of the footing (42 inches). However, if the 27% rule were applied to the Elcadore Cir. crawlspace condition case, then the frostline would be 7 inches below the footing.

The primary lesson is that, for a typical Anchorage area home site, an R-38 stem wall and ground insulation (up to 4 feet in from the stem wall) appears unlikely to cause the frostline to reach the footing as long as the crawlspace maintains an annual average temperature of 59.5°F. Adding R-38 stem wall and ground insulation to typical Anchorage home sites where snow is present on the ground surface near the foundation appears to be just within the range where the frostline does not reach footing depth.

Additionally, as the frostline depth increases at colder locations (as shown in Figure 27 and Figure 28), this strategy is very likely to enable footing freezing in places like Fairbanks. When the Greenscreek Cir. (average 59.5°F) was applied to the model for various locations across the state (based on the air freezing index of each area), the foundation footing froze when the air freezing index (AFI) was greater than 6,000. However, when the 27% corner effect is considered, the footing froze when the AFI was about 4,200. The effect of the colder crawlspace temperature is seen in Figure 28 because when the 27% corner effect is considered, the footing freezes when the AFI is only 3,100. This fact emphasizes the importance of maintaining warm crawlspace temperatures (discussed in further detail later).

One such strategy to overcome problematic situations that may cause freezing (such as areas with no snow due to roof overhangs, parking areas, etc) when the R-38 stem wall and ground strategy is employed in the foundation would be to remove the ground insulation for the portion of the foundation where the ground is clear of snow. For instance, if a deck is present for only 40% the length of the foundation wall, then the interior ground insulation could be removed for the corresponding length of the foundation wall in the crawlspace. Figure 25 supports this assertion as it describes the effect of various amounts of stem wall insulation (with no ground insulation). The dominant heat flow from the crawlspace passes through the foundation footing, thereby impeding the frostline near the footing, as described in Figure 32.
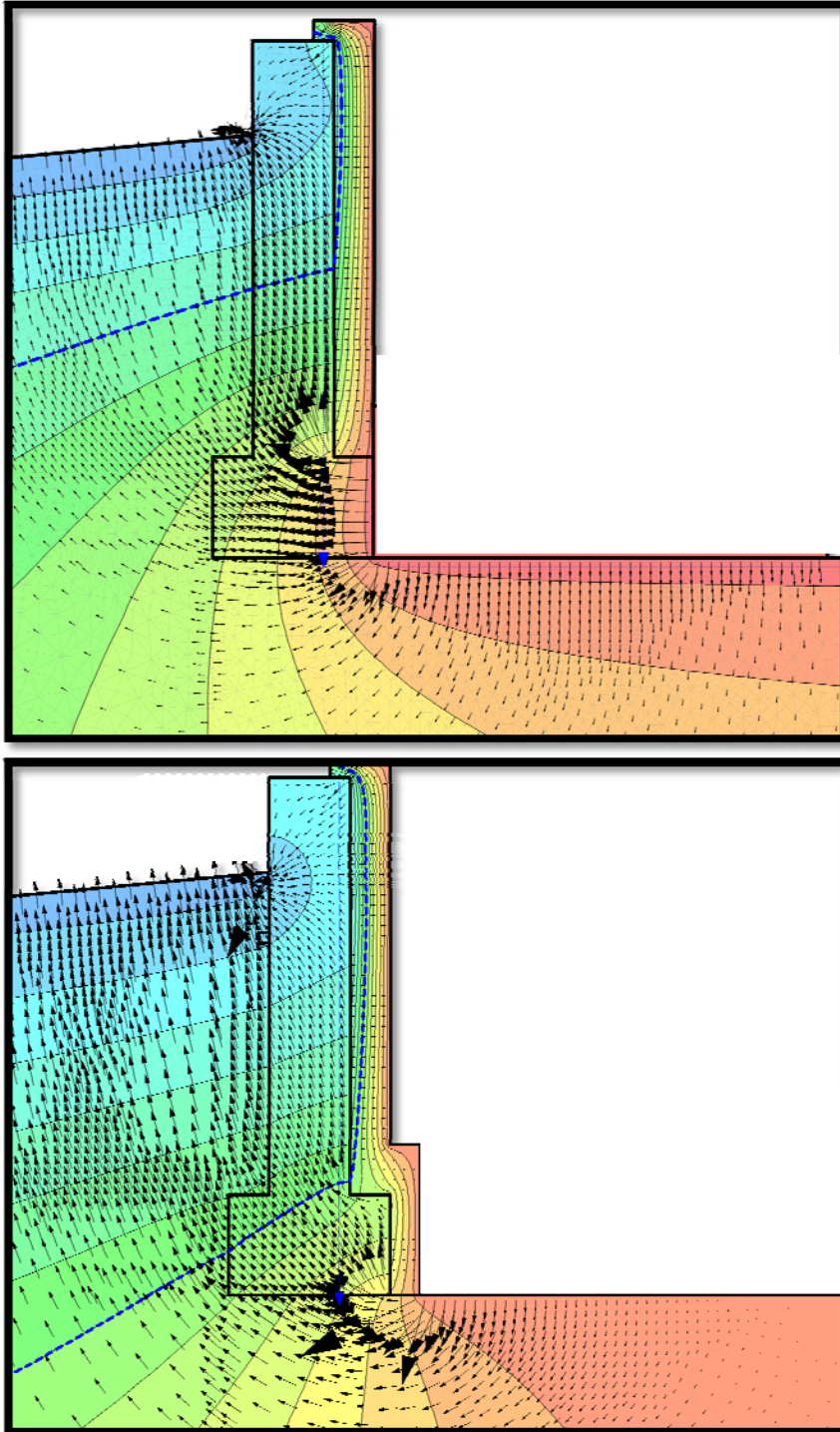
Figure 32. Heat flow through foundation footing when stem wall insulation strategy is employed. The black vectors denote the magnitude and direction of heat flow. Top figure shows the heat flow when the footing base is completely exposed. The bottom figure shows the heat flow when the footing base is covered with insulation.

When stem wall insulation was varied from zero to R-50, the frostline did not come within 14 inches of the footing, as described in Figure 25. While the model in this figure assumes that snow is present during the winter, subsequent modeling of surface conditions without snow did not freeze the

footing base. For Anchorage conditions with no snow at the ground surface, removing the ground insulation and exposing the footing will ensure protection against freezing the footing.

Crawlspace temperatures

The crawlspace temperature has a direct effect on the proximity of the frostline to the foundation footing as shown in Figure 22. The footing base remained above freezing when the annual crawlspace temperature average was at least 50°F. Variations of crawlspace temperatures to the baseline model (which incorporates R-38 insulation on the stem wall and ground) reveals a freezing potential at the foundation footing when the average annual crawlspace temperature was somewhere between 45°F and 50°F. Interpolating between data points suggests that the footing freezes at approximately 47°F. When the additional heat loss at foundation corners is considered, the footing remains above freezing when the average annual crawlspace temperature is at least 57.1°F.

Notably, additional analysis revealed that when the same crawlspace variation was applied to the model using R-19 stem wall insulation with no ground insulation, the footing base remained above freezing when the average crawlspace temperature was at least 40°F. When the heat loss at the foundation corners is considered, the footing remains above freezing when the average annual crawlspace temperature is at least 43.5°F.

During the initial study (Grunau, 2011), the assumed annual crawlspace temperature was 38°F, which was far too conservative based on the results of the crawlspace survey. According to the analysis and the data shown in Figure 22, when the lowest measured crawlspace temperature data set (Elcadore Cir., average 52.2°F) is applied to the model, the foundation does not risk freezing unless the 27% corner effect is considered. However, when the average measured crawlspace temperature data set (Greenscreek Cir., average 59.5°F) is applied to the model, the foundation does not risk freezing, even when the 27% corner effect is considered.

The crawlspace temperature has a direct, almost linear, effect on heat loss through the crawlspace, as indicated in Figure 22. For instance, the baseline model with a 65°F crawlspace (annual average) loses 155,000 BTU/linear foot of foundation wall per year more heat than one with 52.2°F crawlspace (annual average). In practical terms, that amount of heat lost to a house with a 30'x30' footprint (120 linear feet of stem wall) would equate to approximately 18,600 cubic feet of natural gas per year (assuming 1,001 BTU/cubic foot of natural gas).

Additionally, in every scenario modeled, the freezing front penetrates the concrete stem wall to the interior insulation along the stem wall. When the freezing front penetrates the interior insulation during the winter, 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 indoor air quality or structural issues.

Ground Surface Conditions

The simulated ground surface conditions were varied to understand how the ground conditions affected the frostline depth. Changing ground surface conditions near the foundation (discussed later), such as removing snow from the general surrounding area (due to large roof overhangs, snow removal in parking areas, or raised decks that prevent the accumulation of snow beneath the structure) is enough of a change whereby a crawlspace with R-38 stem wall and ground insulation would enable

freezing of the footing. This assertion is supported by Figure 24, which describes the effects of surface conditions on the frostline. The snow provides an insulating layer that mitigates the frostline depth and the lack of snow causes deeper penetration of the frostline toward the foundation footing.

The N-factors used in this modeling conceptually represent the complex energy balance at the surface as a single dimensionless number; the thawing and freezing N-factors are generally paired to describe a particular ground condition. The variation of the thawing N-factor in Figure 23 simulates changes in surface conditions that change the magnitude of ground warming attributable to climate conditions. The change in the thawing N-factor had little effect on the frostline depth. However, by varying the freezing N-factor, also shown in Figure 23, from 0.3 to 1.0, the range of conditions from standard snow cover to little or no snow cover, respectively, was represented. The proximity of the frostline to the foundation footing has an almost linear relation to the freezing N-factor and suggests that the presence of (and possibly the amount of) snow mitigates the frostline depth toward the footing.

When N-factors represented common scenarios, the effect of the ground conditions on the frostline depth is evident. The three ground surface conditions modeled, as described by Figure 24, included: turf with normal snow cover, sand and gravel cleared of winter snow, and asphalt pavement cleared of snow. The latter two scenarios are representations of typical gravel or paved parking lots that are cleared of snow during the winter. When the crawlspace temperature was average (as represented by Greenscreek Cir.), the frostline reached the footing in both cases where the ground was cleared of snow in the winter. The presence of snow clearly acts as an insulating blanket on the ground when the air temperatures drop significantly below freezing.

The significance of these findings is that this could occur at a house that has a driveway adjacent to the foundation, large overhanging eaves, or a raised deck. As previously discussed, minimizing or completely removing insulation from the foundation stem wall in areas close to driveways may inhibit frostline penetration. One example of this strategy at the Edwards St. site instituted a 1-inch-thick rigid polyisocyanurate board (maximum approximate insulation value of R-6.5) extending from the top of the stem wall down 2 feet. The temperature probe assembly for the Edwards St. site was located 25 inches from the house, but was within approximately 7 feet of a 2-car parking area that is regularly cleared of snow. As evidenced in Figure 19, the measured ground temperature did not experience freezing at footing depth. Despite the proximity of the cleared snow area, the low insulation values on the walls may adequately prevent frostline footing penetration. When this situation was modeled and the snow-free ground surface condition was analyzed, the foundation footing did not freeze. An additional option could involve installing an exterior rigid insulation wing (discussed below).

Soil Conditions

The effect of varying moisture contents of sand and silt had little effect on the frostline depth of the baseline model, as evident in Figure 26. Prior research (Grunau, 2011) indicates that frostline penetration is deepest in sandy soils, as compared to silt, clay, or peat soils. Since the baseline model assumes 81% gravel/sand and 19% silt, the model is somewhat conservative. Situations that involve a higher gravel/sand to silt ratio are likely to experience deeper frostline penetration. In these situations, conservative approaches such as removing ground insulation or installing an exterior insulation wing (discussed below) will impede freezing of the footing.

Exterior Wing Retrofit Option

A simulated 42-inch long, 4-inch thick XPS foam board (R-20) was installed approximately 6 inches below the ground surface and applied to the baseline model as described by Figure 29. When the stem wall and ground insulation values were varied, the result was a slightly larger thaw bulb area beneath the foundation. Figure 30 describes the effect of the exterior wing on the frostline depth. When the Greenscreek Cir. Crawlspace conditions were applied to the model, the frostline depth came no closer than 27 inches (vertically) of the footing base. When the Elcadore Cir. crawlspace conditions were applied to the model with R-40 down the stem wall and ground, the frostline came within approximately 19 inches of the footing. When compared to Figure 21, the addition of the R-20 foam caused the frostline to be raised approximately 15 inches.

When the 27% rule is applied to the corner scenario using this exterior wing insulation strategy, the frostline depth remains approximately 12 inches above the footing base. These data demonstrate that the exterior wing retrofit strategy is a potential solution for Anchorage area homeowners who would like to implement the R-38 stem wall and ground insulation strategy described in Figure 1, yet who may have a driveway area (or other area cleared of snow during the winter) adjacent to their crawlspace.

Due to the eventual absorption of water by the rigid foam, some subsurface insulation does not have the same thermal performance as the same piece installed in a dry, above ground installation. For instance, 4 inches of EPS foam may have a nominal rating of R-16, but an actual performance of about R-10. The modeling assumes an actual insulating value of R-20, if this exterior wing strategy were employed, steps should be taken to ensure the overall insulating performance is equal to at least R-20.

Comparison of Findings to Other Studies

Fidley and Snodgrass (1984) suggest that, in shallow basement constructions where the top of footing is less than 6 feet from the surface, very high levels of wall and floor insulation can result in potentially harmful frost penetration to footing depths. Fidley and Snodgrass (1984) considered entire floor insulation, while this Anchorage Foundation Insulation Study only considers ground insulation for 4 feet inward from the stem wall. The findings of Fidley and Snodgrass (1984) parallel the findings in Figure 21, clearly showing a correlation of increased insulation values to an increased frostline depth.

Figley and Snodgrass (1984) also suggest that an uninsulated concrete floor slab would likely be sufficient to prevent frost penetration to the footing depth. This point is also supported by Figure 25 which varies stem wall insulation values without ground insulation; in no case did the frostline depth come within 15 inches of the footing.

The measured mean crawlspace temperatures of the sites ranged from 52.5°F to 71.2°F. These temperatures are much greater than crawlspace temperature estimates found in literature. Lstiburek (2010) suggests that a reasonable estimate for crawlspace ground surface temperatures is to use the average annual ambient air temperature for that location. The yearly average annual ambient air temperature for Anchorage is 36.5°F, which was used in the preliminary model scenarios from Grunau (2011).

An additional relevant finding in the Fidley and Snodgrass 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. The Anchorage Foundation Insulation Study

Interim Report (Grunau, 2011) supports these findings and recognizes that sandy soils with little water content tended to encourage greater frostline depth over other soil types. The soil types and conditions modeled for this current study were based on the geotechnical analysis of soils; however, their properties were based on the assertion that 81% of the soil was sandy soil with fairly low moisture content. This assumption provides a level of conservatism when estimating frostline depth when other soil types are encountered.

Implications of Findings

This study was initiated because energy raters were using the AKWarm energy-rating software to suggest the use of R-38 insulation on the stem wall and ground insulation (described in Figure 1) to minimize heat loss to the ground. Several homebuilders raised concerns over this practice due to the possibility of freezing the foundation.

Findings from this study suggest that this insulation strategy can be employed safely in Anchorage conditions with annual average crawlspace temperatures at least 57.1°F and typical snow-covered turf conditions. However, for areas with little or no snow cover against the foundation stem wall, two options will mitigate freezing the footing: (1) removing the ground insulation in the crawlspace along the portion of the stem wall that has no snow cover on the exterior and (2) employing the exterior shallow subsurface rigid foam horizontal wing technique described earlier. Additionally, this study suggests that the R-38 stem wall and ground insulation strategy should not be employed in areas colder than Southcentral Alaska.

Since the source of this insulation strategy seems to be the energy rating program, AKWarm, perhaps restricting or removing this crawlspace insulation option based on location (or other factors like the presence of decks, driveways, etc.) from AKWarm may warrant consideration. Perhaps a footnote within AKWarm offering this suggestion may prompt the homeowner or rater to scrutinize whether to employ the insulation strategy under investigation. When special situations are encountered in Southcentral homes such as adjacent areas with snow removal during the winter, the strategy involving the placement of 4-inch XPS foam (R-20) exterior wing described in Figure 29 offers a solution to those who wish to receive credit for the increased crawlspace insulation values yet who also want to ensure frost protection for their foundations. This strategy could also be offered as an informative footnote within AKWarm.

These findings also bring awareness to homebuilders, homeowners, energy auditors, and other members of the building community about effect of crawlspace insulation strategies in the Southcentral area as well as in other parts of Alaska. These findings contribute to Alaska's body of knowledge on best practices for crawlspace insulation strategies that could be applied in other parts of the state.

Further Research

Findings in this study have generated discussions across Alaska regarding best crawlspace insulation practices for the entire state. The results of this work can 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. However, the building community would benefit from additional research that investigates this topic. For instance, in Fairbanks, a common practice that involves R-38 down the stem wall and on the ground exposes a portion of the foundation footing to the crawlspace in

an effort to prevent frostline penetration to the footing surface. Initial modeling efforts based on the model generated from this study do not support this concept; however, significantly more analysis is needed before any conclusive statements can be made about the practice.

Further research investigating the hygrothermal aspects of the R-38 crawlspace insulation strategy may answer important questions regarding the movement of moisture through the rim joist, stem wall, and ground.

Additionally, other foundation types with similar concerns of balancing energy conservation and frost protection need to be investigated. For instance, in an effort to minimize heat losses through poured foundation slabs, several builders have been adding insulation directly beneath the thickened edge footing of a shallow frost protected foundation, a strategy that has not been thoroughly vetted. Direct heat loss from the slab through the foundation footing is generally the path from which heat flows into the soil, keeping the frostline penetration away from the footing bearing surface. Efforts to save energy by adding insulation at the bearing surface removes the heat flow mechanism and may cause frostline to reach the footing, causing structural issues. Additional research on this topic, specifically in the Fairbanks area, would be valuable to the building community statewide.

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Appendix A

Geotechnical Site Analysis - Summary of Boring Logs

MATERIAL DESCRIPTION	Depth, Ft.	Symbol	Samples	Ground Water	Depth, Ft.	Penetration Resistance (140 lb. weight, 30" drop) ▲ Blows per foot ● Water Content (%)
Approx. Elevation:						0 25 50 75 100
Organic Mat (leaves, roots, and topsoil)						
Loose, brown, silty SAND; moist; occasional roots	0.5		S1			
Stiff, brown, sandy SILT; moist; occasional roots	2.0					
S2: Blow counts may be biased high due to hammer malfunction 80.0% Fines (F4)			S2			
Loose to medium dense, brown, silty SAND; moist	5.0				5	
S3: Blow counts may be biased high due to hammer malfunction 0% Gravel, 57% Sand, 43% Fines (F4)			S3			
			S4			
	9.5					
Bottom of Boring Boring Completed November, 17, 2011					10	

Groundwater not encountered during drilling on November 17, 2011

LEGEND

- . Sample Not Recovered
- 米 Grab Sample
- ⊥ 2" O.D. Split Spoon Sample
- ▮ Frozen

▨ Blank Section, Cuttings Backfill
▭ Blank Section, Sand Backfill

Water Content (%)
Plastic Limit ├───●───┤ Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.

Foundation Temperature Monitoring
Anchorage, Alaska

LOG OF BORING B-1
Imlach Drive

December 2011   32-1-02212

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Geotechnical and Environmental Consultants   **FIG. 5**

LOG OF BORING B-2
Sue Street

MATERIAL DESCRIPTION

Approx. Elevation:

Depth, Ft.	Symbol	Samples

Organic Mat (grass and topsoil) — 0.3

Frozen to medium dense to dense, brown, slightly silty to silty, sandy GRAVEL; moist

S1: 41% Gravel, 41% Sand, 19% Fines (F2) — S1

S2

Fines content decreases between approximately 4 to 8 feet bgs — S3

S4a: 26.1% Fines (F4) — S4a

Medium dense, brown SAND; moist — 9.5 — S4b — 10.0

Bottom of Boring
Boring Completed November, 17, 2011

Penetration Resistance
(140 lb. weight, 30" drop)
▲ Blows per foot
● Water Content (%)

Ground Water Depth, Ft.

Groundwater not encountered during drilling on November 17, 2011

LEGEND

* Sample Not Recovered
⚏ Grab Sample
⊥ 2" O.D. Split Spoon Sample
▮ Frozen

▨ Blank Section, Cuttings Backfill
▦ Blank Section, Sand Backfill

● Water Content (%)
Plastic Limit |———●———| Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.

Foundation Temperature Monitoring
Anchorage, Alaska

LOG OF BORING B-3
Edward Street

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FIG. 7

MATERIAL DESCRIPTION	Depth, Ft.	Symbol	Samples	Ground Water Depth, Ft.	Penetration Resistance (140 lb. weight, 30" drop) ▲ Blows per foot ● Water Content (%)
Approx. Elevation:					0 25 50 75 100
Organic Mat (roots, leaves, and topsoil)	0.3				
Frozen to loose to dense, brown, slightly silty to silty, gravelly SAND; moist [FILL] Fines content decreases with depth			S1		
S1: 14.2% Fines (F2)					
			S2		
				5	
S3: 37% Gravel, 58% Sand, 5% Fines (NFS)			S3		
			S4a		
Hard, gray-brown, sandy SILT; moist	9.0		S4b		
	9.5				
Bottom of Boring Boring Completed November, 17, 2011				10	

Groundwater not encountered during drilling on November, 17, 2011

LEGEND

*	Sample Not Recovered
	Grab Sample
	2" O.D. Split Spoon Sample
▮	Frozen

Blank Section, Cuttings Backfill
Blank Section, Sand Backfill

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of subsurface materials.
3. Water level, if indicated above, is for the date specified and may vary.

0   25   50   75   100

● Water Content (%)

Plastic Limit ├──●──┤ Liquid Limit
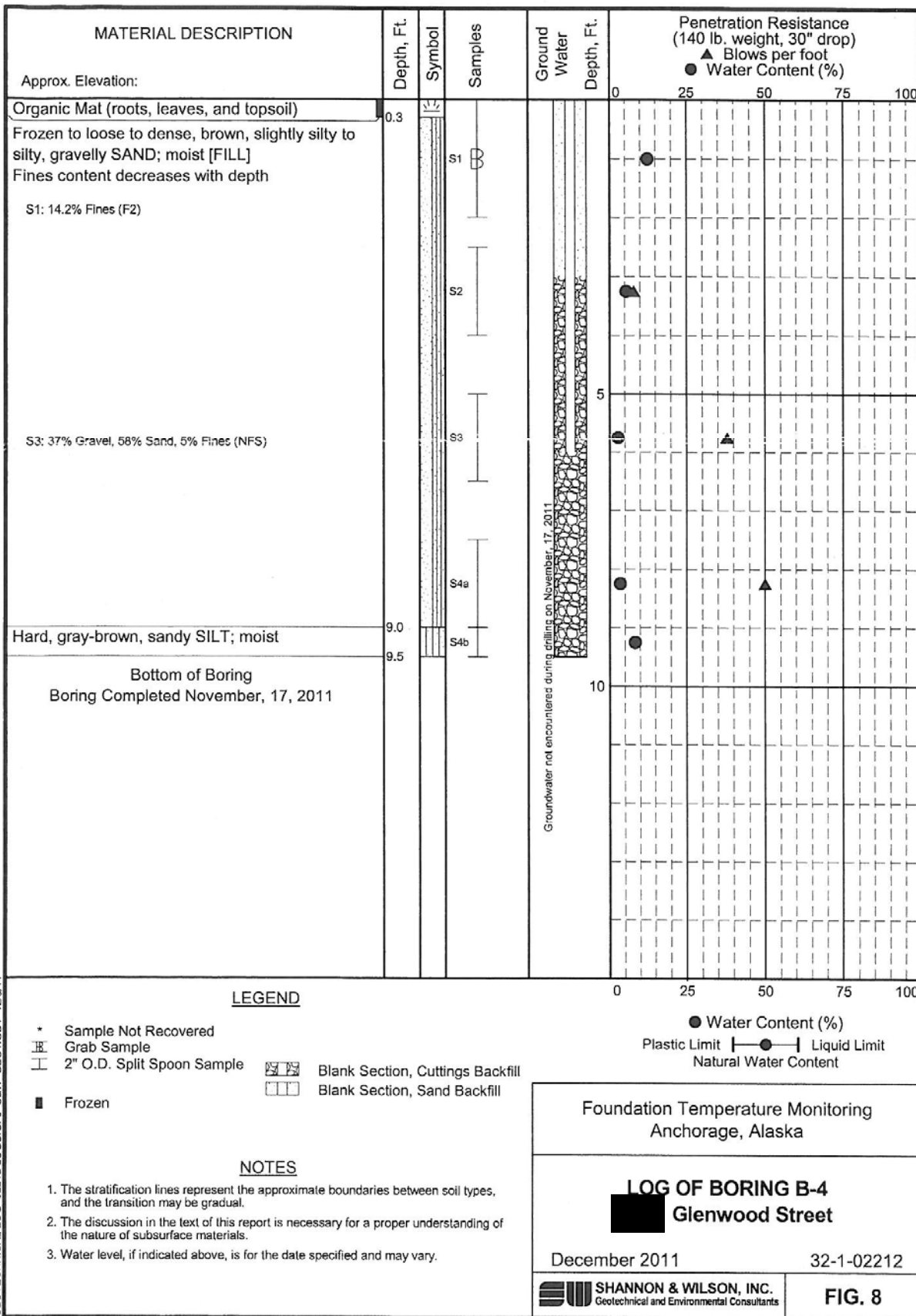Natural Water Content

Foundation Temperature Monitoring
Anchorage, Alaska

LOG OF BORING B-4
Glenwood Street

December 2011   32-1-02212

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FIG. 8

GEOTECHNICAL LOG 02212 LOGS.GPJ S&W GEO1.GDT 12/5/11

GRAIN SIZE IN MILLIMETERS

PERCENT FINER BY WEIGHT

U.S. SIEVE OPENING IN INCHES

U.S. SIEVE NUMBERS

HYDROMETER

COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Sample		Depth, Ft	Classification
●	B-1 S3	5.0 - 6.5	Silty SAND [SM]
■	B-2 S2	3.0 - 4.5	Silty, gravelly SAND [SM]
▲	B-3 S1	0.0 - 1.5	Silty, sandy GRAVEL [GM]

Sample		Depth, Ft	D100	D60	D30	D10	%Gravel	%Sand	LL	PL	PI	Cc	Cu
●	B-1 S3	5.0 - 6.5	4.75	0.13			0	57			43		
■	B-2 S2	3.0 - 4.5	19	0.82	0.21		23	63			13		
▲	B-3 S1	0.0 - 1.5	50	5.05	0.21		41	41			19		

(%Silt and %Clay columns shown in header)
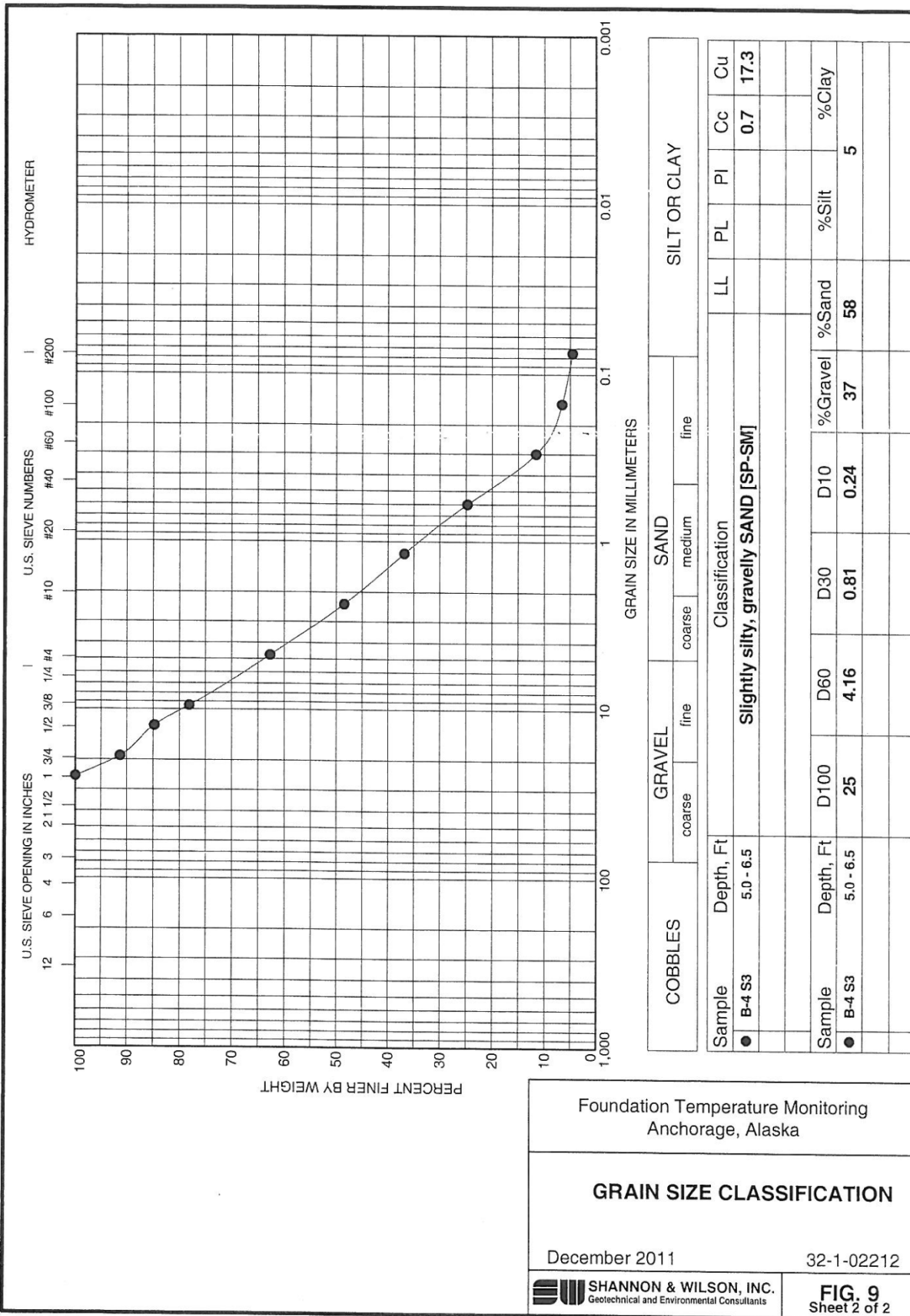
Foundation Temperature Monitoring
Anchorage, Alaska

GRAIN SIZE CLASSIFICATION

December 2011

32-1-02212

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FIG. 9
Sheet 1 of 2

GRAIN SIZE CLASSIFICATION

Foundation Temperature Monitoring
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FIG. 9
Sheet 2 of 2