FROST PROTECTED SHALLOW FOUNDATIONS (FPSF) FOR INTERIOR ALASKA FREEZING INDICES BETWEEN 4,000 AND 8,000 DEGREE-FAHRENHEIT-DAYS A RESEARCH REPORT

Prepared by

Paul V. Perreault, M.S.C.E., P.E.
Ph.D. Candidate, Arctic Engineering
695 Fairbanks Street
Fairbanks, AK 99709
Ph: 907-479-2012, Fax: 907-479-7381
engineer@cbna.org (best contact)

Prepared for

COLD CLIMATE HOUSING RESEARCH CENTER
1000 Fairbanks Street
P.O. Box 82489
Fairbanks, AK 99708
Ph: 907-457-3454, Fax: 907-457-3456

June 15, 2008

Funded by

Cold Climate Housing Research Center (CCHRC)
Experimental Program to Stimulate Competition in Research (EPSCoR)
Permafrost Technology Foundation (PTF)

EXECUTIVE SUMMARY

The goal of this research is to test the hypothesis: "Where no permafrost exists below a building, there is a simple relationship between (a) varying amounts of Arctic winter cold weather and (b) the amount of building heat containment (foundation insulation) needed to protect shallow foundations from seasonal frost heave."

Provided, here, are suggested methods for using a frost protected shallow foundation (FPSF) beyond the current design limits of a 4,500°F-Day air freezing index, up to an 8,000°F-Day limit. Compared with a conventional footing extended into the ground below the seasonal frost line, a FPSF foundation costs less, is more environmentally friendly, and uses less material. A FPSF is easily accessible at ground level.

Six field sites were instrumented with five thermistor strings at each site. The thermistors are arranged to measure ground temperature near the foundation zone, both along long walls and at corners. Data, collected since 2004, has been correlated with both numerical analysis and with finite element modeling. Sample results are presented.

Specifically discussed are: (a) increased corner zone frost depth, (b) increased frost depth near building thermal envelope penetrations, (c) vertical freezing isotherm shape, and (d) possible reverse curvature isotherm shapes that may represent increased frost heaving risks from soils at depth.

Concluding the report is a suggested design method and example design calculations.

This report is intended for the general public, builders, and the engineering design community. Usability and readability intentionally took precedence over scientific rigor.

For widest public access, this document is free of charge and may be accessed directly from the Cold Climate Housing Research Center's website.

Equipment and services for this ongoing research has equipment and services funded from Cold Climate Housing Research Center (CCHRC), from Experimental Program to Stimulate Competition in Research (EPSCoR), and from Permafrost Technology Foundation (PTF).

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION and BACKGROUND

Why Is This Research Important? (What is the research goal?)
The goal of this research is to test the following hypothesis: "Where no permafrost exists below a building, there is a simple relationship between (a) varying amounts of Arctic winter cold weather and (b) the amount of building heat containment required to protect shallow foundations from seasonal frost heave."

What Is A Frost Protected Shallow Foundation (FPSF)?
A heat-contained foundation system that is designed to protect a building from seasonal frost heave is called a frost protected shallow foundation (FPSF). A FPSF typically penetrates less than two feet into the ground – well above the seasonal frost depth for most of interior Alaska. A FPSF entraps building heat within the soils below the foundation system. This trapped-heat restricts seasonally frozen soils to regions outside of and away from the foundation zone. The soils below the footings and foundation zone remain thawed. Thawed soils remove the risk of seasonal frost heave.

What New Knowledge Does This Research Provide? (What is the intellectual merit?)
This research serves to extend knowledgeable use of a FPSF system into colder northern Alaska regions. This research expands the understanding of the thermal regimes in foundation zones below heated buildings.

This research builds upon and does not repeat the building codes, design guides, and seasonally frozen soils information already well documented in publications like:
(1) The International Code Council 2006 International Residential Code (2006 IRC),
(2) The Revised Builder's guide to Frost Protected Shallow Foundations (2004 NAHB), and
(3) American Society of Civil Engineers Design and Construction of Frost-Protected Shallow Foundations (FPSF) Standard ASCE 32-01 (ASCE 32-01).

Current building codes, design guides, and standards do not include northern Alaska's colder winters. Current methods are limited to the amounts of cold generally found in the Continental USA or in the more maritime regions of Alaska (e.g., portions of Anchorage). This current limit is measured by an Air Freezing Index (explained below) of 4,000 Degree-Fahrenheit-Days (^{o}F-days).

Included, here, are heat-containment recommendations for builders, for the design community, and for consideration in future building code revisions. These results extend the understanding of thermal regimes below a FPSF located in regions between 4,000 ^{o}F-days and 8,000^{o}F-days.

Why Is This of Interest to the General Public? (What is the broader impact?)
Accessibility is easy. A FPSF is constructed directly on the ground. Persons with disabilities and "Elders" may have direct access into their home or workplace. Stairs are not needed. There is no step needed from an attached garage into adjoining living spaces. Businesses have an alternative foundation system well suited to vehicle access. Those marginally able to afford their own home or building-expansion may now realize enough cost savings to afford their own home or allow that business expansion. The 1992 U.S. Department of Housing and Urban Development - Final Report (1992 HUD) stated that foundation cost savings varied up to about

3.8% of the total home sales price. Another source indicates an annual construction savings estimated at $300 million (Steurer, 1996). In a case study for a FPSF at Galena air control tower, the construction foreman reports accomplishing a FPSF in about half of the time needed for a conventional foundation (Danyluk 1997).

Environmental impact on sensitive lands warrants appropriate care and response. A FPSF may be an attractive alternative because of the greatly reduced site disruption needed for a FPSF. Depending upon soils specifics, almost no site disturbance may be needed. Excavation needs, under some circumstances, are minimal, if at all.

Resource allocation and the amount of energy needed for obtaining resources are also prime features for review and analysis. A FPSF uses fewer resources within the foundation zone. Instead of having footings that are four-feet deep, a FPSF footing may be as little as 22 inches from top of slab to bottom of footing.

As climate change has a thawing effect on marginally frozen soils, frost protected shallow foundation use may expand, depending upon local soils classifications and moisture conditions.

What Does Air Freezing Index (AFI) Mean?

Winter cold is measured by the air freezing index (AFI). The AFI is an accumulation, day by day, of the difference between the average temperature that day and the freezing temperature. It is used as a combined indicator of the length and magnitude of temperatures below freezing. For example, an outside air temperature of 3°F below zero represents a freezing index for that one day of 35°F-Day (32-(-3)). If, for example, that 3°F below temperature remained constant over a 180-day winter, then the AFI for that entire winter would be the accumulation, as follows: 35*180 =6,300°F-Days.

Historically, much of the research, upon which current design guides and building codes were established, came from the Scandinavian countries of Finland, Norway, and Sweden. The climatology of these countries is more influenced by the sea than is interior Alaska. For these Scandinavian countries, an AFI of 4,000°F-Days is sufficient for the research answers needed in their maritime environment. A FPSF is a foundation type for non-permafrost areas.

Why Stop At An 8,000°F-Day AFI limit?

Frost protected shallow foundations apply to regions where (a) no permafrost exists ("permafrost free zones"), or where (b) ground that has permafrost is intermixed with ground that does not have permafrost (called "discontinuous permafrost zones").

Regions with air freezing indices greater than 8,000°F-Days typically have continuous permafrost below the ground surface (called "continuous-permafrost zones"). Continuous permafrost zones (greater than 8,000 °F-Days AFI) are generally <u>not</u> suitable for a FPSF. The FPSF methodology contains building heat, and directs that heat into the soils below the foundation system. Permafrost, below the building, would likely be thawed over time. With the thawing, depending on the particular frozen soils characteristics, the building may settle.

What Air Freezing Index (AFI) Should Be Used for the Fairbanks Area?

That depends on how long the structure is expected to last.

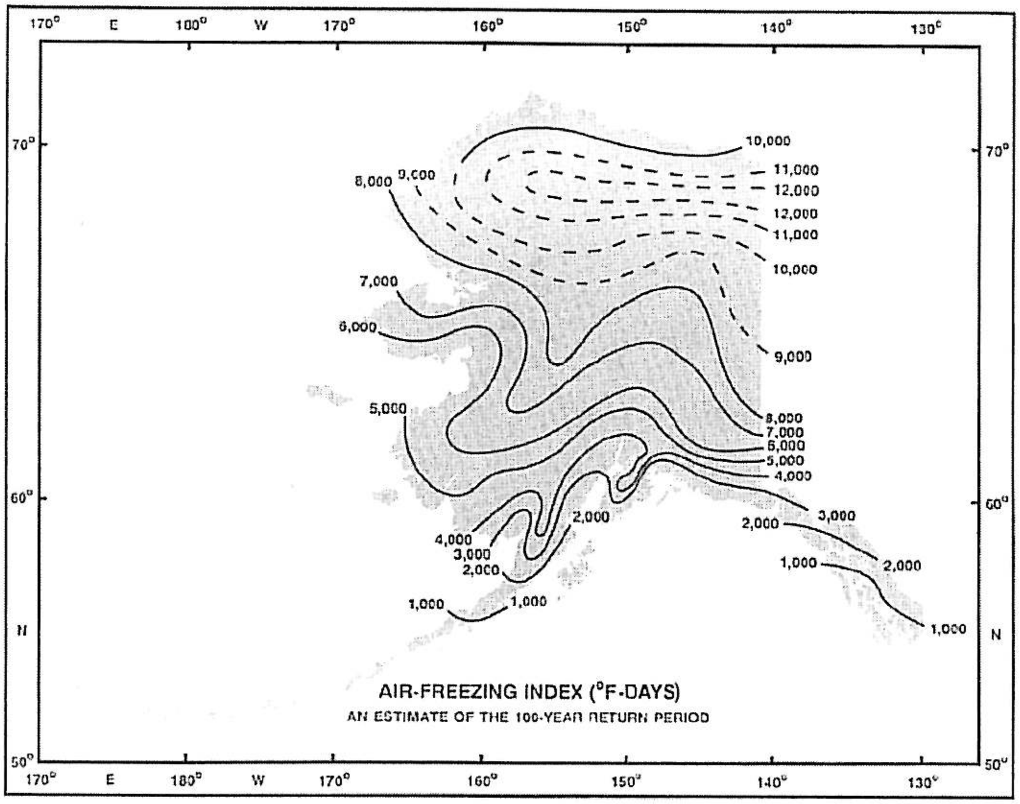


Figure 1: 100 Year Return Period AFI

Available free of charge, without copyright, from
National Climatic Data Center;
NOAA Satellite and Information Service, (NCDC-NOAA)
http://www.ncdc.noaa.gov/oa/fpsf/fpsfmaps.html. June, 2008

On this map (Figure 1), Fairbanks, at 64° 48' N. Latitude, and 147°, 45' W. Longitude, indicates a 100-year return period design AFI of about 7,000°F-Days.

According to the National Weather Service, Alaska Region (NWS-AK), there are recorded weather data from 1904 to present. In 1998, when checked, only 558 days of data were missing (Randy Settje NWS, personal communication, September 1998). This 95-year record showed the following AFIs (°F-Days) for specific winters in Fairbanks:

Winter of 1932	6,571
Winter of 1933	6,569
Winter of 1956	7,271
Winter of 1964	6,602
Winter of 1966	7,104

For Fairbanks, combining actual recorded data from NWS-AK with the map information from NCDC-NOAA suggests a 5,500°F-Days average AFI, and suggests the using following AFI values:

30 Year Return Period AFI	6,500 °F-Days
50 Year Return Period AFI	7,000 °F-Days
100 Year Return Period AFI	7,300 °F-Days

METHODS

Six Field Test Sites with Different Soils Conditions

Six different sites are included in this study to investigate the impacts of different soils types and moisture conditions on FPSF design. The goal was for data from the thermistor strings to be used (1) for calibrating finite element modeling and (2) for validating that the model applied sufficiently correctly to different conditions. Numerical and modeling methods follow.

The sites parameters investigated are:

1. River drainage, dry gravel site, with no perimeter insulation at all
2. River drainage, damp gravel, with about 1.5 times the maximum insulation shown in present design guides.
3. Wet silt site, permafrost at 49-feet deep, no insulation, warm crawl space.
4. Hillside schist site, insulation slightly above maximum shown in current design guides.
5. Hillside silty-sand site, insulation slightly above maximum shown in current design guides.
6. Valley, sandy-silt site, insulation slightly above maximum shown in current design guides.

Data Obtained From Thermsitor Strings

"Answers.com" defines "thermistor" as "A resistor made of semiconductors having resistances that varies rapidly and predictably with temperature."

A thermistor is different than a thermocouple. (Figure 2) "Answers.com" defines "thermocouple" as "A thermoelectric device used to measure temperatures accurately, especially one consisting of two dissimilar metals joined so that a potential difference generated between the points of contact is a measure of the temperature difference between the points" (http://www.answers.com/thermocouple?cat=technology).

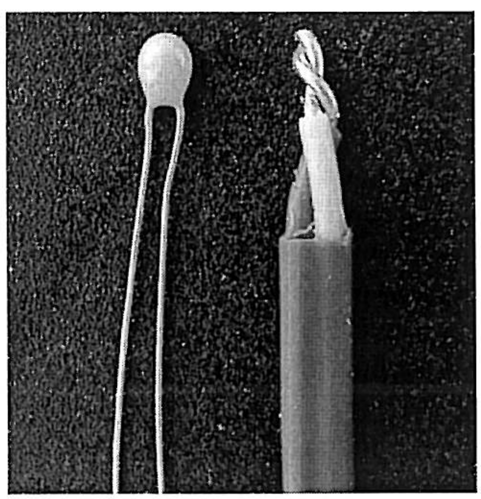
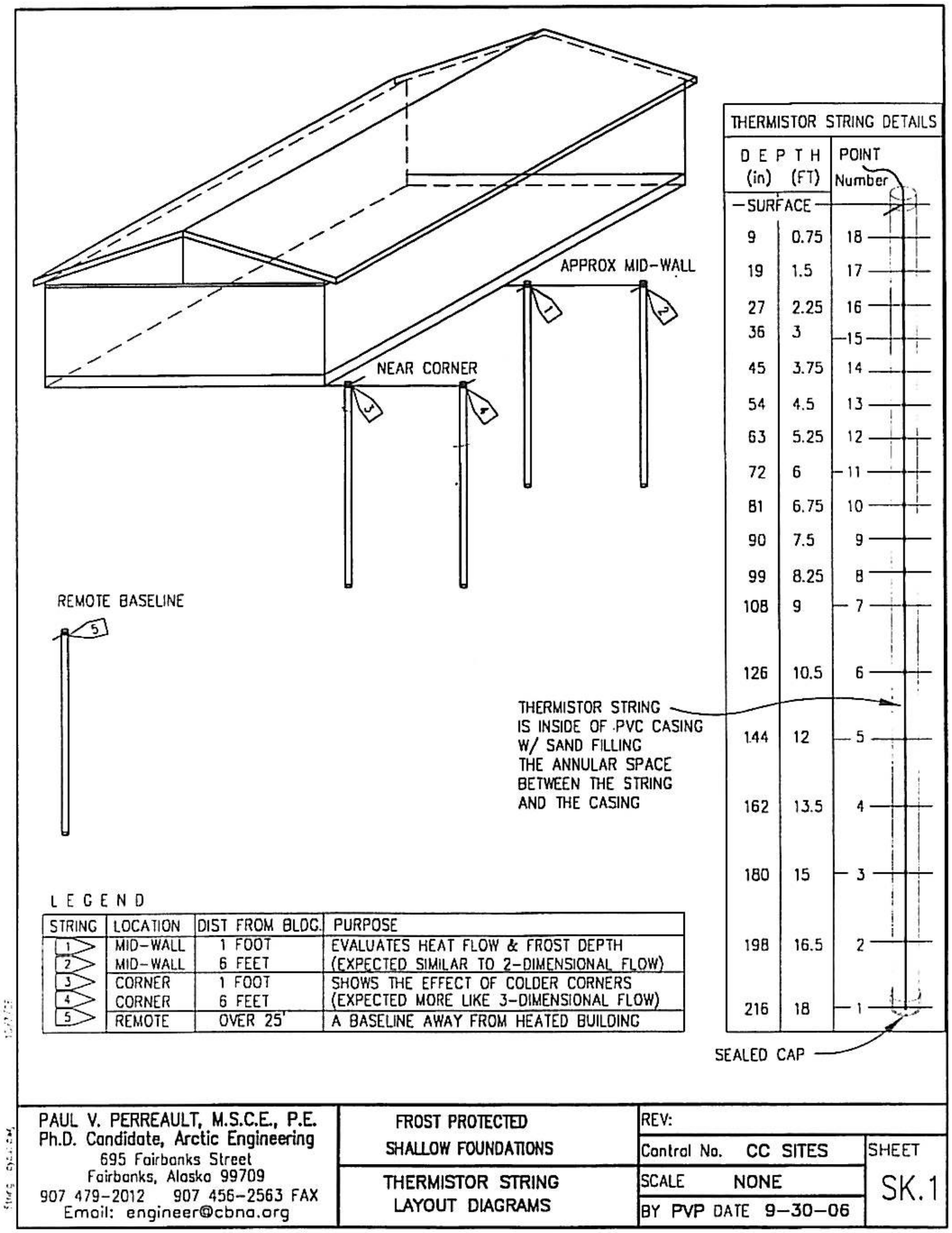


Figure 2: Thermistor (Left) and Thermocouple. Actual thermistor is about 1/16th inch wide

Apogee Instruments makes the following comparisons: Thermistors require no reference temperature, yield a larger signal, have inexpensive wire and need multiple steps in datalogger programming. Thermocouples, in comparison, require an accurate reference temperature, yield a smaller signal, use a more expensive wire, and have easier datalogger programs. (http://www.apogeeinstruments.com/oxygensensor_techinfoTHERM.htm)

The thermistor string layout (Figure 3) was determined and revised, slightly, to measure temperatures closely in the top of the soils region, then are spaced further apart in the lower portions of the boreholes. Five thermistor strings were installed at each site. Two strings along the long wall, to approximate two-dimensional heat flow. Two strings were installed close to the corners, where colder conditions were expected. The fifth string was installed at least 25 feet away from the building, to approximate ambient conditions.



DEPTH (in)	DEPTH (FT)	POINT Number
9	0.75	18
19	1.5	17
27	2.25	16
36	3	15
45	3.75	14
54	4.5	13
63	5.25	12
72	6	11
81	6.75	10
90	7.5	9
99	8.25	8
108	9	7
126	10.5	6
144	12	5
162	13.5	4
180	15	3
198	16.5	2
216	18	1

STRING	LOCATION	DIST FROM BLDG.	PURPOSE
1	MID-WALL	1 FOOT	EVALUATES HEAT FLOW & FROST DEPTH
2	MID-WALL	6 FEET	(EXPECTED SIMILAR TO 2-DIMENSIONAL FLOW)
3	CORNER	1 FOOT	SHOWS THE EFFECT OF COLDER CORNERS
4	CORNER	6 FEET	(EXPECTED MORE LIKE 3-DIMENSIONAL FLOW)
5	REMOTE	OVER 25'	A BASELINE AWAY FROM HEATED BUILDING

Figure 3: Thermistor String Layout

Two different thermistor types were used in this research. Both were advertised to measure temperatures more accurately than thermocouples. Both specific thermistors were chosen because their temperature-resistance curves were close to linear in the freezing temperature range (our temperature-point-of-interest). This research installed and measured temperatures from over 540 thermistors. Readings began in spring, 2004 and continue.

Manufactured by Alpha Technics, in California, Alpha thermistors (Type 14-A-5001-C2) are being used at four sites. Alphas are calibrated to measure 5000 Ohms at 25°C, and measure 16,332 Ohms at 0°C.

Manufactured by YI Precision Temperature Group, in Ohio, YSI thermistors (Model 44033) are being used at two sites. YSI thermistors are calibrated to measure 2,252 Ohms at 25°C and measure 7,355 Ohms at 0°C.

Figure 4 and Figure 5, below, show the drilling operation. Solid stem augers were used for drilling into the soils. Plastic pipe was then installed into the hole. Pre-manufactured thermistor strings were installed into the pipe. The annular space between the thermistor string and the inside face of the pipe was filled with sand.

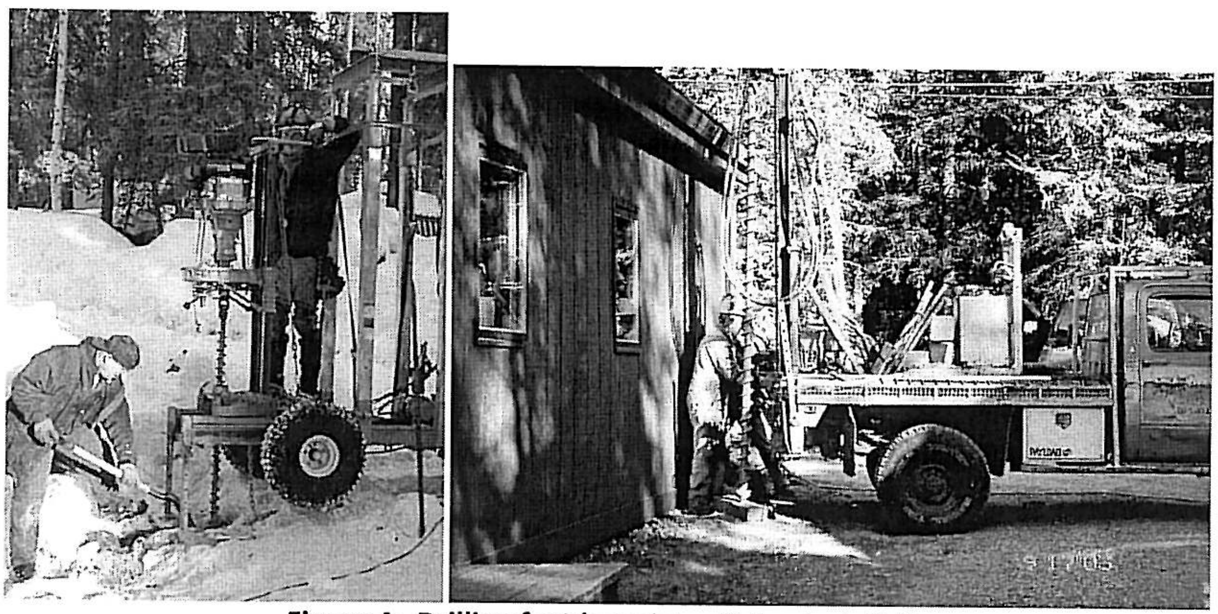


Figure 4: Drilling for Thermistor String Installation

(Left) Irregular Terrain Presents Options for Interesting Solutions.
(Right) Obstructions Limit Boring Closeness to Buildings.

Figure 5: Smaller Drill, Closer Thermistors

Data Collected Onto Data-Loggers

Data collection was onto a CR10X Measurement and Control Module (Datalogger). The Datalogger is manufactured by Campbell Scientific, Inc. In order to input data from 90 thermistor points into the one Datalogger, three AM 16/32 Multiplexers (Multiplexers) were installed. The multiplexers are computer programmed to sequentially take temperature samples and "log" those results onto the Datalogger.

Figure 6 and Figure 7, below, show (a) bench preparation, (b) cold weather field installation, (c) fixed datalogger station recording, and (d) mobile datalogger station recording.

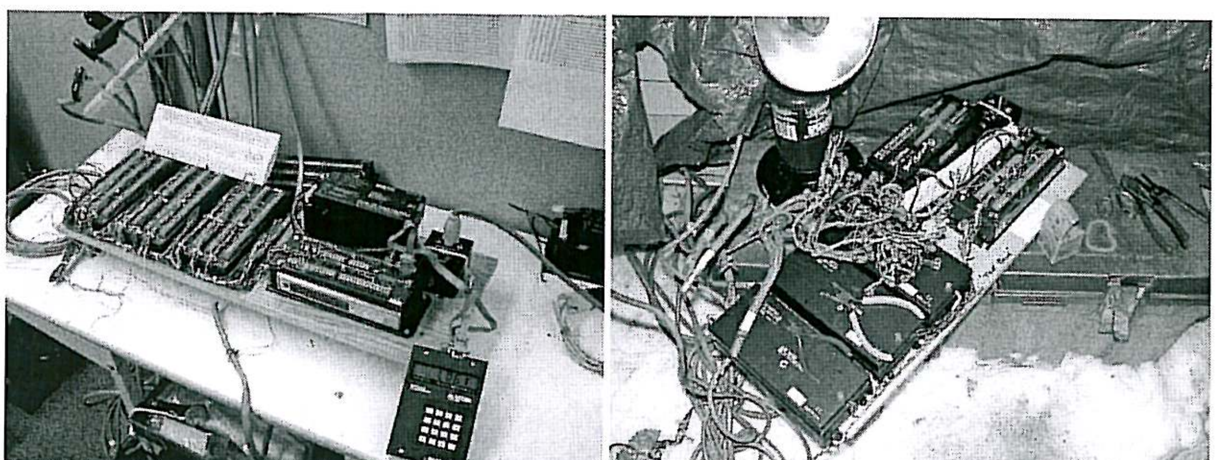


Figure 6: Datalogger Wired at Office, Then Connected to Thermistor Strings in the Field

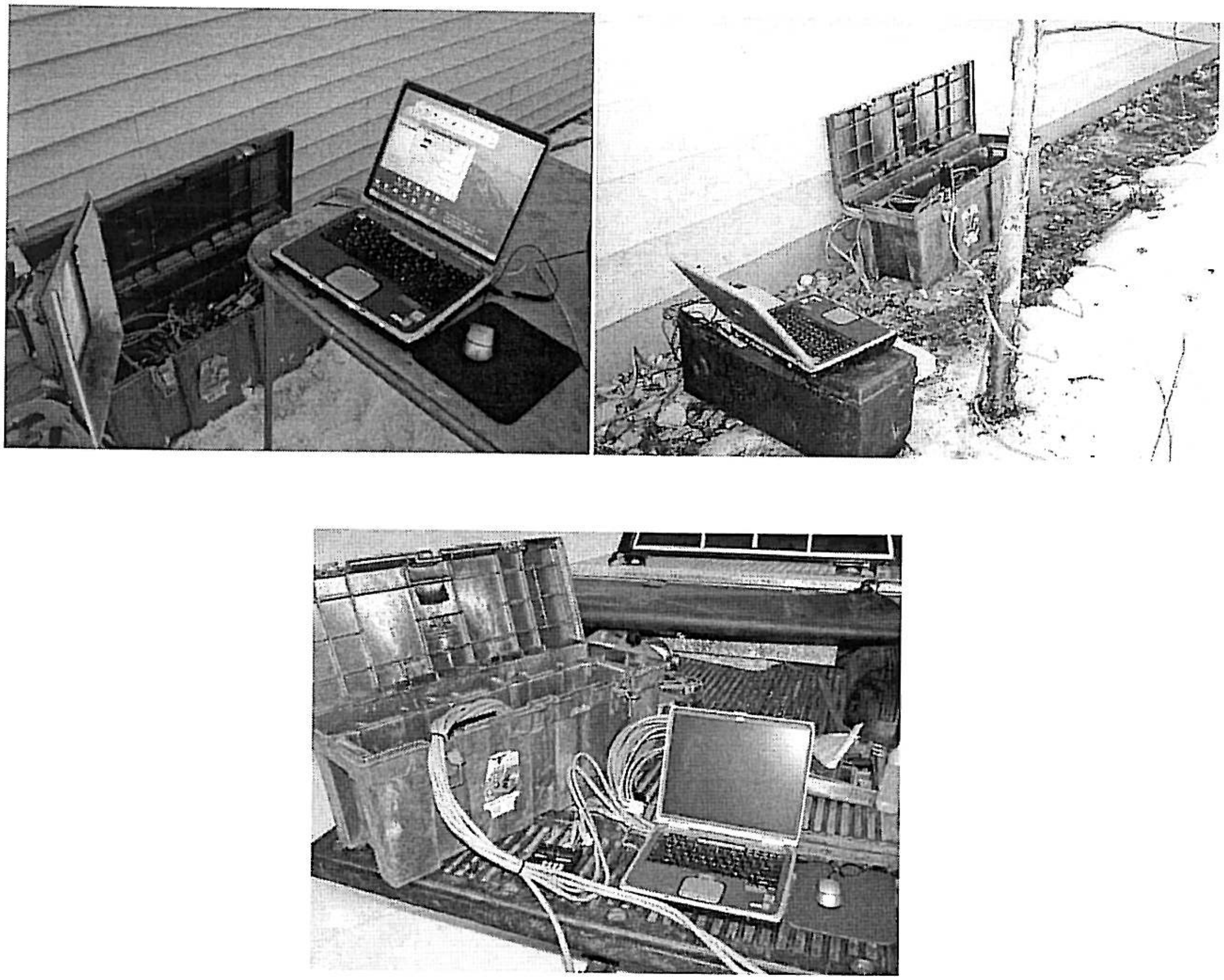


Figure 7: Down Loading Data

(Top Left & Right) from Hard-Wired Dataloggers at Both CCHRC Sites.
(Bottom) from a Mobile Datalogger Station.

Numerical Analysis Method

Conformal mapping (Lunardini, 1981) is mathematical tool for transforming two-dimensional curvilinear heat flow paths into a mathematically equivalent one-dimensional conductive heat flow analysis. It resolves a second-order partial differential equation using isothermal lines.

Dr. Yuri Shur (personal communication) has developed the analysis and applied it to the problem of moving freezing isotherm locations in a non-steady-state heat conduction analysis. Analysis parameters include: (a) frozen soils conductivity, (b) thawed soils conductivity, (c) moisture content, (d) temperature differences between inside and outside, and (e) the length of time the system is exposed to the temperature conditions. For ease of application, soils thermal conductivities are taken from Kersten (1949), which are copied in several texts.

Figure 8, below, shows the fundamental concept of flow tubes. Heat flow is constant through a particular heat flow "tube." Note, the shorter the tube, the less soil is involved; the less total soils R-value is involved. Conversely, the deeper, longer tubes involve greater amounts of soil; therefore, have greater resistance to heat flow.

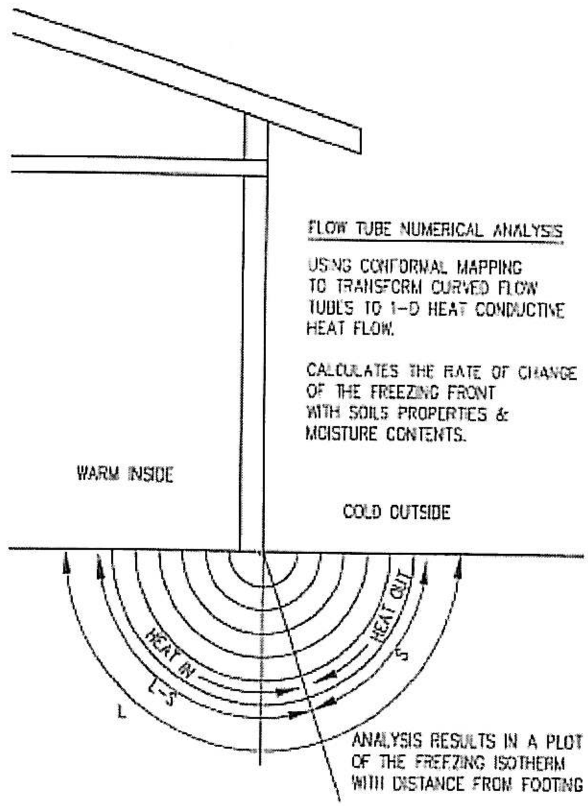


Figure 8: Flow Tube Analogy

Finite Element Analysis, Temp/W Program

Temp/W is a thermal modeling program manufactured by Geo-Slope in Calgary, Alberta. It allows two-dimensional modeling of various configurations for insulation and building geometry. Most of the research effort is in the finite element modeling. Site measurements and numerical methods are used to calibrate and validate the model. Calibration is checking to see that the model yields comparable results to a numerical analysis and to site measurements from one site. Validation is checking that the model yields comparable results to site measurements from sites with differing conditions.

A winter's AFI is represented by a sinusoidal approximation adding up to 5,000 °F-Days. Once a model is correctly calibrated and validated, then colder or warmer winters may be represented by simple multiplication factors of this 5,000 °F-Day winter. A 7,500°F-Day winter, for example, may be (approximately) represented as 1.5 times a more normal 5,000 °F-Day winter.

Based on site conditions observed, the model is input using air temperature, without considering snow cover as being present. Snow cover was minimal or non-existent in all six test sites, close to the building.

RESULTS

Test Site Data Results

The following are descriptions and representative data summaries from different sites. Discussion of these results follows in the next section.

One site, in the hills north of Farmer's Loop road is on fractured schist.

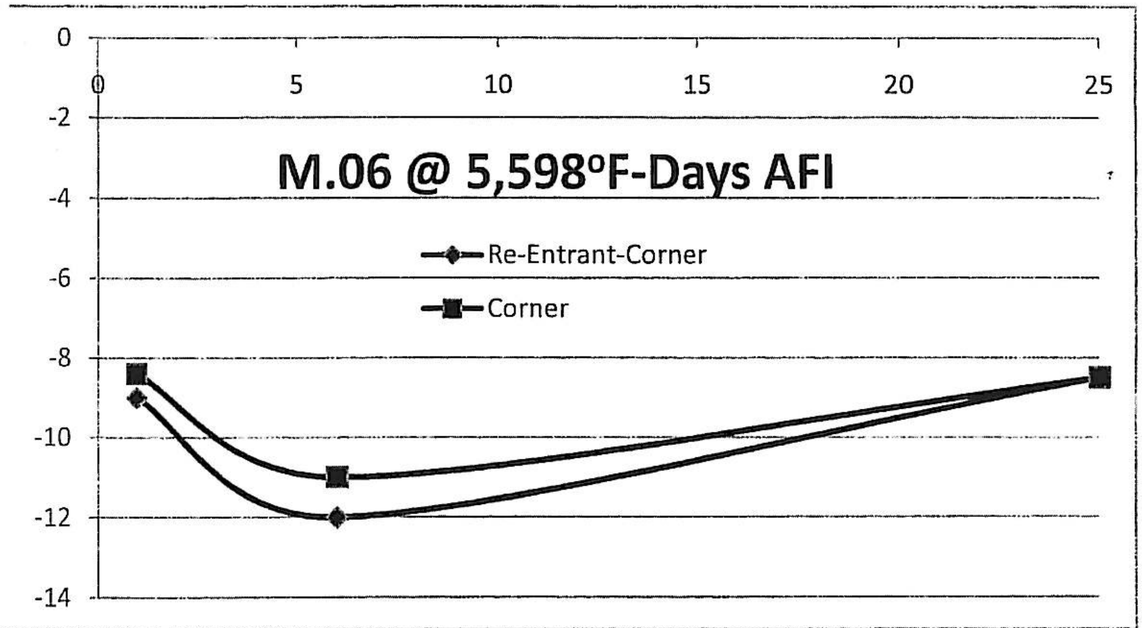


Figure 9: Mid-building Corners are Similar to Outside Corners

Figure 9, above, shows results from that site. Depth below the ground is on the left axis. Distance out from the building is along the top. Here, the frost penetration measures at over 8 feet deep at a distance of only one foot from the foundation system. Both of these boring-sets were near corners. The building outside corner is shown by the upper graph. Along the middle of a long wall are two overhead garage doors and a personnel door, staggered by a re-entrant corner (See Figure 5, above). Here, the frost depth is actually deeper near the penetrations (doors) than at the building corner.

The reported insulation system included (a) two-inch XPS floor insulation below the floor, (b) vertical insulation from insulated concrete forms with two-inch insulation inside and out, and with (c) two inch horizontal wing insulation extending out a distance of two feet.

A second site, also in the hills north of Farmer's Loop, is in a silty sand location. Figure 10, below, shows the deeper frost penetration near corners, relative to along a long wall. Here, the colder corner was adjacent to a garage entrance; while, the long wall measurement was adjacent to a heated room. Measurements near the home had no snow cover. The distance measurements were under snow-cover.

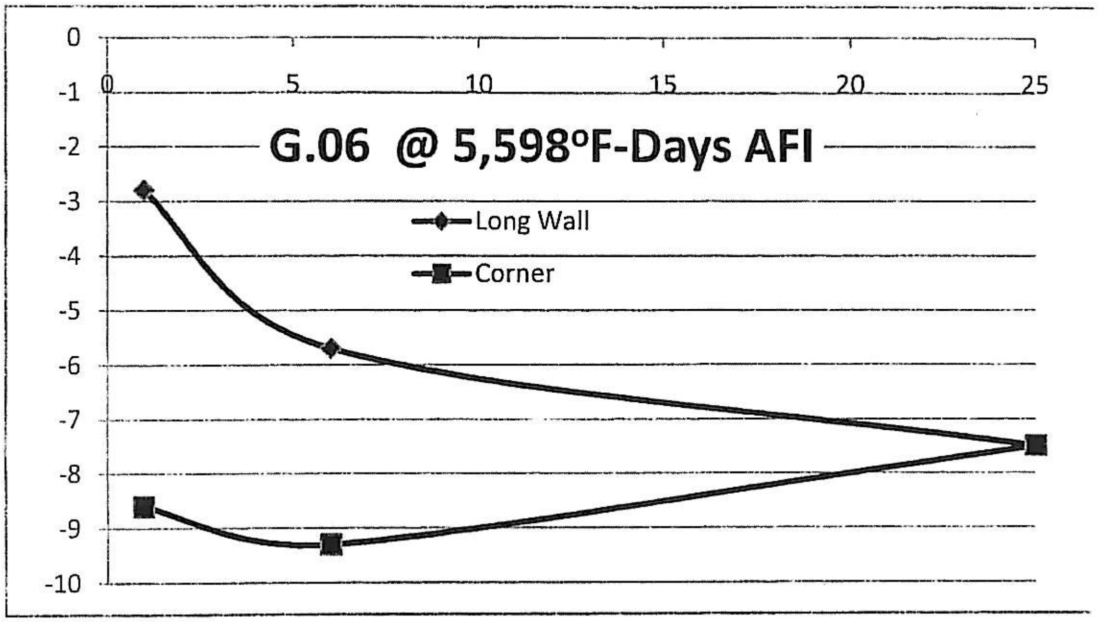


Figure 10: Deeper Frost Penetration at Corners

The reported insulation system was similar to the first site.

A third site is in the Fairbanks City core, on a site with gravel and a shallow water-table.

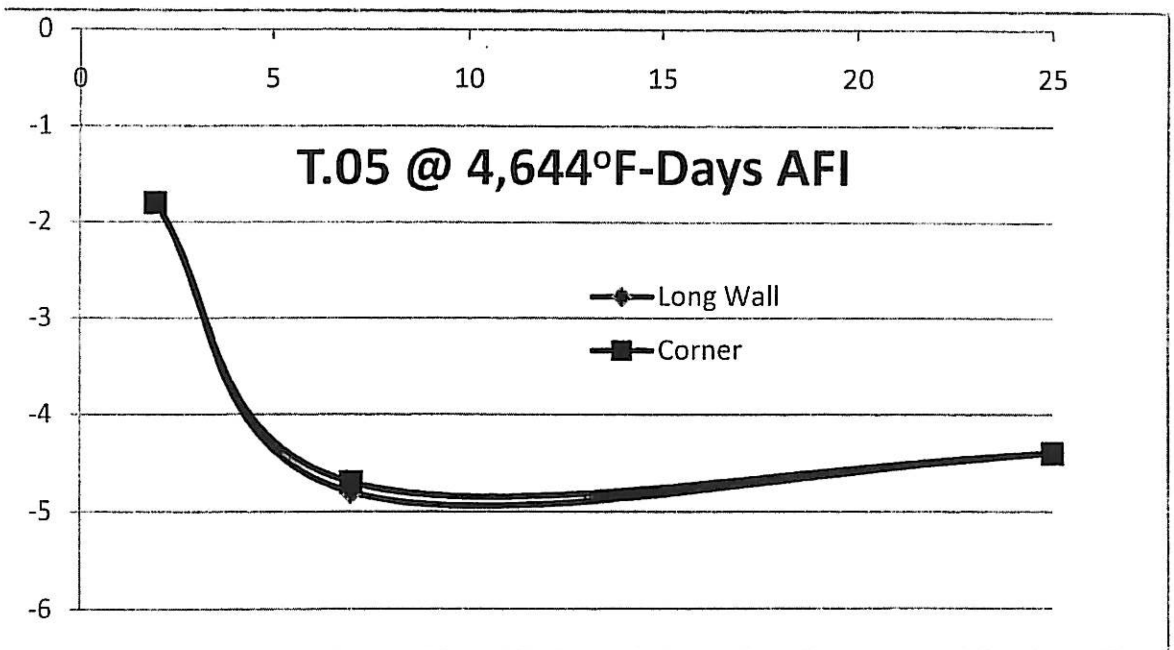


Figure 11: Shallower Frost Depth

Figure 11, above, are measurements from this building with increased corner insulation. The horizontal wing insulation along the long wall was specified as R-20, extending for 36 inches from the wall. The corner insulation was specified as R-25, extending 48 inches from the corner zones. The corner zones were 10 feet long. Temperature measurements show the frost depth and freezing isotherm location to be almost identical. Although measured earlier in the winter (at a lower AFI), the freezing isotherm is well outside of the footing zone.

A fourth site had a different thermistor string arrangement, not the same as the previous three sites. Here, the building was instrumented while it was still under construction. Five thermistor

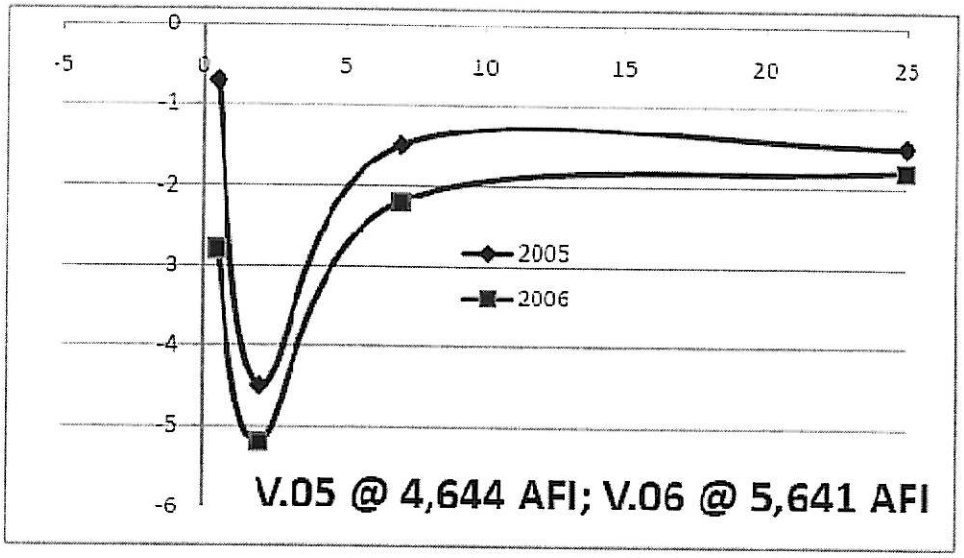


Figure 12: Five Aligned Thermistor Strings

strings were installed in a line. The first was 6-inches inside of the footing, inside the heated space. (The garage floor was still dirt – not concrete.) The second was installed 6-inches outside of the footing space, in the insulation zone. The third, fourth, and fifth thermistor strings were installed two-feet, seven-feet, and 25-feet outside of the building line. This is the only site with five thermistor strings in a line. The measurements within the heated space, at floor line, were above 42°F., showing that the freezing isotherm did not penetrate into the heated space.

Sites five and six are not reported here. One was on a known permafrost site – not generally recommended for a FPSF system. The other had significant damage to its thermistor strings from snow removal equipment.

Numerical Analysis Results

See Figure 13 and Figure 14, below, for typical results for silt with varying moisture contents. Note that the wetter the soil the more the freezing isotherm projects below the footing. Also note the vertical orientation of the freezing isotherm near the footing. These results indicate deep frost penetration may occur quite close to the footing, while the soils below the footings are still thawed.

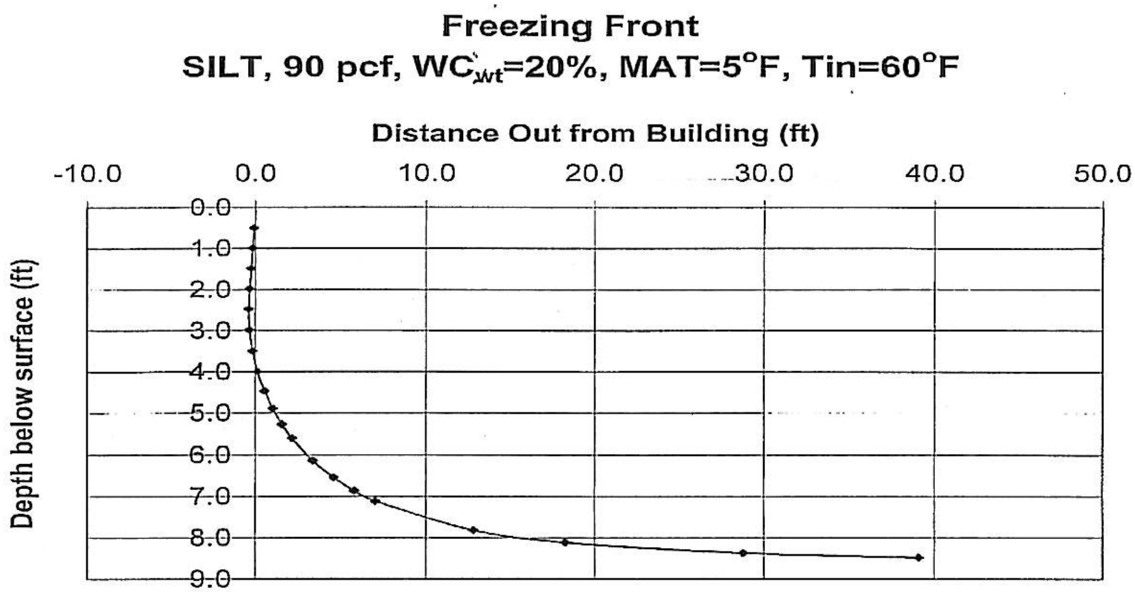


Figure 13: Numerical Analysis Method, Damp Silt

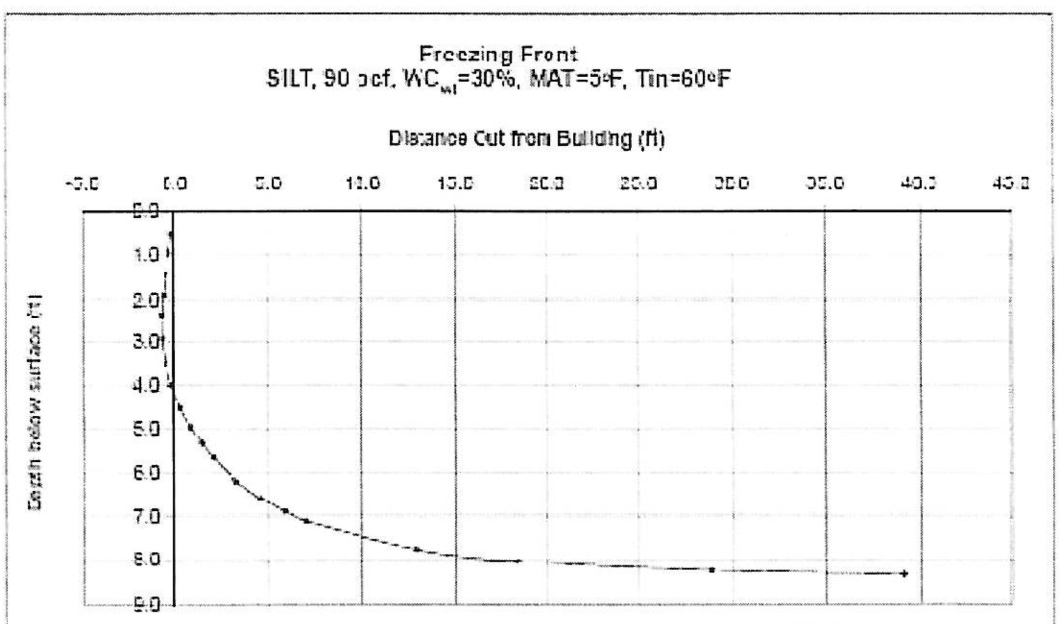


Figure 14: Numerical Analysis Method, Wet Silt

Finite Element Modeling Results

Sample finite element results are shown in Figure 15, below. The left side shows one example model with concrete floor, uniform soils below, and with both perimeter vertical insulation and with horizontal wing insulation. In this model, the horizontal wing insulation extends two feet, just as in two of the test sites evaluated. The right side shows the freezing isotherm location after running the computer analysis. The vertical isotherm orientation is evident, as is the deflection outward from the footings, due to the horizontal wing insulation. Also evident, is the tendency for the freezing isotherm to intrude below the foundation zone at depth.

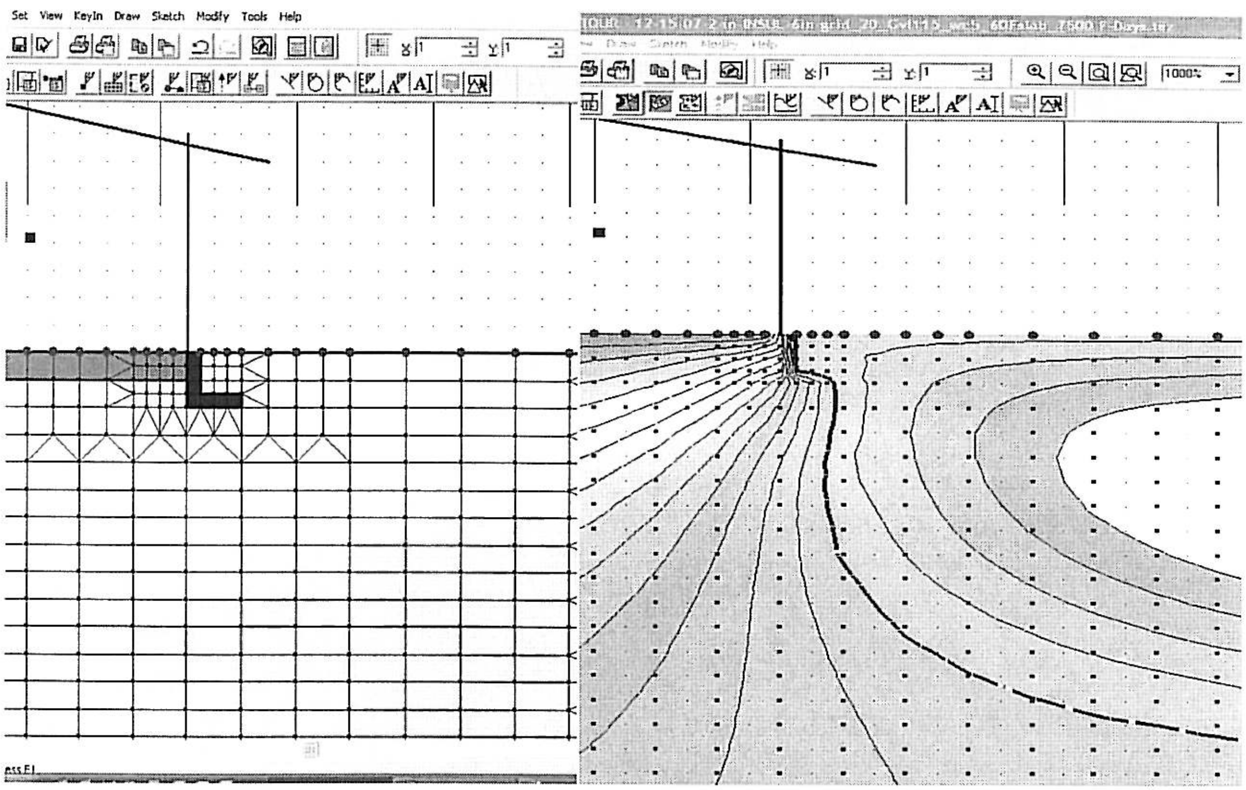


Figure 15: Modeling Output: Insulation Changes Freezing Isotherm Location

DISCUSSION

Discussion: Numerical Analysis Agreement With Finite Element Analysis

There is a close correlation between results from the numerical analysis with the results from the finite element (modeling) analysis. Both show a nearly vertical freezing isotherm in the foundation region. Also, at higher moisture contents, both show a reverse-curved isotherm intruding toward the soils directly below the footings.

Discussion: Freezing Isotherm Shape Next to Footing Zone.

This vertical freezing isotherm is significantly different than the isotherm sketches observed in FPSF design guides for warmer climates. For example, Figure 16, from the NAHB 1994 edition shows a freezing isotherm that is deflected at about 45 degrees from the horizontal – much shallower than the approximately 90 degree deflection found for these colder climates.

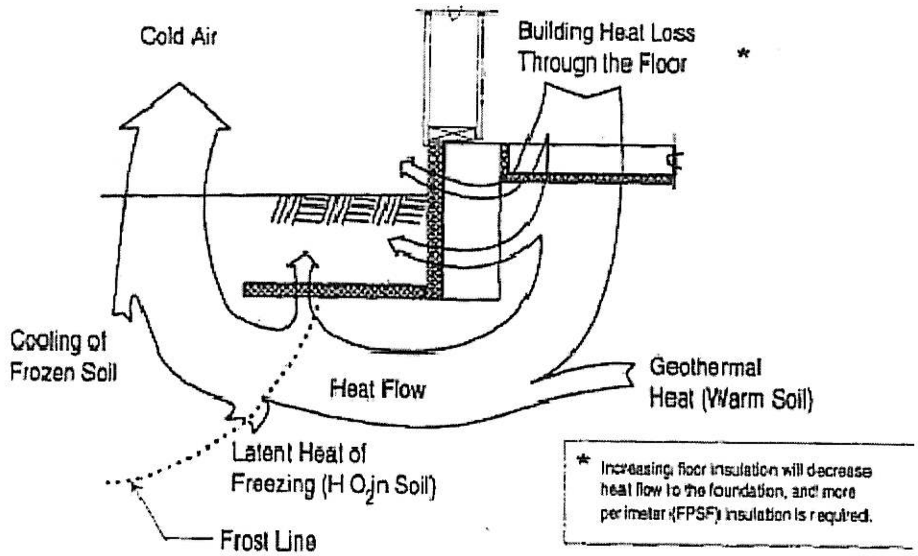


Figure 16: NAHB 1994 Footing Zone Heat Flow Sketch

The reverse deflection increase with (1) marginally insulated FPSF systems, when combined with (2) wetter soils is also significant. FPSF design methods for warmer climates typically specify about a 12-inch non-frost susceptible (NFS) drainage layer above the in-situ soils. With the freezing isotherm reverse curvature, soils at depth become a point for evaluation. It may not be enough to have the freezing isotherm just at the outside corner of the footing zone.

One perspective suggests that with reverse curvature of the freezing isotherm, it may be desirable to have the freezing isotherm further out into the wing insulation. The reversed curvature with potential for freezing below the footings, at depth, presents evidence for increasing the perimeter insulation.

A contrasting perspective recognizes that frost heave forces act generally perpendicular to the freezing isotherm. That means, at least at the ends of higher AFI winters, the frost heave forces below a FPSF act almost horizontally.

This researcher proposes balancing a conservative approach for higher importance or longer lasting buildings with permitting reduced recurrence intervals (e.g., 25 year AFI or less) for buildings of ordinary importance where better soils are present and economy outweighs the need for longer term life.

Discussion: Site Data Agreement with Numerical and Modeling Methods

Specific site data are abundant. For brevity, only the derived results have been included in the "Results" section, above. Figure 9 and Figure 10, above, show a surprising increase in frost depth close to overhead garage doors for two sites investigated. Data have not been obtained in this research to indicate if and how much the freezing isotherm may have penetrated below the footings in these two test sites. However, both the numerical analysis and the finite element analysis suggest that the freezing isotherm may be close to vertical in this region. In fact, the freezing isotherm may not penetrate appreciably below the footing. Further investigation would be warranted.

A third site shows a similar result. Note the apparent thermal sink observed just outside of the footing zone in Figure 12, above. In all three of these sites, the overhead doors represent a discontinuity in the thermal envelope. These footings by garage doors are colder. Localized heaving risk appears to be greater at these penetration discontinuities. One may be correctly cautioned to treat garage openings as if they are corner zones, for the purposes of determining insulation amounts.

Sample City of Fairbanks Four-Feet Foundation System

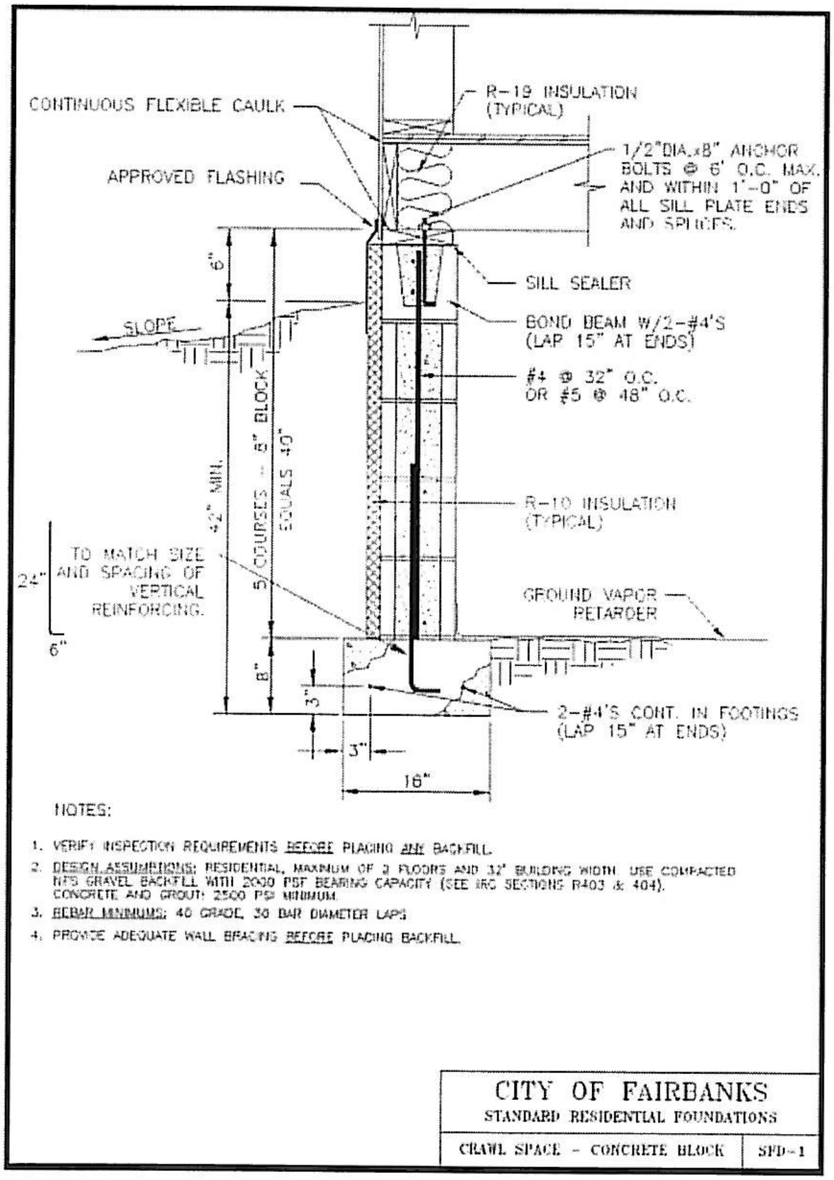


Figure 17: Sample of A Fairbanks Standard Foundation Detail

Standard Fairbanks foundation details are available, free of charge, at http://www.ci.fairbanks.ak.us/departments/building/standard_handouts.php

Figure 17, above, shows one example of a four-foot foundation system: six-inches above grade and 42-inches below grade.

2006 International Residential Code (IRC) Requirements

The following question is frequently asked: Must a FPSF follow the 2006 IRC requirements, or may the FPSF follow design guides, like ASCE 32-01 or the 2004 NAHB. This research does not specifically answer this question. It is up to the building code official having jurisdiction over the project to determine if using a design guide may be considered an alternative means and method equivalent to the building code.

A FPSF Needs More Insulation at Corners

Corners are coldest. Along a long wall, heat flow may be approximated as two-dimensional. At corners, though, building heat may escape from either long wall or end wall. At corners, the heat flow more closely approximates three-dimensional flow.

In an investigation of eleven full-size houses over a period of ten years, researchers documented about a 30 percent deeper frost depth at corners than along the long walls of the buildings (Hong, 1988). Current codes and design guides agree with placing about one-third extra insulation R-value at corners, and with extending the horizontal insulation about one-third further away from the foundation.

Insulation Types XPS or EPS?

Extruded polystyrene (XPS) is forced through a mold. (Tooth-paste is extruded from its tube.) Expanded polystyrene (EPS) is reminiscent of cooked pop-corn.

This investigation has not specifically evaluated the type of insulation used, XPS or EPS.

Latest documents show different requirements regarding insulation-types and where they may be installed. In particular, The 2006 IRC specifies only XPS for horizontal wing insulation application. In contrast, both ASCE 32-01 and the 2004 NAHB allow both XPS and EPS for horizontal application. However, EPS has a reduced "effective R-Value." Extruded polystyrene has long been the insulation of choice for horizontal subgrade installations (Esch. Weinstein). Expanded polystyrene is gaining more popularity.

For the purposes of this report, note the importance of using long-term "effective R-Values." Horizontal extruded polystyrene (XPS) has an effective R-value of R-4 per inch. Horizontal expanded polystyrene (EPS) values are also reduced. Horizontal EPS may be valued at only R2.6 per inch (for EPS Type II) or R2.8 per inch (for EPS Type IX). See NAHB 2004.

Effective R-Values for EPS & XPS, Installed Vertically or Horizontally
(R-Value per Inch Thick

	Vertical Insulation Around Perimeter	Horizontal Insulation Out From Footing
EPS Type II	3.2	2.6
EPS Type IX	3.4	2.8
XPS	4.5	4.0

Radiant Heat Slabs and Ground Insulation

The ASCE Standard (ASCE 32-01), Design and Construction of Frost-Protected Shallow Foundations (FPSF) defines ground insulation as insulation that extends horizontally underneath a foundation to create an insulated pad for the building. Insulation below the slab is observed when radiant floor heating is installed. See Figure 18, below.

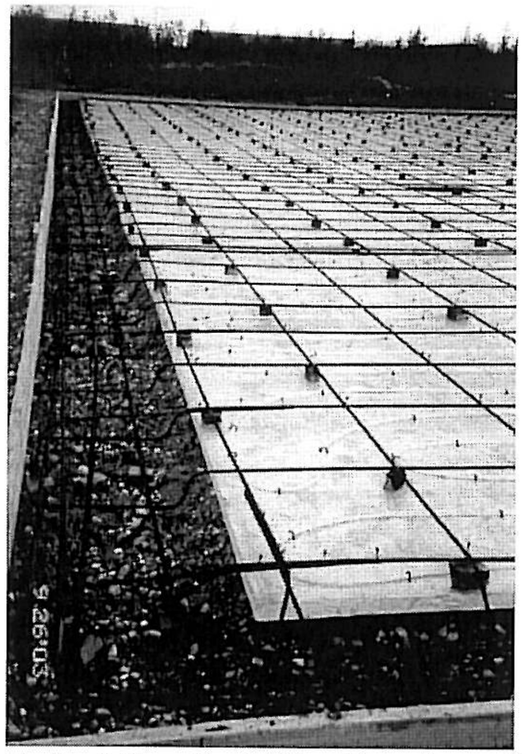


Figure 18: Radiant Floor Heat Often Uses Ground Insulation

Remember, the point of a FPSF is to allow building heat to enter the soils below the building. Ground insulation restricts that heat flow. Therefore, additional perimeter insulation is needed. See the recommended design procedure in Appendix I.

Site Monitoring - Research Lessons Learned

Frankly, this section may not be of general interest to the building and design community. However, the lessons learned during the research provide important information to other researchers. Hopefully reporting these site lessons will help other researchers avoid some of the same difficulties as were experienced here.

Cap the Thermistor Tube Ends. Keep Water Out of the Tube

The first two sites had open-ended tubes into which the thermistor strings were placed. With rising water levels, the thermistor strings, in shallow water-table areas, would be continuously wet. Recommend capping the bottom ends of the tubes. Provide closed-ended tubes to help keep the water out.

Fill the Annular Space between the Thermistor String and the Pipe

Filling annular open space between the thermistor string and the inside wall of the tube allows more direct conductive heat transfer between the soils and the thermistors. Allowing the annular space to remain unfilled may permit internal convective heat-loops to form within the space. The convective loops may be a source of data error. Recommend filling the tubes. This research used ordinary traction sand, available locally.

Bury the Thermistor Wire Leads between the Boring and the Datalogger

Above ground leads between the individual thermistor borings and the centralized datalogger collection site are vulnerable to traffic. (They are no competition for snow removal by front-end loader. Recommend trenching and burying the leads at least 18-inches below the soils. (The leads are also no competition for the paving contractor that excavates six-inches or so to level the finish grade before paving.)

Datalogger Downloading Remarks

Consider the maximum time span of the particular datalogger equipment chosen. This research needed at most one reading per day in the spring – not every minute – not every hour.
Cold weather data downloading onto laptop computers did not work well. Laptop battery life was minimal. This researcher ended up buying an 110 Volt inverter and powering the laptop computer from the vehicle's power supply.

Local Northern Alaska Observations

Engineering, Inspection, and Construction Background.

The site-specific research has been in place for about five years. However, this researcher has over 27-years of arctic engineering, inspection, and construction background. Work has been in about 50 different arctic and sub-arctic villages or projects in northern Alaska. Over 500 arctic and sub-arctic buildings have been personally inspected. These extensive observations are combined with this site-specific research to formulate the discussion points below.

Some Buildings Still "Work" Even Without Having Any Insulation.

I have seen shallow foundations without insulation that work. So why provide insulation at all? It means NFS soils to depth. Not really a FPSF. Comply with local building codes regarding energy conservation.

Two Inch Insulation, Two Feet Down, & Two Feet Horizontal (2x2x2)

The following question has been asked: "Is it enough to use two-inches of insulation on a slab-perimeter, and also provide just two-inches of insulation horizontally out for a distance of two feet all around the building?" The response, based upon this investigation is as follows: "Only if no insulation at all would also work." This 2x2x2 system approximates the current 2006 IRC requirement, along a long wall, for an AFI of 4,000 °F-Days.

This little amount of insulation may serve as a prescriptive energy amount. (For example, The City of Fairbanks has a standard requirement for R-10 perimeter foundation insulation.) Formerly, some installations considered this R-10 requirement satisfied by two-inches of EPS. With the newer standards, that use effective R-Values, thicker insulation is required.

Do not consider this 2x2x2 protection as a frost protected shallow foundation for the higher Air Freezing Indices prevalent in northern Alaska. This means, the 2-inch horizontal insulation, extending just two-feet out from the building may serve as thermal insulation. And, it is not a frost protected shallow foundation. Rather, it is just a thermally insulated foundation.

For a 2x2x2 thermal insulation system, the footing-zone thermal environment, alone, is insufficient for adequate protection against frost heave. Expect the freezing isotherm to fall well inside the footing zone. A foundation with this amount of insulation is not likely to provide frost protection for 6,500 or 7,300°F-Day winters.

Caution, if wicking soils and water also become present over the life of the structure, even for just one winter, foundation heaving may still occur. Wicking soils may become present, for example, from the topsoil added for flower gardens. Water may become present by being perched on top of seasonally-frozen soils, like during spring thaw. This researcher does not recommend using relying upon a 2x2x2 insulation method for frost protection.

Snow or No Snow? Wet or Dry Conditions?

All six sites investigated had pedestrian or vehicle traffic next to the building. All six had eave overhangs. And, all six sites had snow cleared from around the building for at least a significant part of the building perimeter. Therefore, these observations show that it is reasonable to assume "no-snow" conditions for a FPSF design.

Drainage problems have been reported by others (Charles Jeannet, building Inspector, personal communication, May 2008) and personally observed by this investigator. Difficulties may occur in time, even when the Code-required minimum of six-inch drop in ten-feet is originally constructed (2006 IRC R401.3) Rain from roof eave overhangs, combined with soils erosion or localized soils-consolidation correlates with local soil depressions near to the foundation zone. These depressions frequently manifest as a long shallow trench, along the building, almost directly below the eave-overhang.

During spring thaw, this localized trench condition warrants more vigilance. In spring, the soils at depth may still be seasonally frozen. The water, entrapped above, by the local eroded trench, may saturate the thawed soils above the remaining frozen layer. Water, during spring thaw could easily saturate the soils in this case. If the perimeter of the building is paved, at the correct slope drainage problems may still occur. A FPSF protects the foundation zone from freezing near the building, not ten-feet away. Frost susceptible soils away from the foundation may still heave. Pavement tilting from remote heaving has also been observed. Front steps and sidewalks have been seen with reverse slopes (pointed toward the building) directing water toward the foundation, not away.

As a result of these observations, and as a measure of conservatism, this researcher recommends that the designer (1) consider the foundation zone as having no snow, and (2) consider the soils as being wet.

Precautions Regarding Frost Protected Shallow Foundations?

Check for Permafrost.

Have soils data that indicates absence of permafrost below the foundation system before designing a FPSF. Generally, a FPSF system does not apply to permafrost areas. There may be a site specific exception.

If permafrost does exist below a site, long term thaw strain (how much the building settles over time) is a parameter that needs careful evaluation – well outside the scope of this report. Do not use a FPSF over permafrost without first having an engineer evaluate the soils for long-term thaw stability.

Recall, a FPSF directs and constrains building heat into the ground below the foundation. Over time, this heat will likely thaw permafrost if present below the building. The depth of thaw is likely to be on the order-of-magnitude of twice the narrowest building dimension. Caution, if the ground settles, over time, from thawing the building owner may be quite upset. If, by contrast, thawing the permafrost results in minor, acceptable settlements, then a FPSF may be a viable design alternative – on a case-by-case basis. Do an engineering evaluation for permafrost soils areas.

Do not use FPSF where other structural parameters govern the design. For example: structural design of a tall, narrow building may be controlled by wind or seismic events. A three-story building (30 feet high) and 24 feet wide may be controlled by (a) lateral loads from wind, (b) uplift loads from wind, or (c) lateral loads from earthquakes. These lateral loads may require more building anchorage into the ground than is provided by a FPSF. A FPSF system may be too light to restrain these additional building loads.

By contrast, low and wide buildings are more likely to be suitable for a FPSF. As a first approximation, this design engineer has discovered that buildings which are lower than their narrowest dimension may satisfy wind and seismic structural requirements with a FPSF. For example, a 100 foot wide mercantile building or warehouse that is 30-feet high may be well suited for a FPSF.

4,500°F-Day Methods: Not Enough for Interior Alaska.

The latest design guide information provides solutions for AFIs up to 4,500°F-Days. And, about roughly the northern two-thirds of Alaska have higher design air freezing indices (colder winters). Those using design guide methods for 4,000 or 4,500°F-Day winters may be providing a thermally insulated foundation. However, this author knows of no data to support calling this lower level of insulated heat containment a "frost protected shallow foundation" for these higher design AFI winters. For these colder regions, expect the freezing isotherm to intrude well below the footings. If fine-grained (wicking) soils and moisture are both present, this freezing action provides the final parameter needed for frost heave to occur.

APPENDIX

APPENDIX I – DESIGN RECOMMENDATIONS

Design Procedure

The following are recommended design tables and graphs for use in cold regions with Air Freezing Indices of 4,000 °F-Days to 8,000°F-Days. Sample calculations follow. These recommendations extend beyond the current design information available in building codes or design guides. Final review and approval for specific building projects rests with the code official having jurisdiction over the project.

The procedure is as follows:

1. Air Freezing Index

Determine the desired life span of the building. From that lifespan, select a design air freezing index (AFI). Data for Fairbanks, for example, suggests

30-year recurrence	6,500°F-Days AFI
100-year recurrence	7,300°F-Days AFI

2. Vertical Insulation R-value

Determine the recommended Resistance for the vertical insulation (**Rv**) applied around the perimeter-face of the foundation system (Figure 20).

Commentary:

Note: that the City of Fairbanks has a prescriptive requirement for R-10 minimum for Rv.

3. Horizontal Wall Insulation R-value

Along long walls (away from corners) determine the recommended Resistance for the horizontal wall insulation (**Rhw**) (Figure 21). This insulation will be installed horizontally out from the bottom of the foundation.

Commentary:

There are two graphs: one for poorer soils (SM or worse) and one for better soils (SP or better). The soils are evaluated using a standard Unified Soil Classification System (USC). The USC is chosen because it is widely used and is in the International Building Code. This distinction applies to the soil from the surface to about 12 feet deep. See the examples, below.

4. Horizontal Wall Insulation Projection Distance

Along long walls, determine the Distance from the wall (**Dw**) that the insulation will project (Figure 21).

5. Corner Zone Length

Determine the Length of the corner zone (**Lc**) (Figure 22).

6. Corner Zone Insulation R-value and Projection Distance

Calculate the recommended Resistance for the horizontal corner insulation (Rhc) as follows:

EITHER USE

Alternative A:

Add 30% more insulation and extend the insulation 30% further.

Do both: **Rhc = 1.3 x Rhw** (corner zone R-value is 30% higher than along the wall).

And **Dc = 1.3 x Dw** (corner insulation projects further from the foundation).

OR USE

Alternative B:

Add more 50% more corner insulation, and keep the same projection all around.

Do one: **Rhc = 1.5 x Rhw** (corner zone R-value is 50% higher than along the wall).

And **Dc = Dw** (the Dw distance applies to the corners as well).

Commentary:

Recall, corner zones are colder because heat may escape from both the adjoining cold-faces of the foundation system. Research by others (Hong), as well as my own indicates a simple multiplier is sufficient to account for the increased heat loss at corners. That multiplier adds 30% more insulation value and distance to the corners than is present along the long walls. A case study, reported from the Galena Project (Danyluk) and 2004 NAHV both show adding enough extra insulation R-value (50% more) at corners decreases the need for extending that insulation further.

7. Increasing Perimeter Insulation to Overcome Ground Insulation (e.g., Radiant Heat)

See Rv, shown in Figure 19: Insulation Locations and Nomenclature, below.
(1) Add Rf to Rv. (2) Add Rf to Rhw. (3) Add Rf to Rhc.

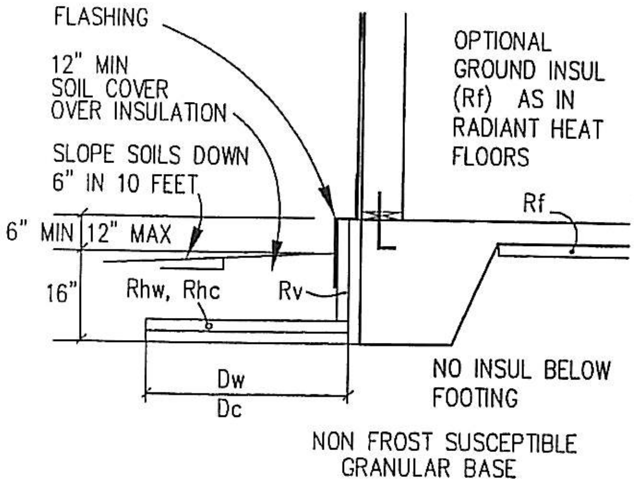
Commentary

Ground insulation, below the slab, may be chosen in certain radiant floor heating systems. The ground insulation helps provide a means of positively anchoring the radiant floor tubing before placing the concrete slab. Two inches of EPS insulation has commonly been observed – in order to resist foot traffic loads without breaking.

However, the ground insulation retards the heat flow from the heated space into the soils below the slab. Note the comment in NAHB 1994, Figure 16, *which states, "Increasing floor insulation will decrease heat flow to the foundations and more perimeter FPSF insulation is required."*

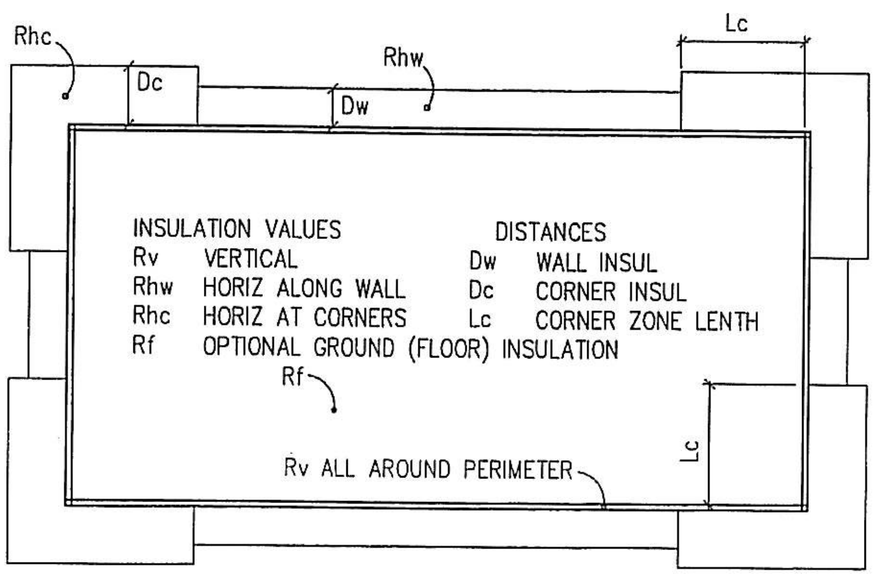
That heat flow from the building into the soils is a vital salient feature, enabling a FPSF system to keep the winter frost line (freezing isotherm) from intruding below the footings. The heat, in the soils, resists the freezing isotherm movement into the foundation zone, below the footings.

Therefore, when ground insulation (Rf) is used below the slab (e.g., for radiant floor heating) additional insulation is also needed around the perimeter of the foundation. The added perimeter insulation is provided to overcome the restricted heat flow caused by the ground insulation.



SECTION THROUGH FOOTING

A	VERTICAL WALL INSULATION ALL AROUND PERIMETER		
	SYMBOL / MEANING		
	Rv	R-VALUE, VERTICAL INSUL	PER Rv GRAPH
B	AWAY FROM CORNERS HORIZONTAL "WING" INSULATION		
	Rhw	R-VALUE FOR HORIZONTAL INSUL ALONG WALLS, NOT @ CORNERS	Rhw & Dw PER Rhw GRAPH
	Dw	DISTANCE INSULATION EXTENDS OUT FROM WALL	
C	AT CORNERS HORIZONTAL "CORNER" INSULATION		
	Rhc	R-VALUE FOR HORIZONTAL INSUL IN THE "CORNER ZONE"	Rhc =1.3 x Rhw
	Dc	DISTANCE INSULATION EXTENDS OUT FROM WALL	Dc =1.3 x Dw
	Lc	CORNER ZONE DISTANCE	PER Lc GRAPH



PLAN VIEW

NOTE: IF GROUND INSUL (Rf) IS USED,
THEN ADD Rf VALUE TO BOTH Rhw AND Rhc.

Figure 19: Insulation Locations and Nomenclature

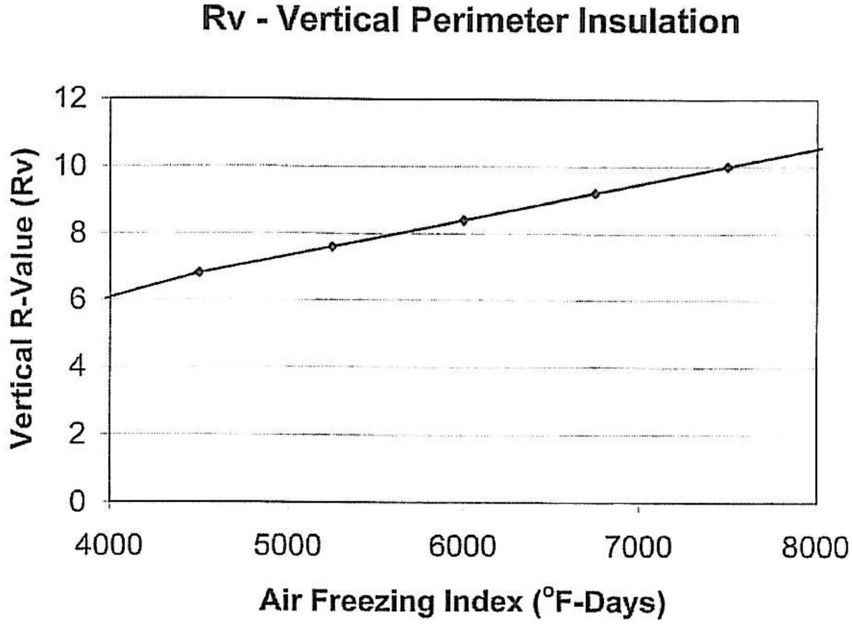


Figure 20: R-Value for Vertical Perimeter Face of the Foundation

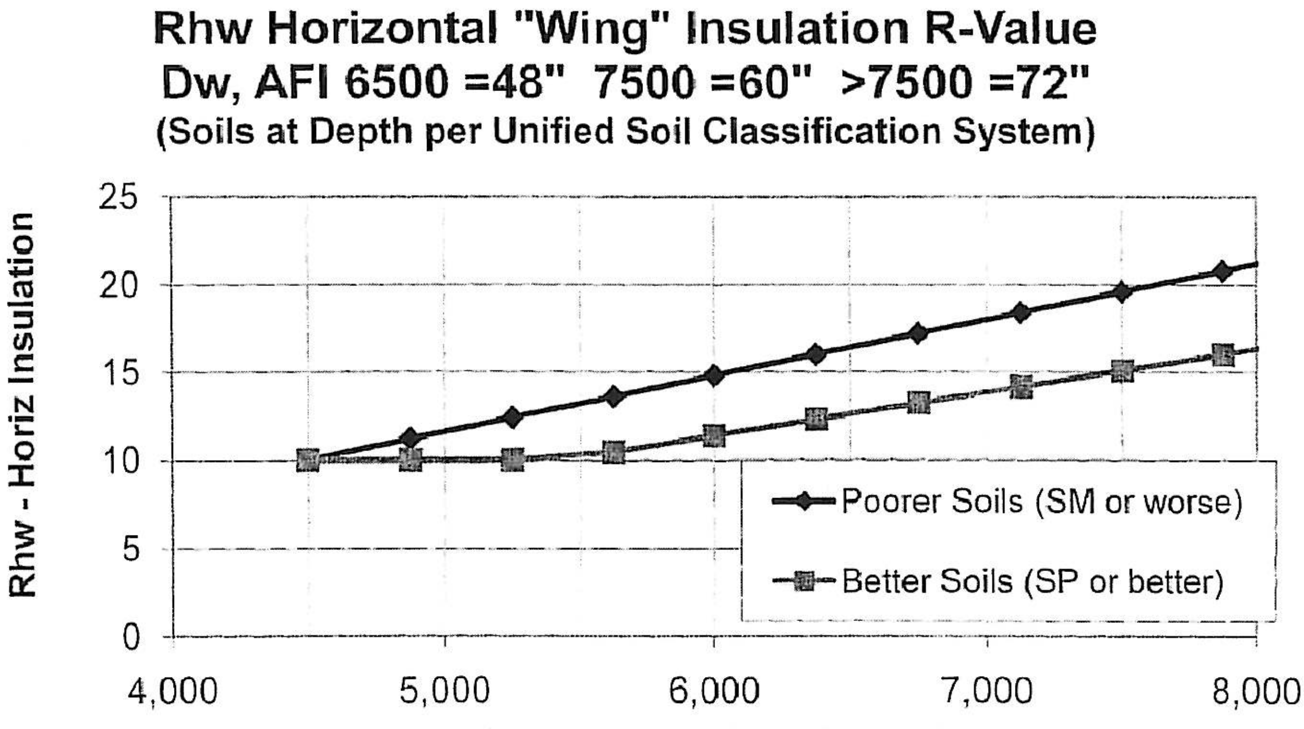


Figure 21: R-Value for Horizontal Wall Insulation

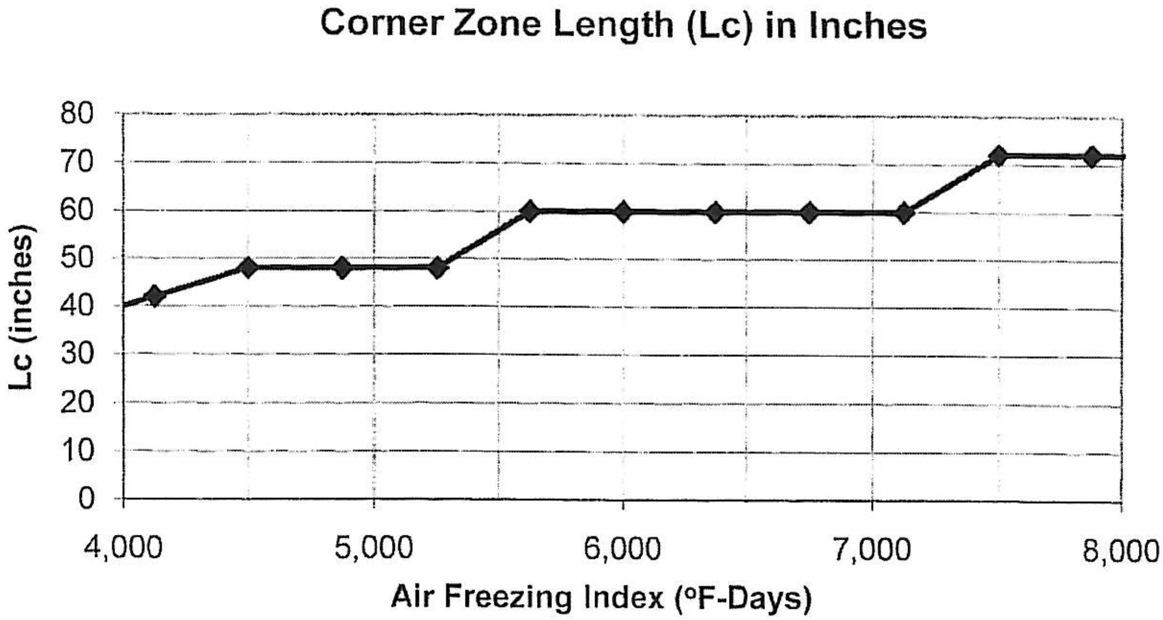


Figure 22: The Length of the Corner Zone (Lc) in Inches

Design Examples

<u>EXAMPLE 1</u>

The building is a residence with a 30 year mortgage. The soils are sandy silts. The ground floor has radiant floor heat, with 2-inches EPS Type II insulation below the slab.

Suggested Solution:

<u>1. Air Freezing Index (AFI)</u>

A 30-year mortgage suggests using a 30 year AFI. From weather data (Page 3), select

AFI_{30yr} = 6,500°F-Days

<u>2. Vertical Insulation R-Value</u>

From Figure 20, select Rv = 9. Note: In Fairbanks, use R-10, minimum, per Local requirements. **Rv = 10**

<u>3. Horizontal Wall Insulation R-Value, away from corners.</u>

A. Evaluate soils parameters using the Uniform Soil Classification (USC) System from ASTM D2487. The USC Classification for sandy silt is "<u>SM</u>."

Commentary

The USC classification system is used here because it is also used in the 2006 International Building Code, adopted for use in Alaska and in Fairbanks. Website http://www.asphaltwa.com/wapa_web/modules/04_design_factors/usc.htm shows a USC Classification table.

B. From Figure 21, with poorer soils, and with AFI=6,500, select **Rhw = 16**

Select insulation thickness:

Alternative insulations for R-16:	EPS II	@ R2.6/in	= 6.15 in (say 6 in)
	EPS IX	@ R2.8/in	=5.71 in (say 6 in)
	XPS	@R4.0/in	= 4 in

<u>4. Horizontal Wall Insulation Projection Distance</u>

From Figure 21, with AFI = 6,500°F-Days, **Dw = 48 inches.**

5. Corner Zone Length.

From Figure 22, with AFI = 6,500°F-Days, Select **Lc = 60 inches.**

6. Corner Zone: Horizontal R-value and Projection Distance

Alternative A

Alternative A adds both 30% more R-value, and 30% more projection distance.

Rhc, Alternative A

Rhc = 1.3 x Rhw: 1.3 x 16. **Rhc,a = 20.8**

Select insulation thickness:

Alternative insulations for R-20.8:	EPS II	@ R2.6/in	= 8 in
	EPS IX	@ R2.8/in	=7.73 in (say 8 in)
	XPS	@R4.0/in	=5.2 in (say 6 in)

Dc, Alternative A

Dc = 1.3 x Dw: 1.3 x 48 inches = 62.4 inches **Dc,a= 60 inches.**

Alternative B

Alternative B adds 50% more R-value, but does keeps one insulation projection distance all around. z1

Rhc, Alternative B

Rhc = 1.5 x Rhw: 1.5 x 16 **Rhc,b = 24**

Alternative insulations for R-24:	EPS II	@ R2.6/in	= 9.23 (say 9 in
	EPS IX	@ R2.8/in	=8.57 (say 9 in)
	XPS	@R4.0/in	= 6 in

Dc, Alternative B

Dc is unchanged. Dc =Dw **Dc,b = 48 inches.**

7. Increased Perimeter Insulation due to presence of Ground Insulation

Ground insulation = 2=inches EPS-II, at R2.6/in. 2 X 2.6 = 5.2 (say R5)

Add R5.2 to vertical and horizontal insulation

Rv + 5	Rv,w/ground insul = 14
Rhw + 5	Rhw,w/grnd insul = 21
Rhc + 5	Rhc, w/ grnd insul = 26

EXAMPLE 2

The building is a commercial building (e.g. a shop or a warehouse). The soils are silty sands with few fines. The design life is 50 years. The building is heated with overhead forced-air heating, not radiant floor heating.

Suggested Solution:

1. Air Freezing Index (AFI)

Select AFI from weather data (Page 3). **AFI_{50yr} = 7,000 °F-Days**

2. Vertical Insulation R-Value

From Figure 20 **Rv = 10**

3. Horizontal Wall Insulation R-Value, away from corners.

USC Classification for soils type **SP or better**

From Figure 21, with better soils, and with AFI=7,000, select **Rhw = 14**

Select insulation thickness:

Alternative insulations for R 14:	EPS II	@ R2.6/in	= 5.38 (Say 5 in)
	EPS IX	@ R2.8/in	= 5
	XPS	@R4.0/in	= 3.5 (say 4 in)

4. **Horizontal Wall Insulation Projection Distance**

From Figure 21, with AFI = 7,000°F-Days, (interpolate) **Dw = 54 inches.**

5. **Corner Zone Length.**

From Figure 22, with AFI = 7,000°F-Days, Select **Lc = 60 inches.**

6. **Corner Zone: Horizontal R-value and Projection Distance**

Alternative A

Alternative A adds both 30% more R-value, and 30% more projection distance.

Rhc, Alternative A

Rhc = 1.3 x Rhw: 1.3 x 14. **Rhc,a = 18.2**

Select insulation thickness:

Alternative insulations for R-18.2:	EPS II	@ R2.6/in	= 7 in
	EPS IX	@ R2.8/in	=6.5 in (say 7 in)
	XPS	@R4.0/in	=4.6 in (say 5 in)

Dc, Alternative A

Dc = 1.3 x Dw: 1.3 x 54 inches = 70.2 inches **Dc,a= 72 inches.**

EXAMPLE 3

This is a government building, a school, or a hospital. It is to have a 100 Year design life. The soils are poorly graded sands or gravelly sands. The floor is insulated with two inches of XPS ground insulation. Perimeter insulation is specified as XPS only.

1. **Air Freezing Index (AFI)**

Select AFI from NCDC Map (Page 3). **AFI_{100yr} = 8,000 °F-Days**

2. **Vertical Insulation R-Value**

From Figure 20 **Rv = 10**

3. **Horizontal Wall Insulation R-Value, away from corners.**

USC Classification for soils type **SP or better**

From Figure 21, with better soils, and with AFI=7,000, select **Rhw = 16**

Select insulation thickness:

XPS @R4.0/in 4 inch XPS

4. **Horizontal Wall Insulation Projection Distance**

From Figure 21, with AFI = 8,000°F-Days, **Dw = 72 inches.**

5. **Corner Zone Length.**

From Figure 22, with AFI = 8,000°F-Days, Select **Lc = 72 inches.**

6. **Corner Zone: Horizontal R-value and Projection Distance**

Rhc, Alternative B

Rhc = 1.5 x Rhw: 1.5 x 16 **Rhc,b = 24**

Dc, Alternative B

Dc is unchanged. Dc =Dw **Dc,b = 72 inches.**

7. Increased Perimeter Insulation due to presence of Ground Insulation

Ground insulation = 2=inches XPS, at R4/in = **Rf = 8**

Add R8 to vertical and horizontal insulation

Rv + 8	Rv, w/grnd insul = 18
Rhw + 8	Rhw,w/grnd insul = 24
Rhc + 8	Rhc, w/ grnd insul = 32

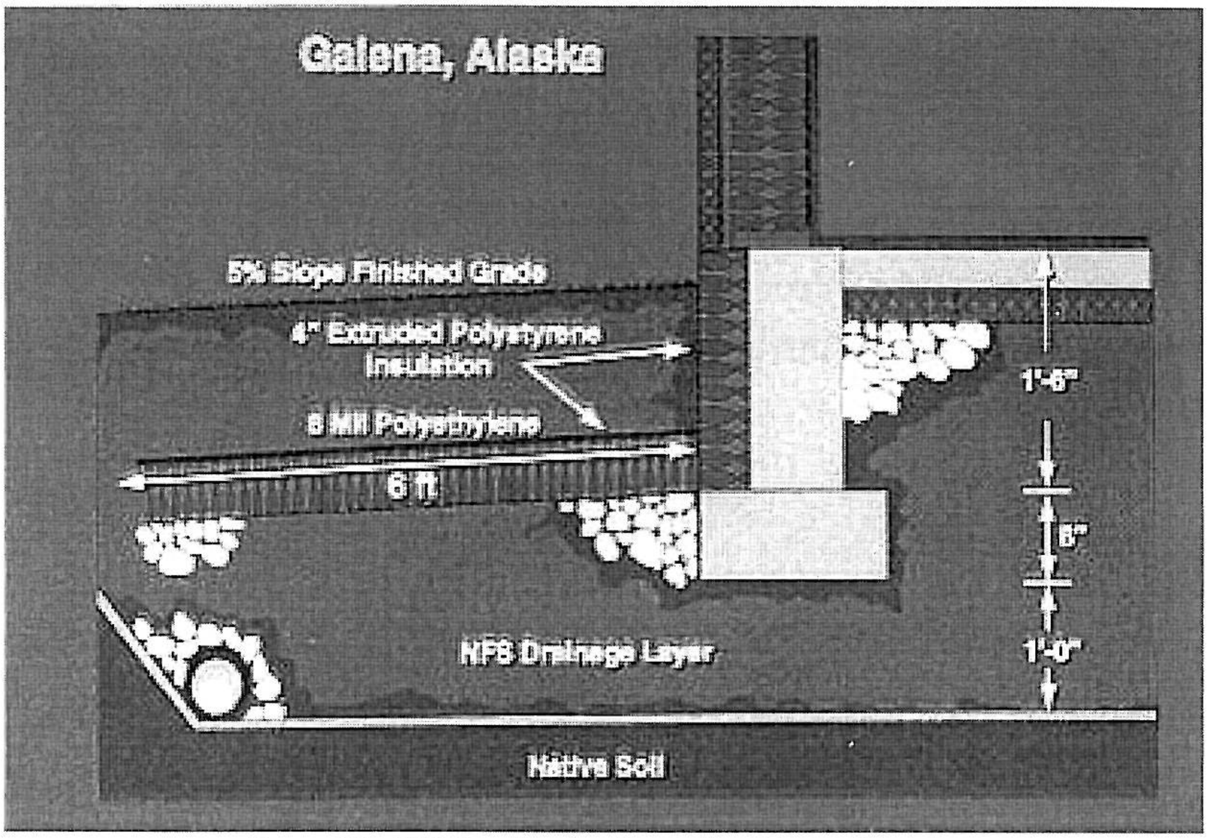


Figure 23: 100-Year Design Example, Galena, Alaska

Example of a CRREL Designed FPSF at Galena Alaska (Danyluk 1997)
Report available at
http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA325471&Location=U2&doc=GetTRDoc.pdf

EXAMPLE 4

An initially heated building is expected to be closed down ("mothballed") and left unheated for extended periods of time. Frost susceptible soils are within the active frost layer that is seasonally frozen each year.

Commentary:

Consult an Alaskan registered design professional for a site specific evaluation.

In interior Alaska (including the greater Fairbanks area) the average annual soils temperatures are below freezing. Over time, expect the soils to freeze below unheated buildings. If frost susceptible soils and water are additionally present, expect frost heave. Either, change the soils or choose a different site.

By contrast, if the soils are non-frost susceptible and dry throughout the active frost layer, then FPSF methods may apply. Again, consult an Alaskan registered design professional for a site specific evaluation.

REFERENCES

American Society of Civil Engineers. (2001) Design and construction of frost-protected shallow foundations (FPSF), SEI/ASCE 32-01. ASCE Publications. http://www.asce.org /bookstore/book.cfm?book=4139

Bowles, J. E. (1984) *Physical and Geotechnical A Properties of Soils*. New York: McGraw-Hill.

City of Fairbanks (2008) *Standard Residential Foundation, SFD-1.* Standard Foundation Details http://www.ci.fairbanks.ak.us/departments/building/standard_handouts.php

Danyluk, L. S. (1977) Shallow insulated foundation at Galena, Alaska, A case study. *CRREL Technical Publications Special Report 97-7.*

Esch, D. C. (1986) Insulation Performance Beneath roads and Airfields in Alaska. Alaska *Department of Transportation and Public Facilities.* Research Report AK-RD-87-17

Farouki, O. (1992). *European foundation designs for seasonally frozen ground.* Monograph 92-1, U.S. Army Corps of Engineers, Cold Regions Res. & Engineering Lab., Hanover, N.H.

Hong, Y. and Jiang, H. (1988) Proceedings from Permafrost - Fifth International Conference, Vol. 2. August 2-5, 1988: *Effect of heating on frost depth beneath foundations of buildings.* 1393-1396.

Johnston, G. H. (1981) *Permafrost: Engineering Design and Construction.* New York: John Wiley & Sons.

Jumikis, A. R. (1977) *Thermal Geotechnics*. New Brunswick, New Jersey: Rutgers University Press

Lunardini, V. J. (1981) *Heat Transfer in Cold Climates*. New York: Van Nostrand Reinhold Co.

The International Code Council (2006) *International Residential Code for One- and Two-Family Dwellings*. International Code Council Publications, Country Club Hills, IL.

National Association of Home Builders (1988) *Frost-Protected Shallow Foundations – for Houses and Other Heated Structures – Design Details Developed by The Norwegian Building Research Institute*.

National Association of Home Builders (1994) *Frost Protected Shallow Foundations, Phase II, Final Report - June 1994*. NAHB National Research Center, Marlboro, MD.

National Association of Home Builders (2004) *Revised Builder's Guide to Frost Protected Shallow Foundations.* NAHB National Research Center, Marlboro, MD

National Climatic Data Center (2008); *NOAA Satellite and Information Service, and Information Service,* http://www.ncdc.noaa.gov/oa/fpsf/fpsfmaps.html. June, 2008

National Weather Service, Alaska Region (NWS-AK) (1998) *Manuscript printouts of recorded weather data from 1904 to present.* (unpublished data).

Saetersdal, R., Regsdall, G. (1979) Frost Protection in Building Construction. *Design Parameters in Geotechnical Engineering.* BGS, London, 1, 57-62.

Steurer, P. M. (1996) Probability Distributions used in 100-Year Return Period of Air-Freezing Index. *Journal of Cold Regions Engineering, Vol. 10, No. 1, March 1996,* pp. 25-35.

Weinstein, J. L., (1994) The Importance of Extruded Polystyrene Insulation. *Building Standards, May-June, 1994,* pp. 14-17.

Zarling, J. P., and Braley, W. A. (1984) Proceedings from Cold Regions Engineering: Third International Specialty Conference: Northern Resource Development. Vol. II. April 1984: *Heat Loss Factors for Building Foundation Insulation Systems.* Montreal, Quebec: Canadian Society for Civil Engineering.

!Final-Rpt-CCHRC-6-15-08.docx