U.S. Department of Housing and Urban Development
Office of Policy Development and Research

FROST-PROTECTED SHALLOW FOUNDATIONS

Phase II - Final Report

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Notice

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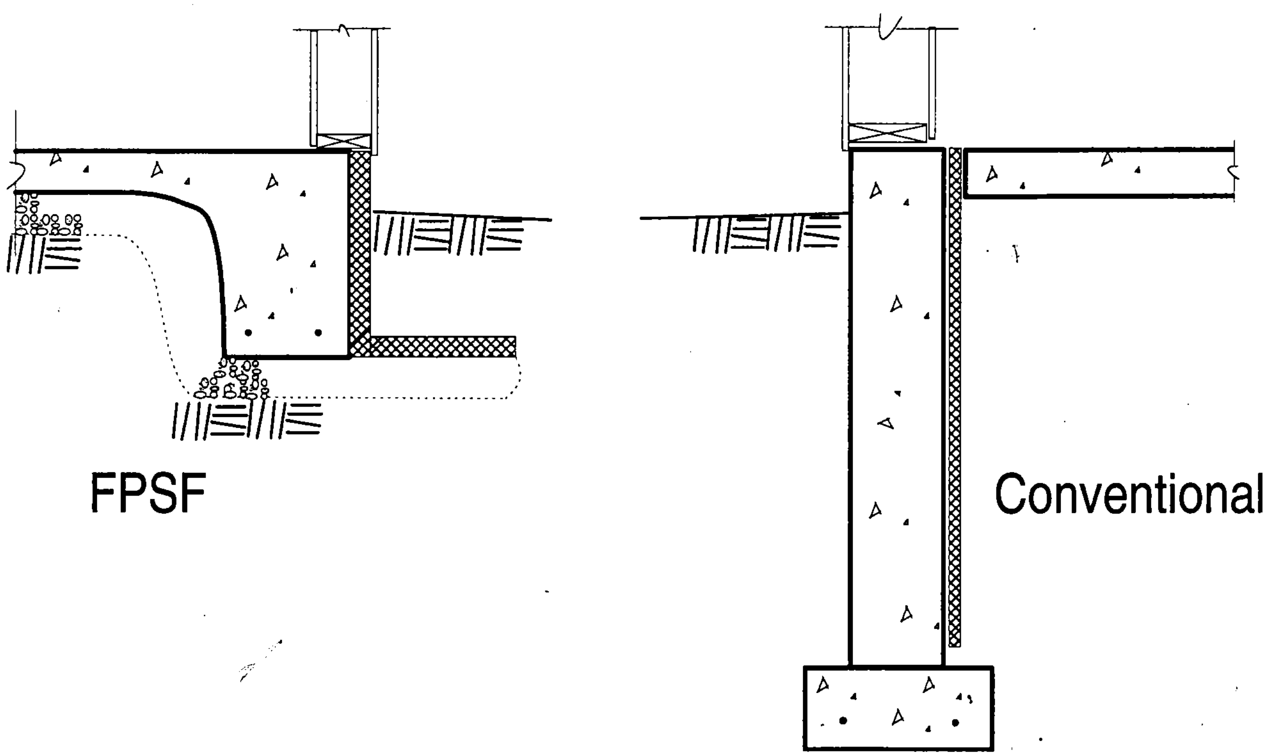
EXECUTIVE SUMMARY

This report contains the results of an investigation and demonstration of the frost-protected shallow foundation (FPSF) technology. Specific tasks include field performance testing of the technology in five homes in the United States; investigating the cost-effectiveness of the technology; and developing design and construction guidelines for builders, designers, and code officials.

A frost-protected shallow foundation is a practical construction method in cold climates where more costly conventional foundation methods are used. The most extensive use of the technology has been in the Scandinavian countries, where over 1 million homes have been constructed successfully over the last 40 years.* The figure below illustrates a frost-protected shallow foundation compared with a conventional foundation. Briefly, a frost-protected shallow foundation relies on insulation strategically placed around the foundation to raise the frost depth around a building, thereby allowing foundation depths as shallow as 16 inches (0.4 meters) in the most severe U.S. climates.



Schematic of FPSF and conventional foundation systems.

The insulation around the foundation perimeter conserves heat loss from the foundation and prevents the freezing of soils under the foundation. The frost-protected shallow foundation is

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* Morris, Richard A. *Frost-Protected Shallow Foundations: Current State-of-the-Art and Potential Application in the U.S.* Prepared for the Society of the Plastics Industry, Inc., (EPS division) by the NAHB Research Center (August 1988); distributed by SPI Literature Sales, Waldorf, MD.

also applicable to unheated parts of buildings such as garages by conserving the geothermal heat reserves in the soil below the building.

CONSTRUCTION AND MONITORING OF DEMONSTRATION HOMES

Five homes were constructed for this project over a two year period to demonstrate and test the technology. During the 1992-93 winter heating season (phase I), one home was constructed and instrumented in each of three sites - Fargo, North Dakota, Spirit Lake, Iowa, and Williston, Vermont. During the 1993-94 winter season (phase II) two additional homes were built - one in Fargo and another in Palmer, Alaska. All of the homes were built on slab-on-grade foundations. The styles of these homes varied from affordable townhomes and detached residences to custom built homes. The FPSF design for each site was based on the established practice in Norway. Four sites were constructed with extruded polystyrene (XPS) insulation, and one site with expanded polystyrene (EPS).

Temperature sensors and an automated data logger were installed at each site during the construction of the homes. Sensors were placed to obtain foundation temperatures, ground temperatures, indoor and outdoor air temperatures and slab surface temperatures. Soil type, moisture content, and other parameters were recorded at each site.

DESIGN PERFORMANCE ANALYSIS

Data from the five homes provided valuable information for the assessment of the frost-protected shallow foundation performance with respect to the recommended design guidelines. The frost heave potential at all of the sites was successfully mitigated for both the heated and unheated areas of the homes and none of the homes experienced freezing of the subgrade soil supporting the foundation. Test areas on two homes were purposely under-designed to subject the technology to a severe test as would be expected should a 100-yr return period winter event occur. These designs were also successful in preventing the potential for frost damage, and further validate the integrity of the design recommendations.

COST OF FROST-PROTECTED SHALLOW FOUNDATIONS

During phase I of the project, a detailed cost analysis was compiled for the homes built for the 1992-93 winter season. Although the builders each realized cost savings compared to their conventional construction practices, there was a wide variability in costs due primarily to different degrees of familiarity with the technique and to differences in house type. Cost savings ranged from 1.1 to 3.8 percent of the total home sales price.

Previous cost studies also illustrate the cost savings potential of frost-protected shallow foundations. A study by Morris compared shallow foundations without garages or other unheated spaces to conventional deep-foundation practices in Fargo, ND; Minneapolis/St. Paul, MN;

Chicago, IL; Pittsburgh, PA; Washington, DC; and, St. Louis, MO.** The savings calculated for a frost-protected shallow foundation in this study were similar to that achieved by the demonstration homes. Morris has projected a potentially large annual savings in energy and construction costs if the technology experiences wide-spread acceptance.

DESIGN AND CONSTRUCTION RECOMMENDATIONS

Design and construction recommendations were developed under this project based on data from a proposed consensus standard by the Comité Européen de Normalisation (CEN). The CEN draft standard is based on well-documented experiences in Europe, covers a broad range of frost-protected shallow foundation applications, and is also being considered as a standard by the International Standards Organization. Results from the five homes in this investigation further validate the proposed CEN design standard for the type of applications covered in the demonstration homes. The design and construction guidelines are published under a separate title: *Design Guide for Frost-Protected Shallow Foundations****.

CONCLUSIONS

Findings from this study support the following conclusions:

1. Houses and other structures may be built on shallow, slab-on-grade foundations in cold-climates when properly insulated to protect against frost heave.

2. The demonstration homes performed well and provide substantiating evidence for the frost-protected shallow foundation techniques design recommendations.

3. Frost-protected shallow foundation construction provides a cost-effective alternative to conventional foundation construction in the United States. Cost savings to the home buyer range from approximately 1 to 4 percent of the cost of a conventional slab-on-grade home and are even greater when compared to basement construction.

4. Experience has shown that the frost-protected shallow foundation technology may be used to increase the energy efficiency of new houses at a minimal or reduced construction cost.

**Morris, Richard A. *Frost-Protected Shallow Foundations: Current State-of-the-Art and Potential Application in the U.S.* Prepared for the Society of the Plastics Industry, Inc., (EPS division) by the NAHB Research Center (August 1988); distributed by SPI Literature Sales, Waldorf, MD.

*** NAHB Research Center. *Design Guide for Frost-Protected Shallow Foundations*. Prepared for the United States Department of Housing and Urban Development, Washington, DC: GPO, 1994.

INTRODUCTION

This report addresses one of a series of projects conducted for the U.S. Department of Housing and Urban Development (HUD) to investigate technologies that may reduce the construction costs of housing. Specifically, this document reports on findings from a two-phase investigation of frost-protected shallow foundations (FPSF).

In the Phase I report[1] to HUD, it was verified that the FPSF technology was capable of reducing the cost of foundation construction and successfully preventing frost heave of foundations. A detailed presentation of the performance of the first three homes during the 1992-93 winter season is presented in that report. Construction cost savings of 1 to 4 percent of the total home sales price are also reported. These findings are in agreement with the European experience over the last 40 years which is exemplified in over 1 million homes built using FPSF techniques.

While the Phase I study was instrumental in demonstrating the feasibility of the FPSF technology, it did not provide conclusive test results of the performance limit of FPSF homes during an extreme winter event.

The main objectives of this second phase study were

1. to provide a stringent field test of the frost-protected shallow foundation technology on homes built in severe climatic and soil conditions of the United States;
2. to demonstrate and investigate alternative applications of the technology;
3. to provide a concise, yet comprehensive, design and construction document for builders, designers, and code officials; and
4. to initiate changes to the model U.S. building codes as supported by substantiating evidence from this project.

The tasks conducted during this Phase II investigation of frost-protected shallow foundations were:

1. **Monitoring of Phase I demonstration homes**. The continued monitoring of the three demonstration homes in North Dakota, Iowa, and Vermont required maintenance of automated data acquisition systems at the sites, periodic data quality/operational checks, and performance analysis of the FPSF designs during two winter seasons (1992-94).

2. **Construction and monitoring of additional test homes.** Two additional homes were constructed to demonstrate alternative uses of the FPSF technology. Special test areas on the foundations were designed and instrumented to simulate relatively extreme

[1] NAHB Research Center. *Frost-Protected Shallow Foundations in Residential Construction - Phase I.* Prepared for the United States Department of Housing and Urban Development, Washington, DC: GPO, 1993.

environmental conditions. Performance was monitored and analyzed during the 1993-94 winter season.

3. **Preparation of final design and construction recommendations.** The preliminary design recommendations of the Phase I study were updated in accordance with site monitoring results, construction experience, and development of consensus standards. The final design guidelines are published separately as *Design Guide for Frost-Protected Shallow Foundations*. In addition, return period estimates of the air-freezing index, an important climatic parameter required for the design procedure, were validated by investigations using reliable long-term weather records.

BACKGROUND

CONCEPT

A frost protected shallow foundation (FPSF) is a practical and cost-effective alternative to conventional residential foundations which, in practice, require excavations to prescribed frost depths. Figure 1 shows a typical FPSF application compared to a conventional foundation. Briefly, a FPSF relies on strategically placed insulation to raise the frost depth adjacent to a building foundation, thereby allowing foundation depths as shallow as 16 inches (0.4 meters) in severe climates.

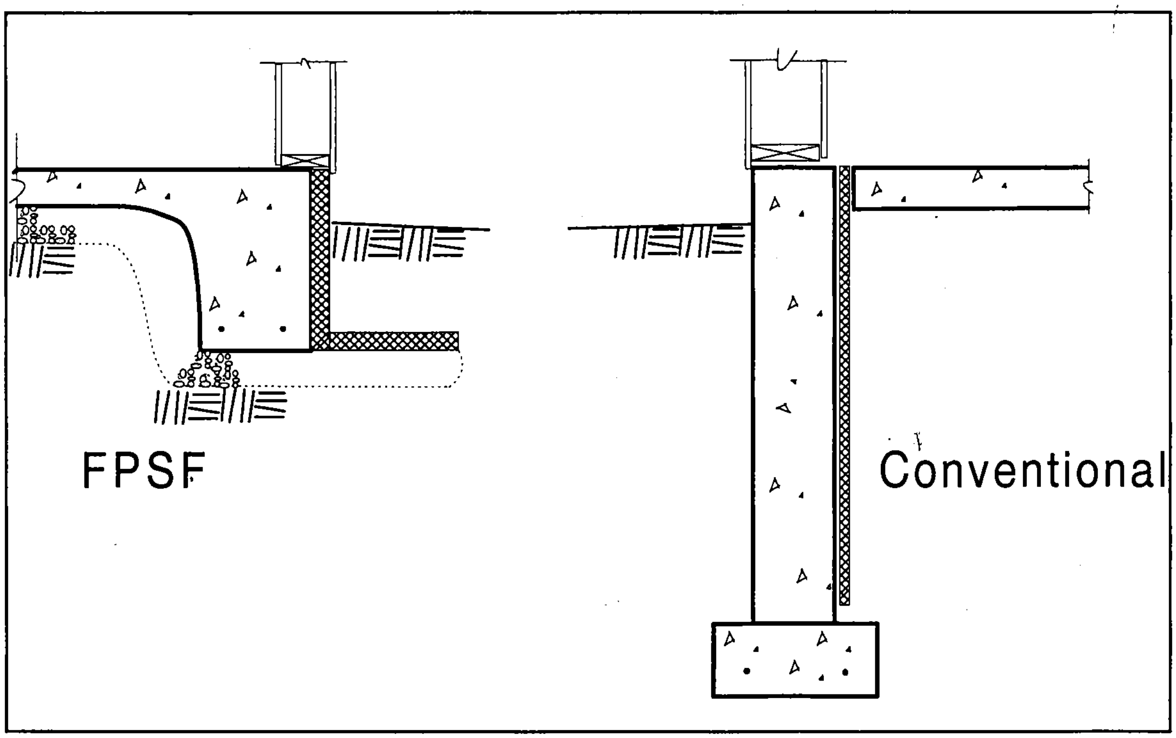

Figure 1. A frost protected shallow foundation in comparison to a conventional house foundation.

Figure 2 illustrates the effect of ground coverings and other conditions on frost penetration. It is important to note that the frost line rises near a foundation if the building is heated. This effect is magnified when insulation is strategically placed around the foundation.

Figure 3 illustrates the heat exchange process of a FPSF, which acts to prevent soil freezing below the foundation. The vertical (wall) insulation and horizontal (wing) insulation around the foundation perimeter conserves heat loss through the slab and redirects it toward the soil below the foundation. Energy efficiency is increased by limiting heat loss through the above ground portion of the foundation wall where the most severe losses occur in conventional foundations. Stored geothermal heat released from the underlying ground also helps to raise the frost depth around the building.

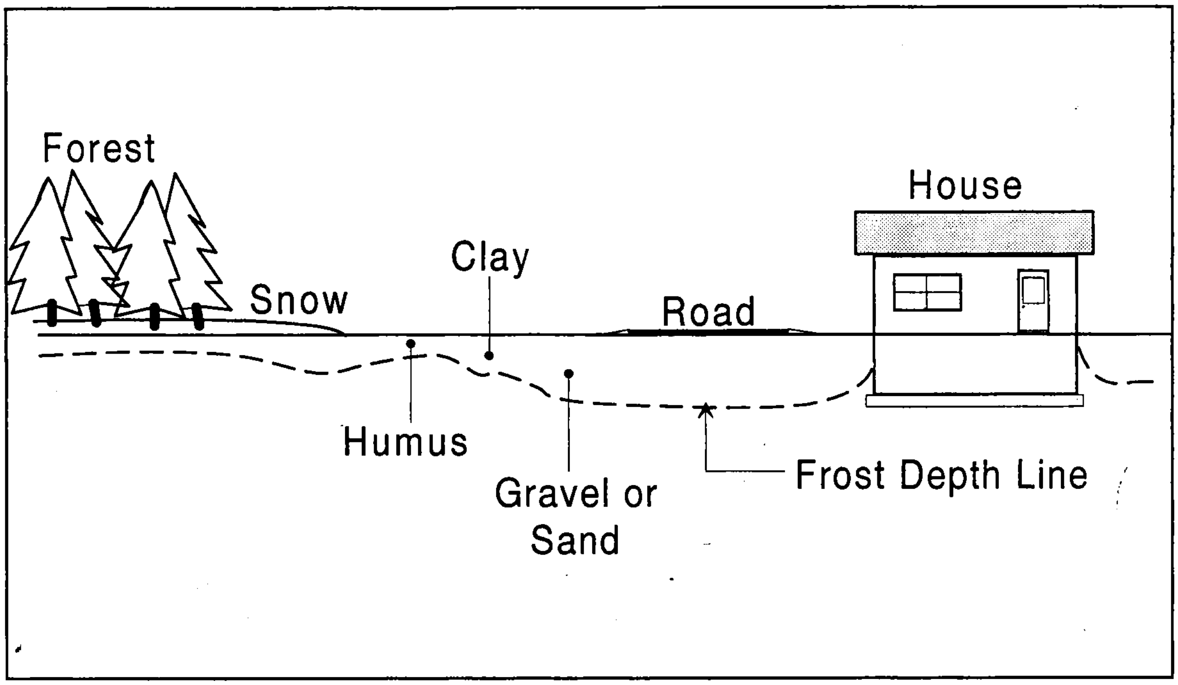

Figure 2. The effect of various conditions on frost penetration into the ground.

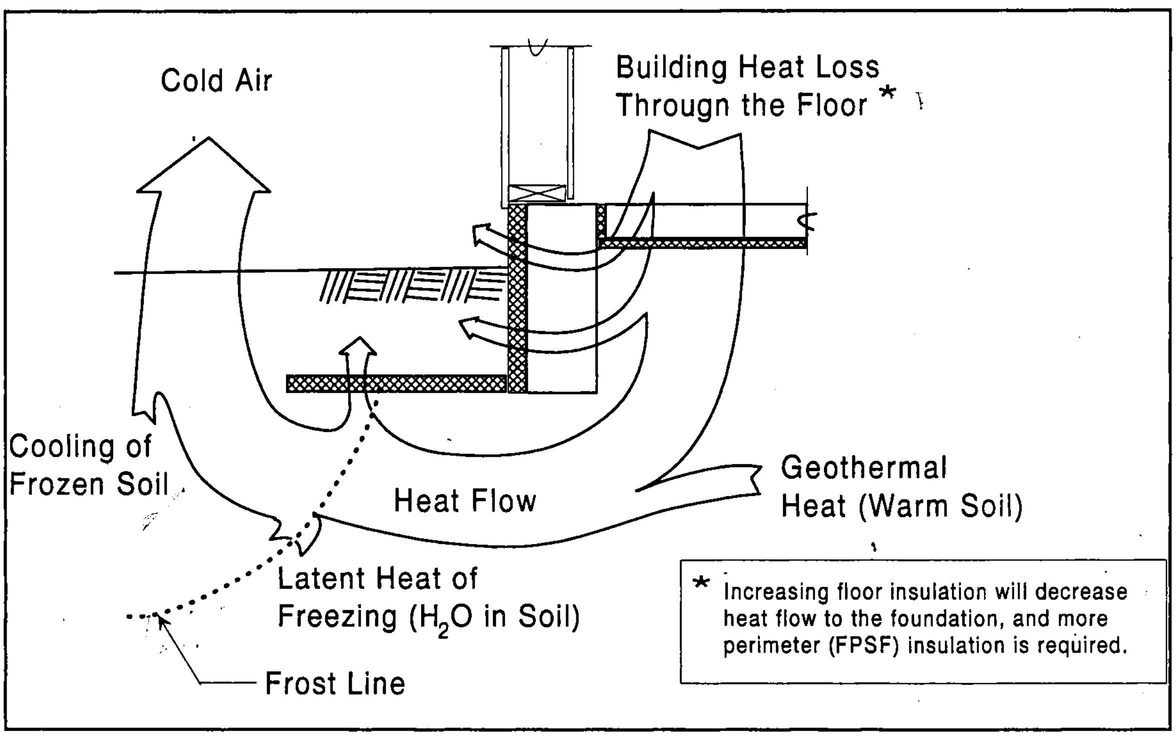

Figure 3. Heat exchange occurring at an insulated building foundation.

By increasing insulation under the entire slab and improving the conservation of existing geothermal heat, the FPSF concept can also effectively protect unheated buildings as well. Unheated areas of homes such as garages, porches, and stairwells may be protected in this manner.

FPSFs are most suitable for slab-on-grade homes on sites with moderate to low sloping grades. The method may also be used effectively with walk-out basements by insulating the foundation on the downhill side of the house, thus eliminating the need for a stepped footing. FPSFs are also useful for remodeling projects and sites with difficult ground conditions because they minimize site disturbance and excavation depth. They are also useful to solve existing frost-heave problems by retrofitting foundations with a protective FPSF insulation design.

While this report focuses on slab-on-grade construction methods, the technology may also be applied to crawlspace foundations with some added considerations such as ventilation control. In addition to residential, commercial, and agricultural buildings, the technology has been applied to control frost-heave damage in highways, dams, underground utilities, railroads, and earth embankments.

It is estimated that FPSF techniques could provide 590,000,000 kilowatt-hours in energy savings annually and nearly $300,000,000 savings in annual construction costs[2].

HISTORY

In the United States, slab-on-grade houses were constructed around the turn of the century in cold climates near Chicago, Illinois. During the Depression, Frank Lloyd Wright designed and built a type of FPSF to meet affordability needs and used FPSF techniques in his "Usonian" style homes with shallow slab-on-grade foundations. However, the technology was never developed or applied to the degree realized in Europe.

In the 1950s, Swedish and Norwegian researchers constructed the first experimental houses using insulated shallow foundations. These homes provided practical experience and empirical data on the FPSF technology. By 1972, nearly 50,000 slab-on-grade foundations had been built in Sweden, and the FPSF technology had gained wide acceptance. In the 1970s, the Scandinavian countries consolidated their research efforts in an attempt to address cold regions engineering topics. The effort led to the 1976 publication of *Frost I Jord* ("Frost Action in the Ground")[3]. Scandinavian engineers consider *Frost I Jord* a reliable guide for design against frost action in soils. Based on the results of the Frost I Jord Project, the Norwegian Building Research Institute started publication in 1978 of "Building Details" specifically detailing FPSF design and construction methods. The FPSF technology is now considered standard practice in Norway, Sweden, and Finland.

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[2] Morris, Richard A. *Frost-Protected Shallow Foundations: Current State-of-the-Art and Potential Application in the U.S.* NAHB Research Center. Prepared for the Society of the Plastics Industry, Inc. (EPS Division), Washington, DC. (1988).

[3] Heiersted, R.S. Frost I Jord (Frost Action in Ground), Nr. 17. Committee on Frost Action in Soils. Prepared in Norwegian for the Royal Norwegian Council for Scientific and Industrial Research (Oslo, Norway). 1976.

CURRENT STATUS

It is estimated that several thousand homes and other structures have been built in the United States using the FPSF technology, but only in circumstances where building codes are non-existent, special engineering was performed, or local conditions (e.g. Alaska) necessitate consideration of insulated foundations placed at depths above the maximum seasonal frost penetration.

The major model building codes in the U.S. do not specifically address the FPSF technology. However, recent amendments to the CABO *One and Two Family Dwelling Code* and the BOCA *National Building Code* recognize performance-based criteria for frost protection of foundations. The ICBO *Uniform Building Code* (common to many northern states) and the SBCCI *Standard Building Code* do not permit any alternate methods of protecting foundations from frost heave. Foundation insulation is required by national energy codes (e.g., CABO *Model Energy Code*), but it is not recognized for its frost-protection benefits.

A significant current activity is a proposed Comité Européen de Normalisation (CEN) consensus standard that is based on the extensive European experiences of the past four decades. This European community standard, also being considered by the International Standards Organization (ISO), will likely become a U.S. consensus standard.

RESULTS

DESCRIPTION OF DEMONSTRATION HOMES

During Phase I of this project (1992-93), three FPSF demonstration homes were constructed, monitored and evaluated for foundation performance and construction costs. These homes were located in Vermont, Iowa, and North Dakota. The homes varied in style from a 4-unit townhome complex, to a custom single-family detached home (see Figures 4 through 7). In each case, the foundations were constructed with 12 inch deep monolithic slab footings (plus an additional 4 inch depth of gravel). The foundations were protected against frost heave according to European FPSF design guidelines. Two homes used 1.6 pcf extruded polystyrene (XPS) insulation, and one used 1.8 pcf molded or expanded polystyrene (EPS). Construction details are shown in Appendix A for each site.

Because the foundations in Phase I were designed for a 100-year return period winter freezing event, the average winters experienced during 1992-93 did not provide a stringent performance test of the FPSF designs. Consequently, two additional demonstration homes were built in Phase II with the intention of subjecting the FPSF designs to a severe design event. The foundations were designed using the normal 100 year return period, with exception of a test zone created in each design. The insulation in the test zone was sized for an average winter event for that climate, instead of the 100-yr return period as normally required in the design guidelines.

The Phase II homes are located in Palmer, Alaska and Fargo, North Dakota. The Alaska home was an affordable, single-story ranch style home constructed on a monolithic slab-on-grade. The North Dakota site (#2) was an affordable, single-story 3-unit townhome complex on a slab-on-grade and stem wall foundation. The foundation stem wall was constructed of recycled plastic lumber in a manner similar to permanent wood foundations. The sites are shown in Figures 8 and 9. Except for the special test areas, the foundations were protected against frost according to European FPSF guidelines, specifically the proposed CEN standard method. Both sites were built with 1.6 pcf XPS insulation products, one of which incorporated post-consumer wastes. Construction details are provided in Appendix A for each Phase II site.

INSTRUMENTATION OF DEMONSTRATION HOMES

Each of the five demonstration homes were outfitted with automated data acquisition systems to record and download performance data to the NAHB Research Center in Upper Marlboro, MD. Temperature sensors were installed in the ground and around the foundations during construction in the summer of 1992 (Phase I homes) and the summer/fall of 1993 (Phase II homes). Other sensors were placed to obtain indoor air temperatures and slab surface temperatures. A weather station that measured ambient air temperature, wind speed, and frost penetration into undisturbed soil was also deployed at each site. Both thermocouple and thermistor sensors were used and, at some locations, sensors were duplicated to allow simple data quality checks. Automated dataloggers were installed when the homes were completed.

Figure 4. Photograph of the Williston, Vermont site.

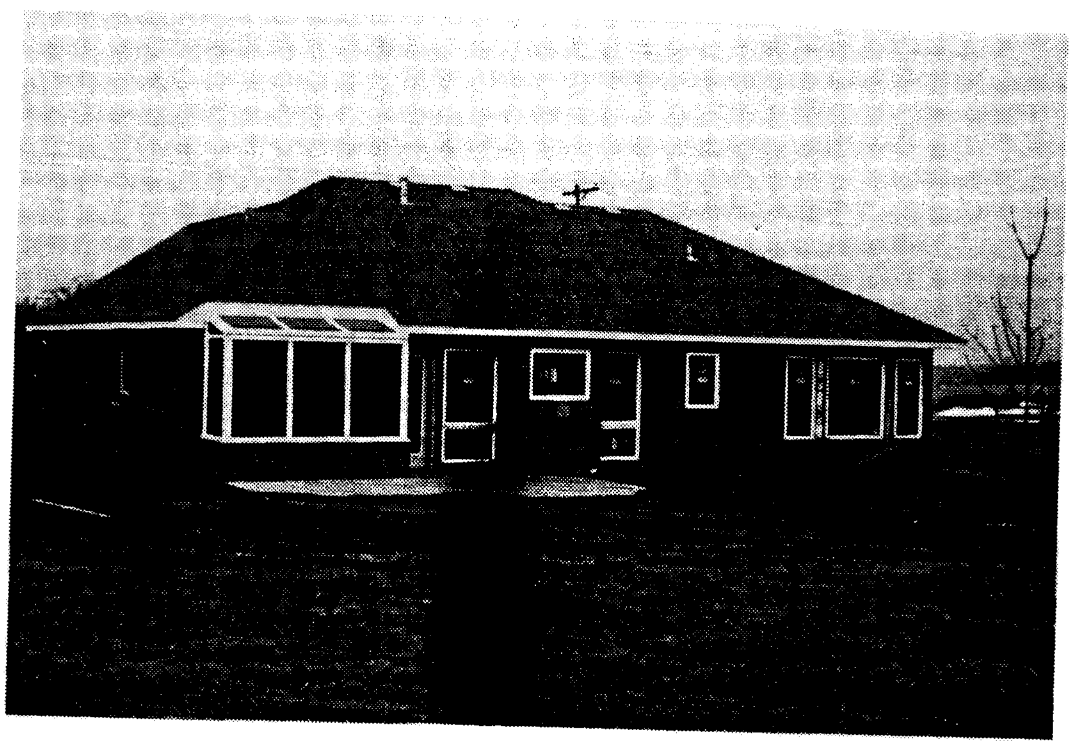

Figure 5. Photograph of the Spirit Lake, Iowa site.

Figure 6. Photograph of the Fargo, North Dakota site (home #1).

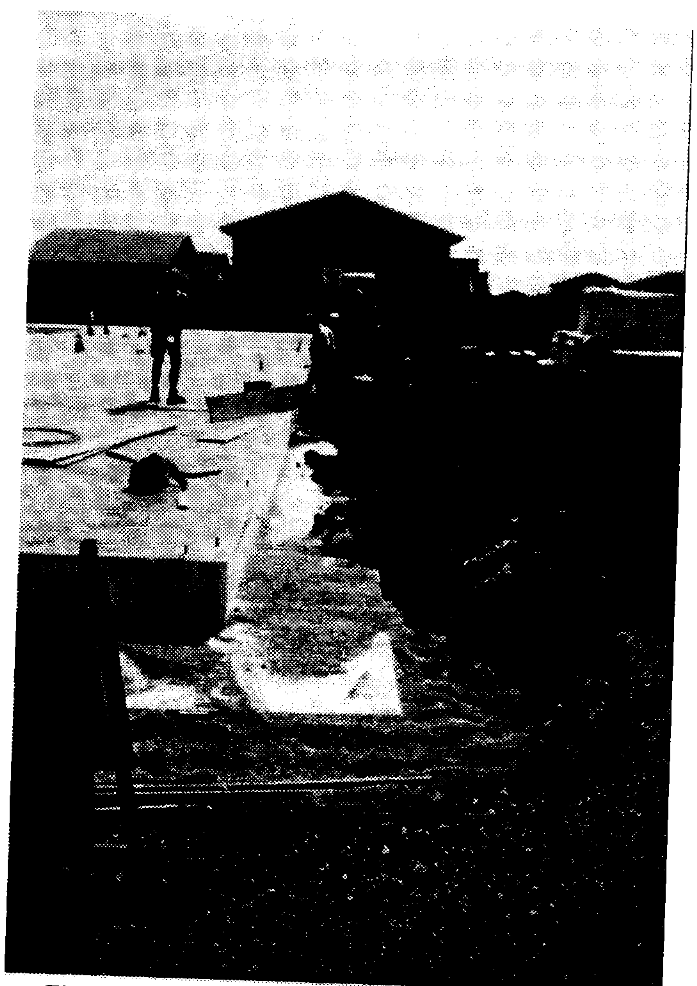

Figure 7. Photograph of the FPSF foundation construction at Fargo, North Dakota (home #1).

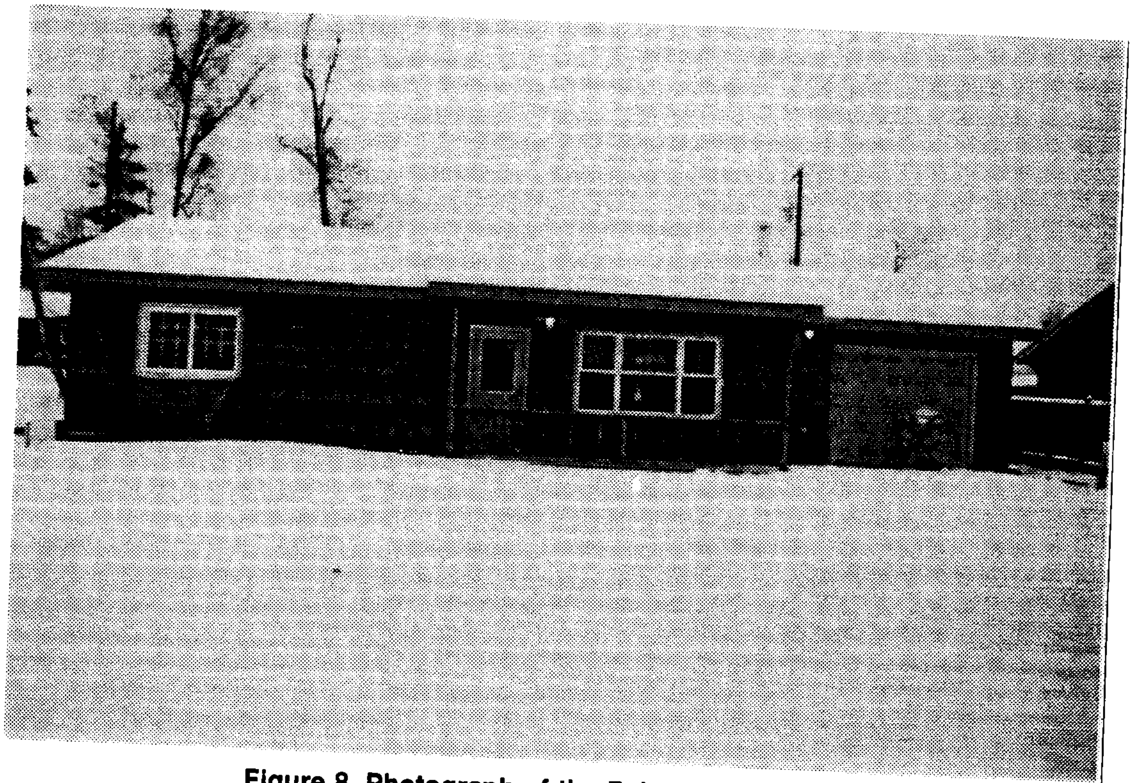

Figure 8. Photograph of the Palmer, Alaska site.

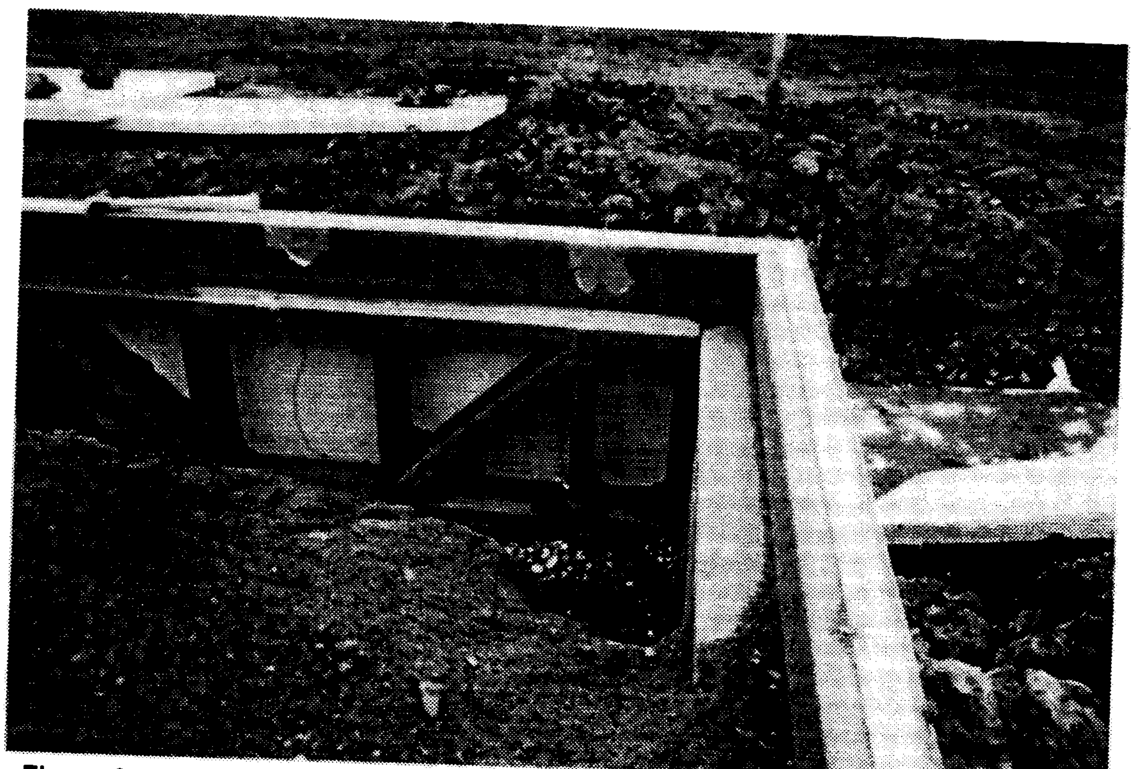

Figure 9. Photograph of the recycled plastic lumber used in the FPSF design at the second Fargo, North Dakota site (home #2)

PERFORMANCE OF DEMONSTRATION HOMES

An analysis of the winter events experienced at each of the sites is needed to accurately assess the FPSF performance. The air-freezing index (AFI) is a climatic index used to determine the magnitude of the ground freezing potential experienced during a winter season. In fact, the 100 year return period of the AFI is used to size insulation requirements in the FPSF design procedure. A detailed discussion of the AFI is included in the Phase I report as well as other technical reports referenced in this document. While the AFI is the primary factor in determining the ground freezing potential (frost depth), other important variables include ground cover, snow depth, soil type, and amount of soil moisture. These key environmental parameters are summarized for each site in the Appendix. For all but the Alaska site, the most severe winter was recorded in the 1993-94 season. In terms of the air-freezing index the North Dakota, Iowa, and Vermont sites experienced approximately a 4-yr return period event during the 1993-94 winter season. Short duration freezing episodes of 1-day and 7-day average temperatures broke previous 30-yr extreme low temperature records in Fargo, North Dakota and challenged previous records in Iowa and Vermont.

To assess the performance of each foundation design, records of the minimum daily average temperatures were plotted at every sensor for the period of record at each site. For simplicity in judging the maximum frost line penetration around the foundations, the 32°F (0°C) isotherm was also plotted. Selected data is shown in the Appendix. It is realized that this provides a conservative criteria for assessing the onset of frost damage since freezing of soil water will actually begin at a somewhat depressed temperature. Other factors, such as a late completion of some of the test foundations, the angle of the frost line, amount of penetration underneath the footings required for significant heave forces to develop, and the actual amount of soil moisture in terms of latent heat content, add further to a conservative assessment. These factors may be offset to a large degree by the amount of snow accumulation at each site. Since these factors cannot be easily controlled by design, the FPSF design method assumes the worst case of a severe winter in combination with no snow accumulation and a minimum amount of soil water sufficient to allow frost heave to occur but minimizing the latent heat contribution. For this reason, the insulation requirements may be applied to all soil types and successfully prevent frost heave from occurring as was evidenced by the variety of soil types at the demonstration sites (see the Appendix).

The homes constructed during Phase II in Palmer, Alaska and Fargo, North Dakota (home #2) are of particular interest in assessing the integrity of the frost-protected shallow foundation technology. As described previously, these homes were designed with a test zone which had undersized insulation to withstand only the average freezing index for that site. In effect, a near average winter event would simulate a 100-yr return period test of the frost protection provided by the design guidelines. In North Dakota, where the 1993-94 winter was particularly severe, the frost line was successfully withheld from penetrating into the subgrade underneath the perimeter of the building in the test zone. The frost penetration was significantly less in the remaining areas of the foundation where normal levels of insulation were utilized for frost protection. This finding indicates that the insulation requirements specified in the design guidelines provide a high degree of protection against frost heave, as intended. Similarly the test was successful at the Alaska site, but the winter there was relatively mild.

As reported for the Phase I demonstration homes, the foundation performance was satisfactory and the foundation soils were protected against freezing temperatures[4]. The homes constructed during Phase I were monitored continuously for two winter seasons. This allowed a more thorough investigation of the long-term performance of frost-protected shallow foundations with respect to the thermal impact of a building on ground temperatures and freezing. In spite of a more severe winter at each of the sites in the second season of monitoring, the general increase in ground temperatures in the vicinity of the building indicates that buildings provide a significant increase in the thermal storage of heat in the ground. In turn, this thermal mass in the soil under the building contributes to greater frost protection and increased comfort for slabs-on-grade in cold climates.

While all of the sites were successful in preventing frost penetration in the soil underneath the footings, one home experienced a frost penetration at the corner of the foundation greater than expected for a near average winter. Highly conductive soil thermal properties and/or a low moisture content may have contributed to a greater frost penetration, but the maximum frost depth recorded at the weather station doesn't appear to support this hypothesis. The proper specification of insulation products, paramount to the success of any FPSF application, could also have contributed to the performance at this site. Because few insulation products are able to maintain a dry R-value in a moist, below-grade environment over any great length of time, insulation products specified for a FPSF must be rated with an effective R-value, determined by their ability to maintain a certified R-value in such an environment for the expected life of the structure. Because some insulation materials resist water absorption less effectively than others, which in turn degrades their thermal resistance (R-values), insulation material should be specified carefully. Interestingly, EPS insulation (Type IX) was used at this site, for both the vertical and horizontal insulation, and a modestly reduced effective R-value was used to determine the required material thicknesses. The reader is directed to related references listed in the bibliography for greater detail on this issue.

Slab surface temperatures at the building perimeter were monitored to investigate the level of comfort provided by the minimum insulation requirements for frost protection. A sufficiently high slab surface temperature at the perimeter must also be maintained to prevent moisture condensation. The interior areas of the slab are affected very little by the perimeter insulation levels. However, the slab surface temperatures along the perimeter are affected by the insulation levels, particularly the vertical wall insulation R-value. Quality of installation with respect to air-infiltration and elimination of cold-bridges also affect the slab temperatures. Given the extreme cold temperatures experienced during the 1993-94 winter (exceeding the 30-year extreme cold on record), the minimum slab surface temperatures recorded were generally within an acceptable range. As expected, the lowest temperatures were recorded near the corners of the foundations were heat loss is greatest. The coldest slab surface temperatures were recorded at 1 foot (0.3 meters) in from the slab edge at the corner, and they ranged from 37 to 48°F (3 to 9°C) for all but the Alaska site. At midwall locations and 3 foot from the edge, the coldest slab surface temperatures ranged from 52 to 64°F (11 to 18°C). The most uniform and warm slab surface temperatures were recorded at the Alaska site where insulated hot water lines for baseboard heating were run in the slab around the perimeter of the home. The minimum surface

[4] NAHB Research Center. *Frost-Protected Shallow Foundations in Residential Construction.* Prepared for the U.S. Department of Housing and Urban Development (Washington, DC:GPO, 1993).

temperatures at all monitoring locations around the perimeter of this slab ranged from 57 to 61°F (14 to 16°C).

DESIGN AND CONSTRUCTION RECOMMENDATIONS

The frost-protected shallow foundation design and construction recommendations resulting from this project rely extensively on data from a proposed consensus standard by the Comité Européen de Normalisation (CEN). The CEN draft standard for frost-protected shallow foundation design is based on well-documented experiences in Europe, covers a broad range of frost-protected shallow foundation applications, and is also being considered as a standard by the International Standards Organization. The results of this investigation further validate the proposed CEN design standard for the type of applications covered in the demonstration homes. The design and construction guidelines for the United States are published under a separate title: *Design Guide for Frost-Protected Shallow Foundations*[5]. The design guide provides both a detailed and a simplified procedure which includes the necessary climate data, construction recommendations, details, and examples. The simplified method is based on a code change recently proposed to the CABO *One- and Two- Family Dwelling Code.* The outcome of this proposal will not be known until late 1994.

[5] NAHB Research Center. *Design Guide for Frost-Protected Shallow Foundations.* Prepared for the United States Department of Housing and Urban Development, Washington, DC: GPO, 1994.

RECOMMENDATIONS

The frost-protected shallow foundation technology has seen tremendous growth in the Scandinavian housing industry after first being discovered in the United States. While the technology has been highly developed and proven in Europe, great effort will be required to re-introduce it to the United States. Even then, with such a "new" construction concept, building code adoption will be quite unpredictable and time-consuming. The following recommendations are offered:

1. Efforts to encourage adoption of this technology by the major building code organizations in the United States should continue.

2. Educational seminars and materials should be established for building officials, builders, engineers, and architects.

3. Building energy codes should be encouraged to recognize the use of frost-protected shallow foundations as a means of meeting minimum insulation requirements for energy conservation.

4. A material test standard to define the effect of moisture absorption on the thermal resistance (R-value) of various insulation products is needed. The standard should identify a range of typical ground-use conditions which may promote moisture absorption and thermal degradation of insulation. The standard will help with correctly specifying and rating insulation for use on foundations to protect against frost heave and excessive heat loss.

5. Future research should investigate alternative foundation materials to be used for frost protection which provide structural support as well as significant thermal resistance. Some materials might include plastics, light-weight insulated concrete and blocks, permanent wood foundations, and others.

CONCLUSIONS

Findings from this study support the following conclusions:

1. Houses and other structures may be built on shallow, slab-on-grade foundations in cold-climates when properly insulated to protect against frost heave.

2. The demonstration homes performed well and provide substantiating evidence for the frost-protected shallow foundation techniques.

3. Frost-protected shallow foundation construction provides a cost-effective alternative to conventional foundation construction in the United States. Cost savings to the home buyer range from approximately 1 to 4 percent of the cost of a conventional slab-on-grade home and are even greater when compared to basement construction.

4. Experience has shown that the frost-protected shallow foundation technology may be used to increase the energy efficiency of new houses at a minimal or reduced construction cost.

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Appendix

DEMONSTRATION SITE DATA

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SITE CHARACTERIZATION

The following tables describe the climate and soil conditions at each of the demonstration sites. Historical climate data in Table A1 include the air-freezing index and mean annual temperature, important parameters in the design procedure. Complete climate data summaries for the 1992-94 winter seasons are shown in Table A2 for each site. Table A3 provides a more detailed breakdown of the severity of a winter by identifying the coldest 1- and 7-day average temperatures occurring during the 1992-94 winter seasons. Soil characteristics are shown in Table A4.

Table A1.
HISTORIC CLIMATE DATA

LOCATION	Mean Annual Temperature (°F)[1]	Air-Freezing Index[2] (°F-days)		Heating Degree-Days[3] (Base 65°F)	Mean[4] Snowfall (inches)	Local Code Footing Depth[5] (inches)
		100-Year Return	Mean			
Fargo, ND	40	3,600	2,340	9,254	36	60
Spirit Lake, IA	45	2,560	1,595	8,110	36	48
Williston, VT	44	2,050	1,379	7,771	60 to 100	72
Palmer, AK	35	3,890	2,425	10,900	60 to 100	120[6]

1. Climatography of the U.S. No. 81--Supplement No. 3, "Maps of Annual 1961-90 Normal Temperature, Precipitation, and Degree Days."
2. Steurer, Peter and J. Crandell, "Comparison of Methods Used to Create an Estimate of the Air-Freezing Index," NOAA National Climatic Data Center, Asheville, NC (1993).- unpublished data
3. "Annual Degree Days to Selected Bases Derived for the 1961-90 Normals", U.S. Department of Commerce, NOAA, NCDC, Asheville, NC (1992).
4. Climatic Atlas of the U.S., U.S. Department Commerce (1968).
5. Measured from finish grade to bottom of the footing. Locally established frost depths for determining footing depths do not necessarily follow a logical climatic progression as realized in Williston, VT.
6. In Alaska, footing depths of 42" are standard when crawlspace walls are insulated with R10 batt or foam insulation, the crawlspace area is heated, and ventilation is eliminated during the winter months.

Table A2.
ACTUAL 1992-94 CLIMATE INFORMATION

LOCATION	1992-93 Air-Freezing Index		1992-93 Snowfall (inches)	1993-94 Air-Freezing Index		1993-94 Snowfall (inches)
	Estimated Return Period (Years)	Recorded AFI (°F-Days)		Estimated Return Period (Years)	Recorded AFI (°F-Days)	
Fargo, ND	2.5	2,475	47.3	4	2,607	78
Spirit Lake, IA	2.0+	1,688	30.7	4	1,862	—
Williston, VT	2.0-	1,307	64.1	4	1,584	—
Palmer, AK	--	--	--	1.1	1,251	—

Table A3.
SHORT-DURATION OUTDOOR FREEZING CONDITIONS

	Extreme Cold Temperature for Short-Duration Averages (°F)							
	1-Day Average				7-Day Average			
	30-Year Mean	30-Year Extreme	1992-93 Record	1993-94 Record	30-Year Mean	30-Year Extreme	1992-93 Record	1993-94 Record
Fargo, ND	-17.4	-25.3	-16.9	-26.5	-8.2	-16.1	-7.4	-20.0
Spirit Lake, IA	-11.4	-21.5	- 8.4	-20.2	-1.7	-11.7	3.5	-11.0
Williston, VT	- 9.3	-18.0	-14.3	-16.6	2.0	-10.9	7.0	1.0
Palmer, AK	-17.3	-30.0	--	-0.4	-8.1	-22.9	--	—

Source: Steurer, Peter and J. Crandell, "Comparison of Methods Used to Create an Estimate of the Air-Freezing Index," NOAA National Climatic Data Center, Asheville, NC (1993) -- unpublished data.

Table A4.
GEOGRAPHIC AND SOIL INFORMATION

Location	Topography	USDA Soil Name (Texture)	Unified Soil Classification (PI,LL)	In-situ Soil Dry Density (#/ft^3)	Water Table Depth (ft)	In-situ Soil Moisture (%db)	Estimated Heave Susceptibility	Estimated Shrink/Swell Potential
Fargo, ND	Flat, Riverine Plains	Fargo Clay (silty clay)	CH (45,71)	Unknown	Varies 4 to 10	28 to 45	Slight to moderate	High
Spirit Lake, IA	Rolling Plains	Clarion (clay-loam)	SC (15,36)	108	Varies 6 to 8	17 to 25	Moderate	Low
Williston, VT	Hilly, Mountainous	Unknown (sandy silt)	GP-GM (10,36)	Unknown	Unknown	6 to 10	Moderate to high	Low
Palmer, AK	Valley, Mountainous	Unknown (silt)	ML (0,34)	65*	Unknown	26 to 35 (53% sat.)	High	Low

* Laboratory tests by ASTM D1557-a gives a maximum compacted density of 103 pcf at 19.5% optimum moisture content.

CONSTRUCTION DETAILS AND SELECTED PERFORMANCE DATA

The following drawings show the as-built construction conditions at each of the demonstration sites. Although similar designs (with respect to slab type, drainage layer thickness, and foundation depth) were provided to each participating builder, the actual field-built conditions varied. As a result, the instrumentation of the sites varied with respect to sensor locations and quantity. Also shown is the maximum penetration of the 32°F (0°C) isotherm based on the minimum recorded average daily ground temperatures. The frost line penetration is reported as a distance, measured along the surface of the sub-grade soil, from the edge of the footing to the frost line

FARGO, NORTH DAKOTA (HOME #1)

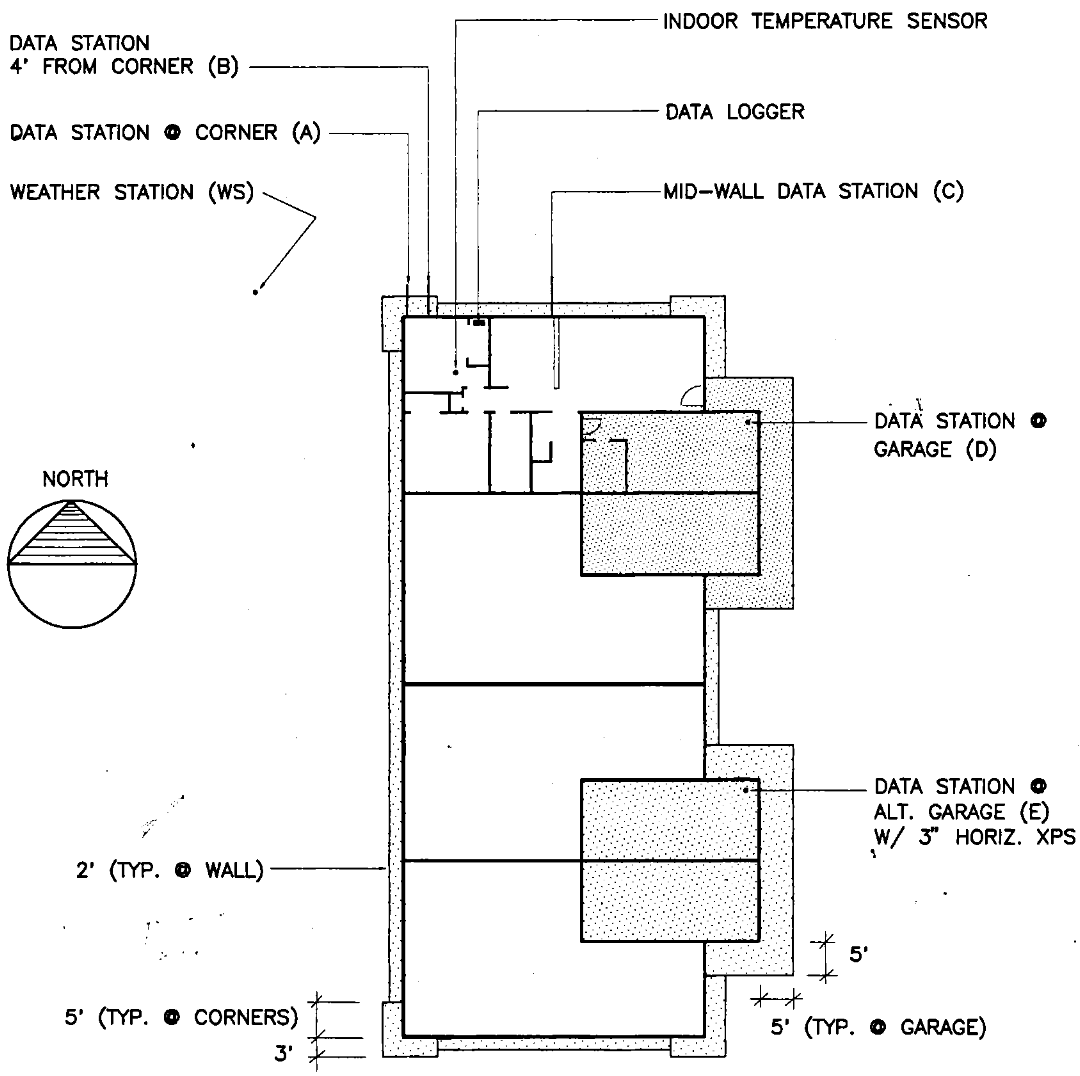


Figure A1. Site plan for home #1 in Fargo, ND.

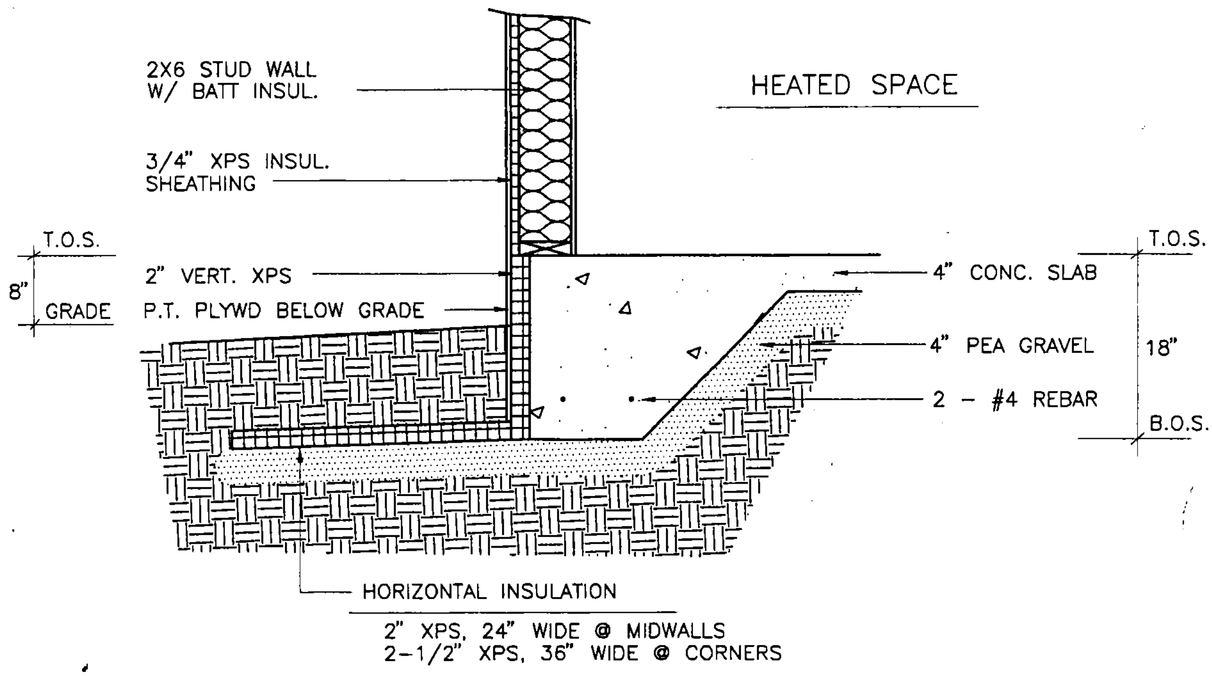


Figure A2. Heated FPSF as-built detail for house #1 in Fargo, ND.

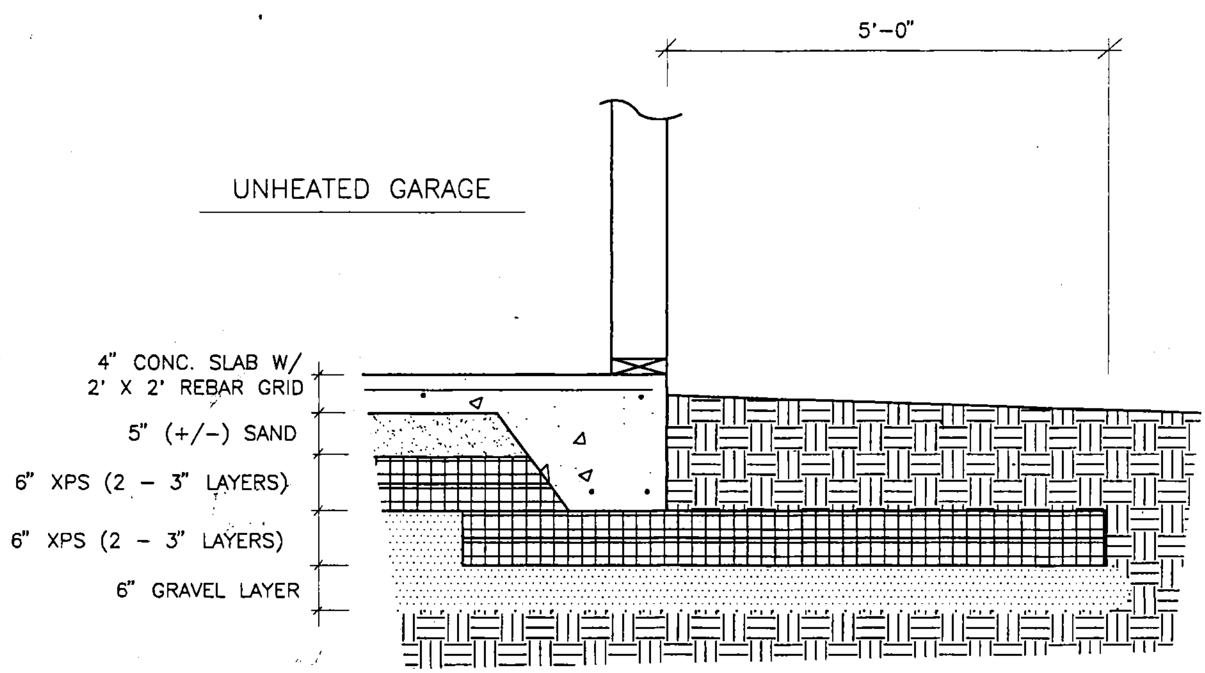
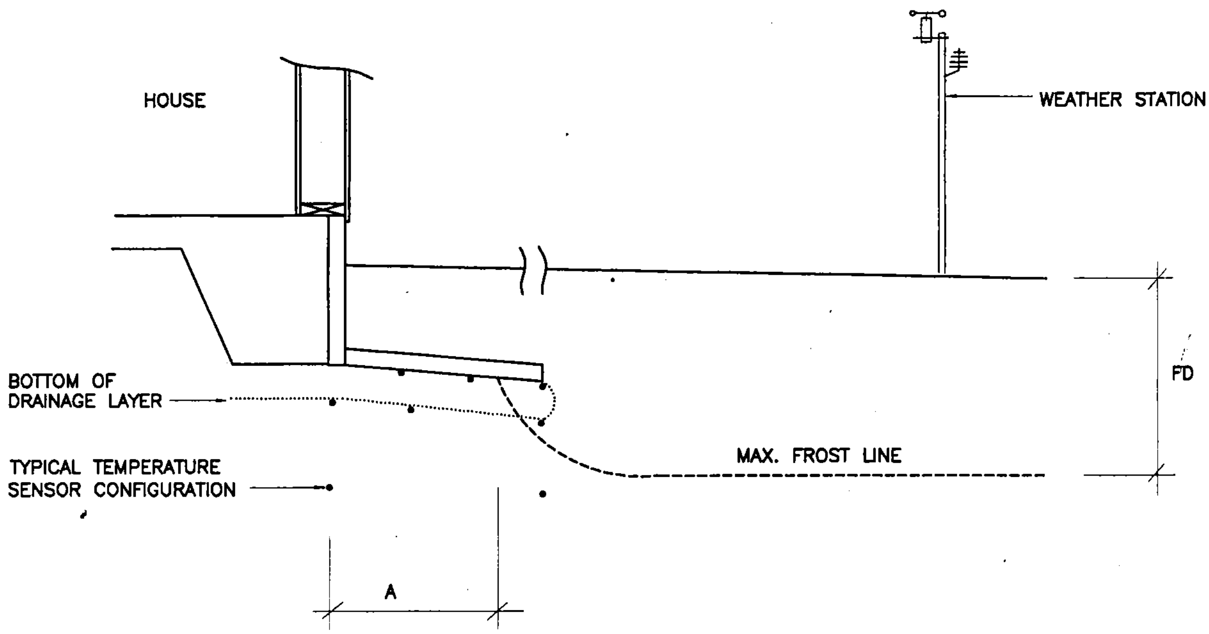


Figure A3. Unheated garage FPSF as-built detail for house #1 in Fargo, ND.



Winter Season	Frost Depth, FD (inches)	Horizontal Distance From Footing to Frost Line (A)	
		@ Corner	@ Mid Wall
1992-93	25	36"	26"
1993-94	12	>38"	>26"
Comments: Frost penetration underneath the garage foundation was not detected by the sensors and a frost line could not be plotted. Performance was as expected.			

Figure A4. Frost line penetration @ house #1 in Fargo,,ND.

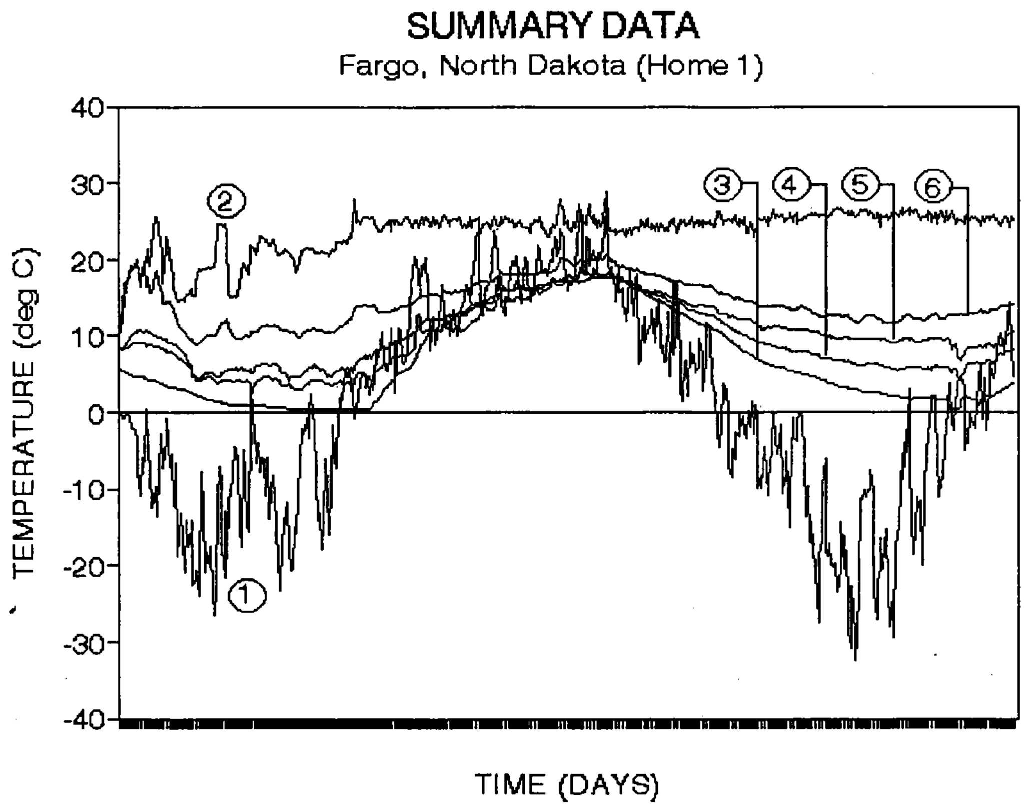


Figure A5. Selected temperature data @ house #1 in Fargo, ND.

KEY:

1. Outdoor
2. Indoor
3. Ground, 30" Depth
4. Bottom of Footing at Corner
5. Bottom of Footing at Wall
6. Slab Surface, 3' from Edge

PERIOD OF RECORD: 11/7/92 to 4/20/94

SPIRIT LAKE, IOWA

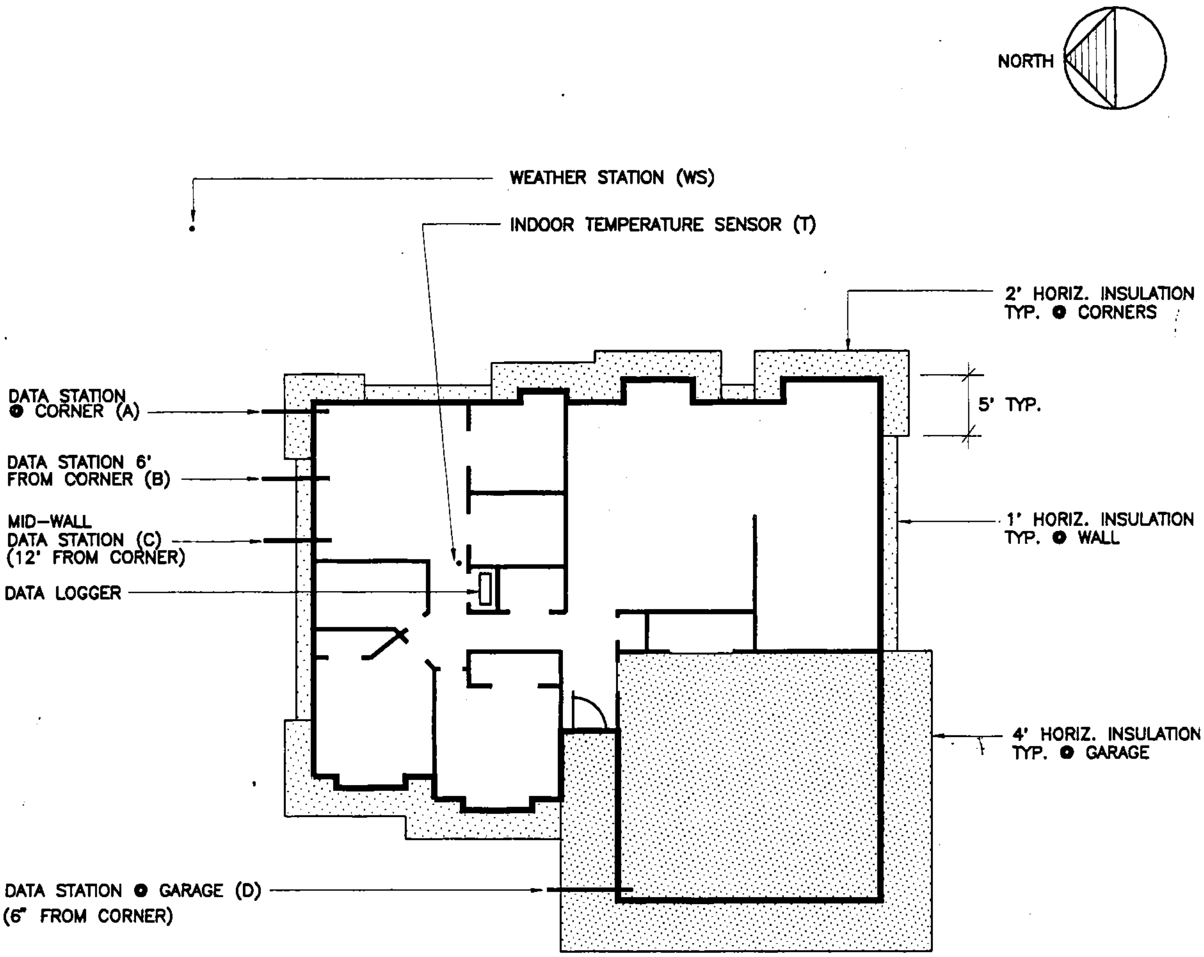


Figure A6. Site plan for Spirit Lake, IA.

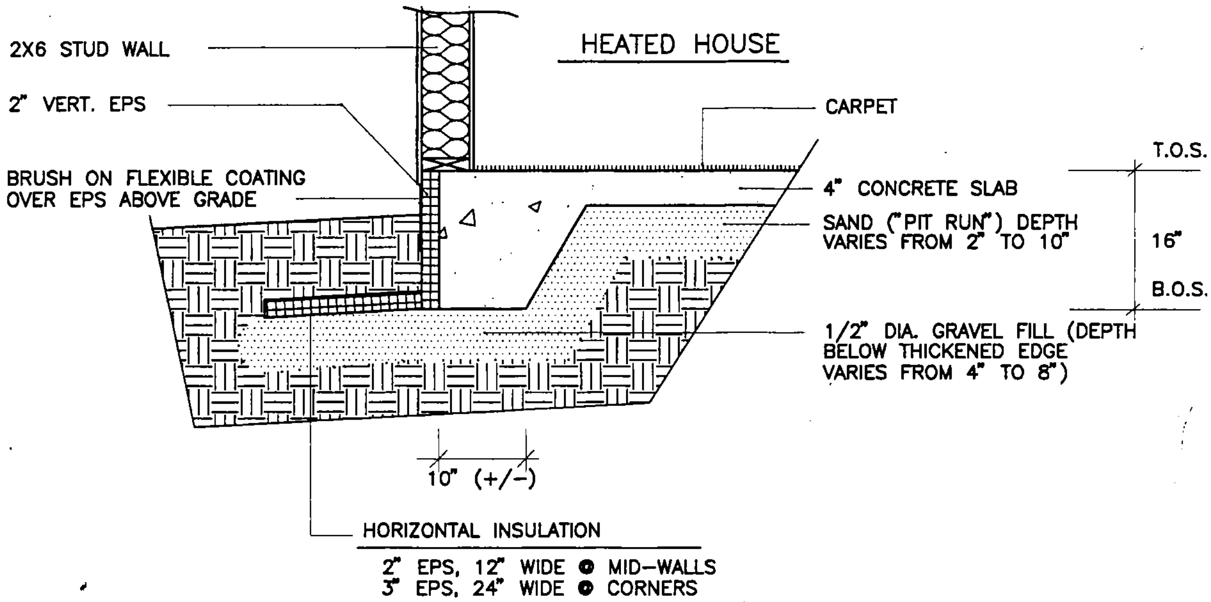


Figure A7. Heated FPSF as-built detail for Spirit Lake, IA.

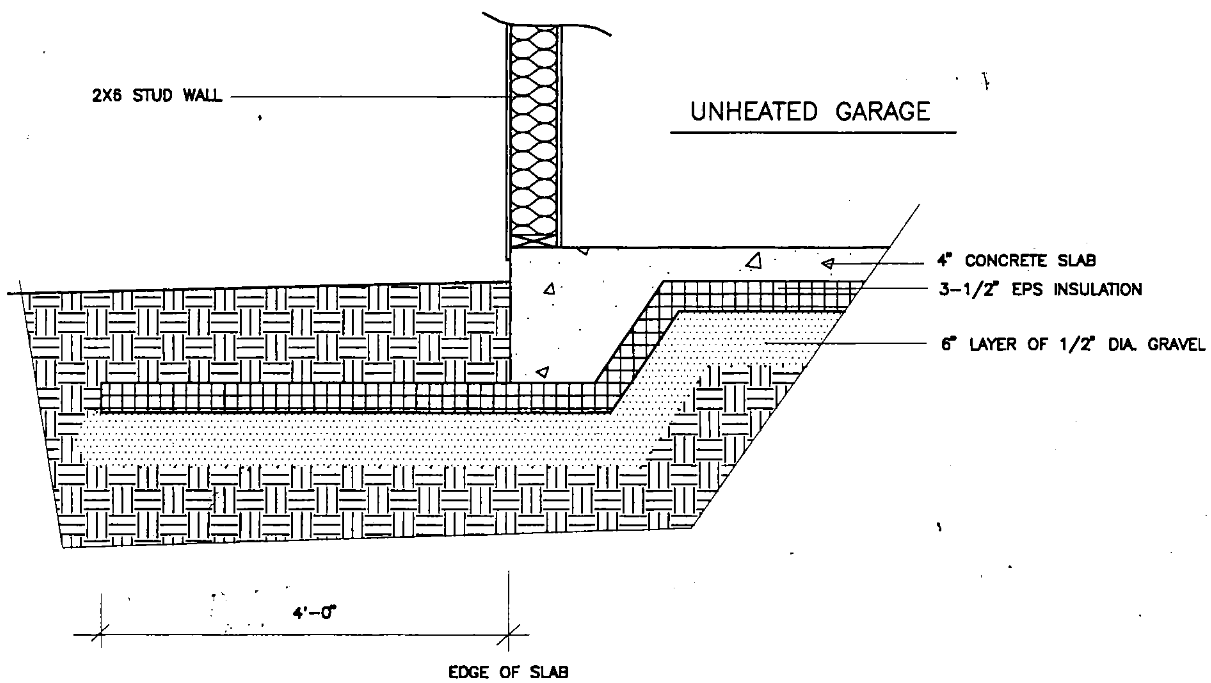
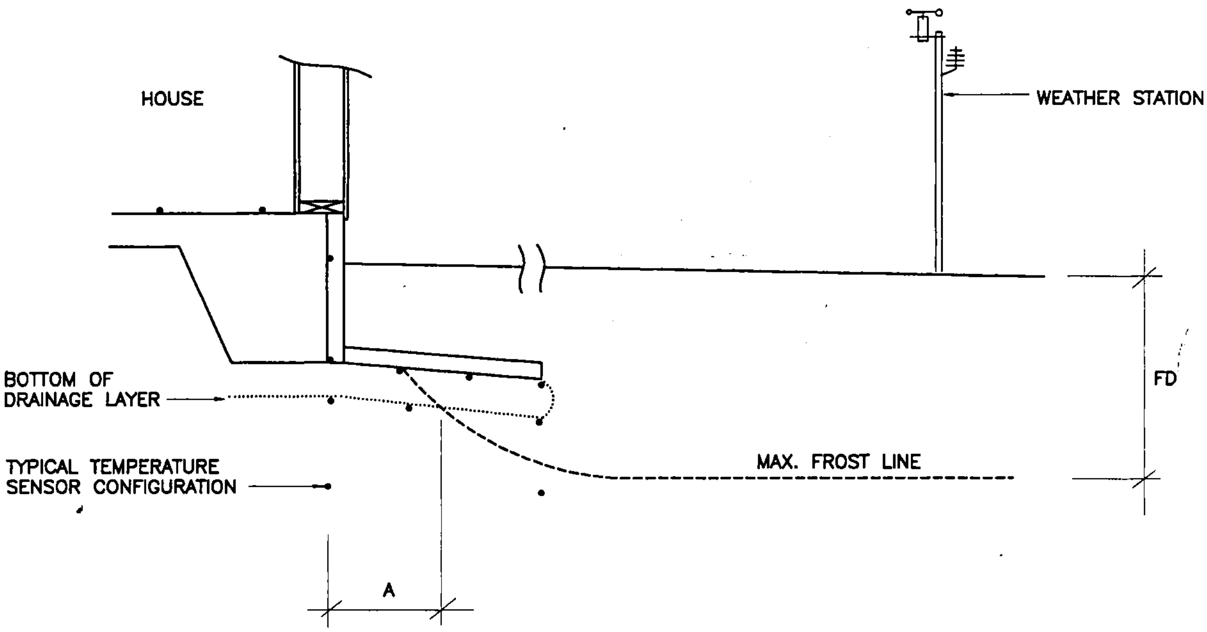


Figure A8. Unheated garage FPSF as-built detail for Spirit Lake, IA.



Winter Season	Frost Depth FD	Horizontal Distance From Footing to Frost Line (A)		
		@ Corner	@ Mid-Wall	@ Garage
1992-93	24"	16"	14"	36"
1993-94	25"	0"	10"	24"

Comments: The frost penetration at the corner was greater than expected. This result might be explained by: (1) thermally conductive ground conditions which are not heave-susceptible, even when frozen, or (2) degradation of insulation material R-value. As discussed in the report, this was the only site which used molded or expanded polystyrene (EPS).

Figure A9. Frost line penetration @ Spirit Lake, IA.

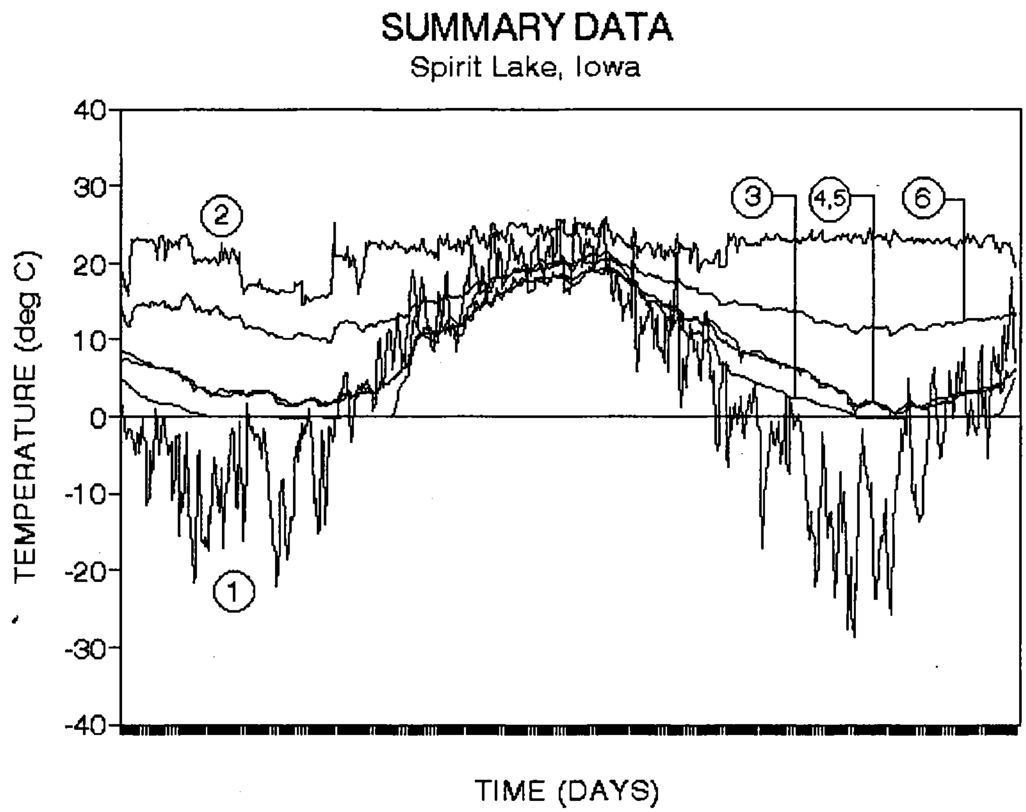


Figure A10. Selected temperature data at the Spirit Lake, IA site.

KEY:

1. Outdoor
2. Indoor
3. Ground, 21" Depth
4. Subgrade at Corner
5. Subgrade at Garage Corner
6. Slab Surface, 3' from Edge

PERIOD OF RECORD: 11/20/92 to 4/20/94

WILLISTON, VERMONT

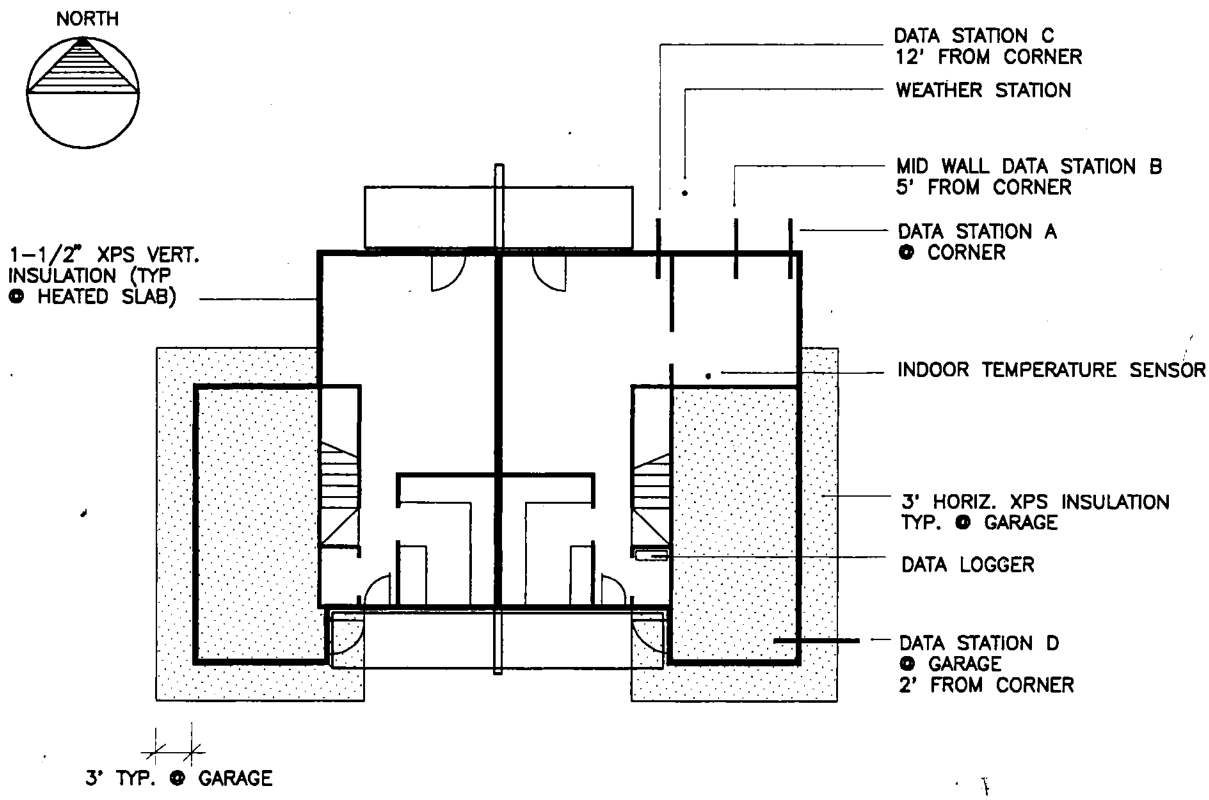


Figure A11. Site plan for Williston, VT.

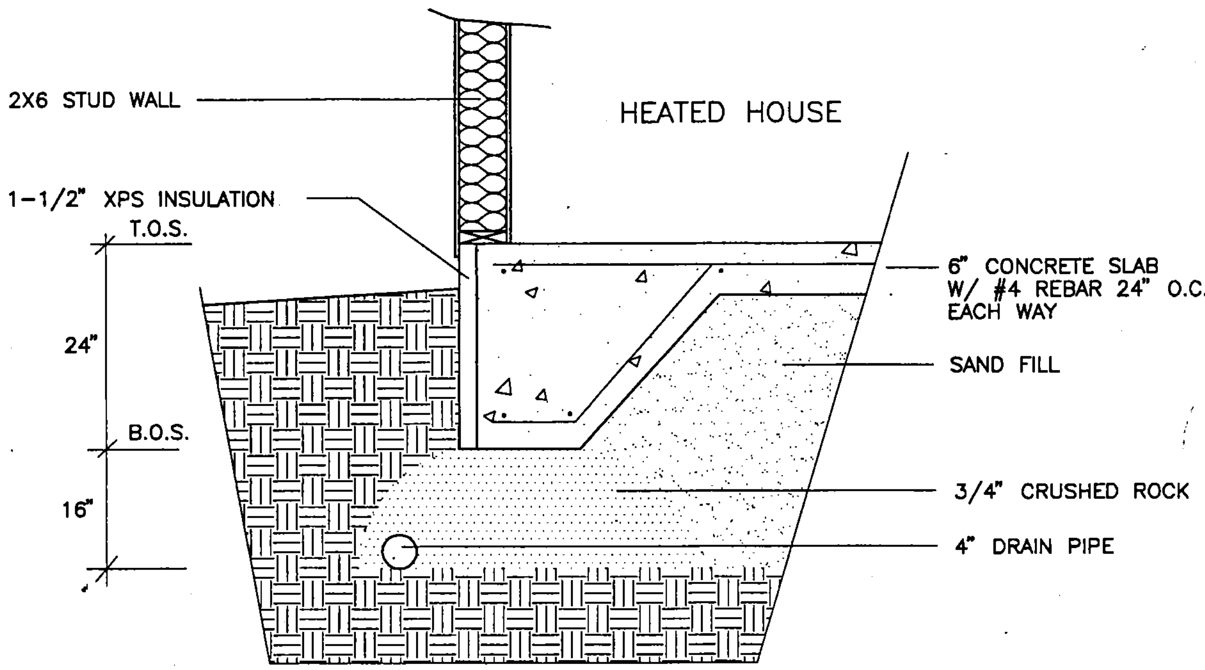


Figure A12. Heated FPSF as-built detail for Williston, VT.

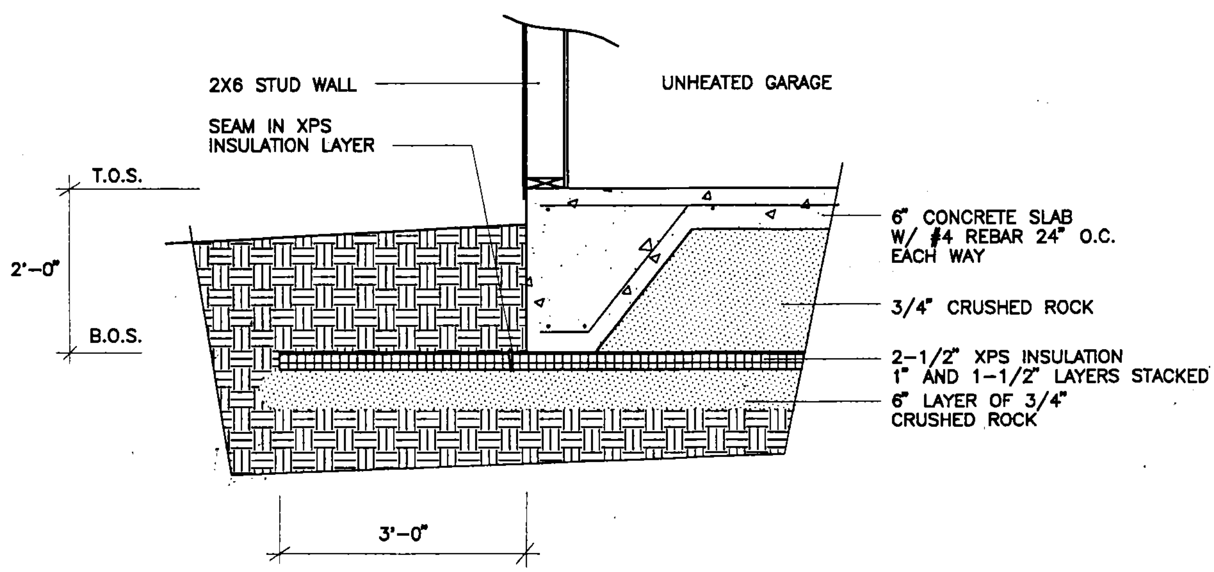
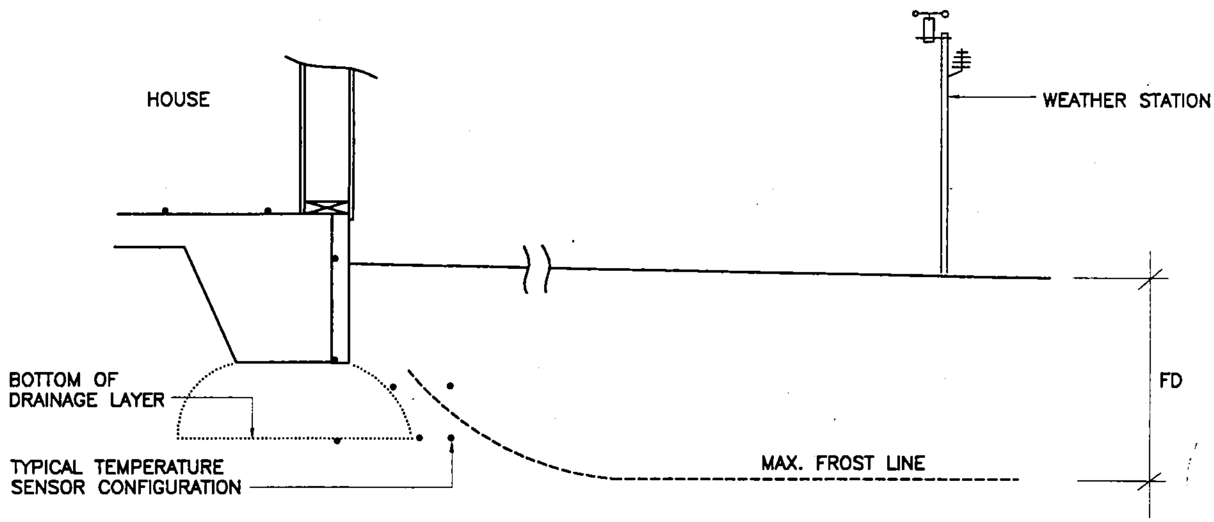


Figure A13. Unheated FPSF as-built detail for Williston, VT.



Winter Season	Frost Depth, FD	Horizontal Distance from Footing to Frost Line
1992-93	14"	Frost penetration next to the building was not sufficient to allow precise measurement.
1993-94	10"	
Comments: Performance was as expected		

Figure A14. Frost line penetration @ Williston, VT.

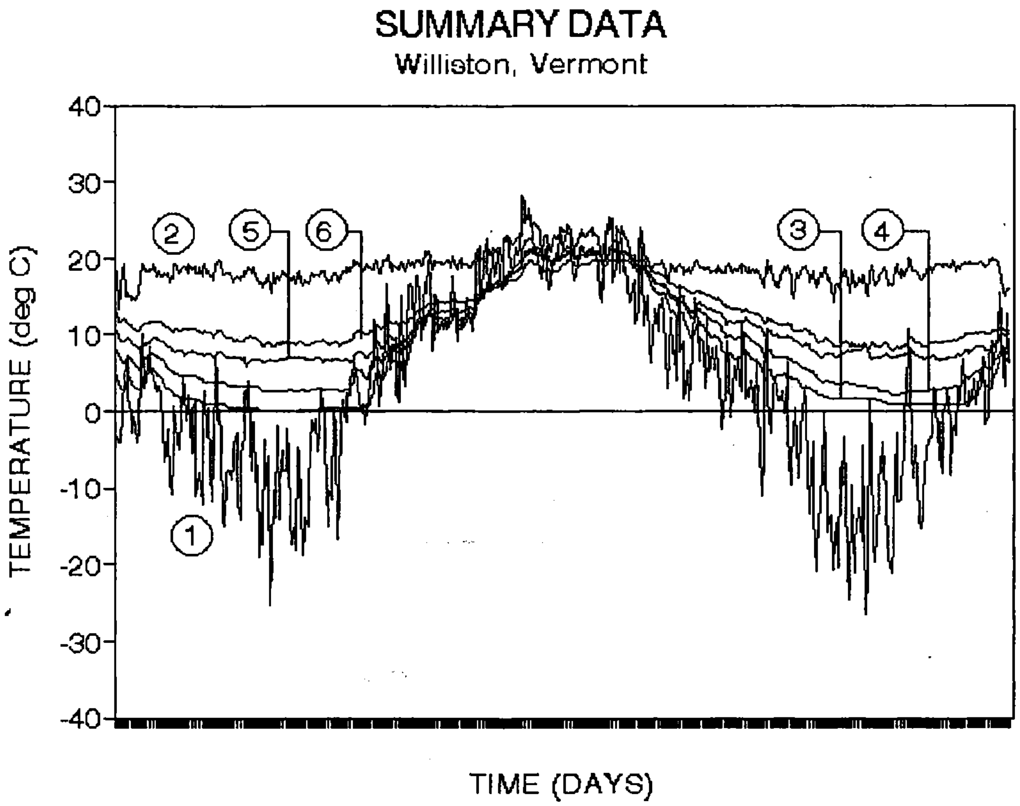


Figure A15. Selected temperature data at the Williston, VT site.

KEY:

1. Outdoor
2. Indoor
3. Ground, 14" Depth
4. Subgrade at Corner
5. Subgrade at Wall
6. Slab Surface, 3' from Edge

PERIOD OF RECORD: 11/16/92 to 4/20/94

PALMER, ALASKA

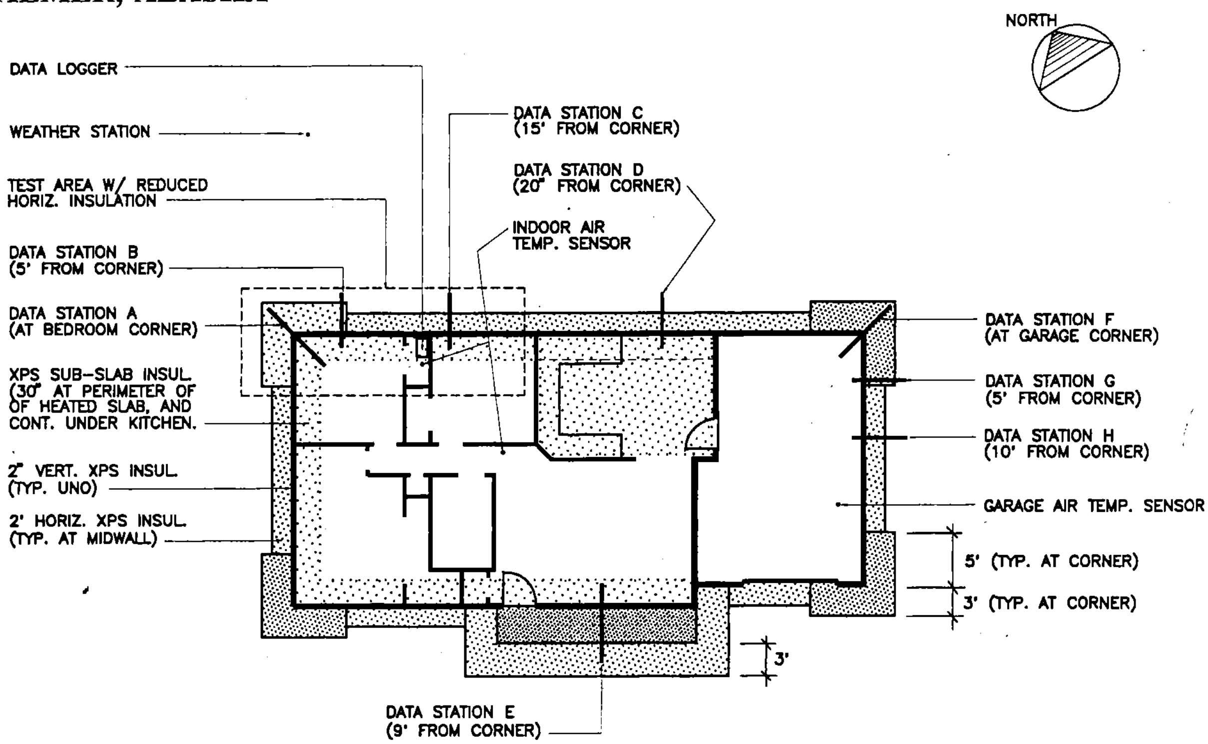


Figure A16. Site plan for Palmer, AK.

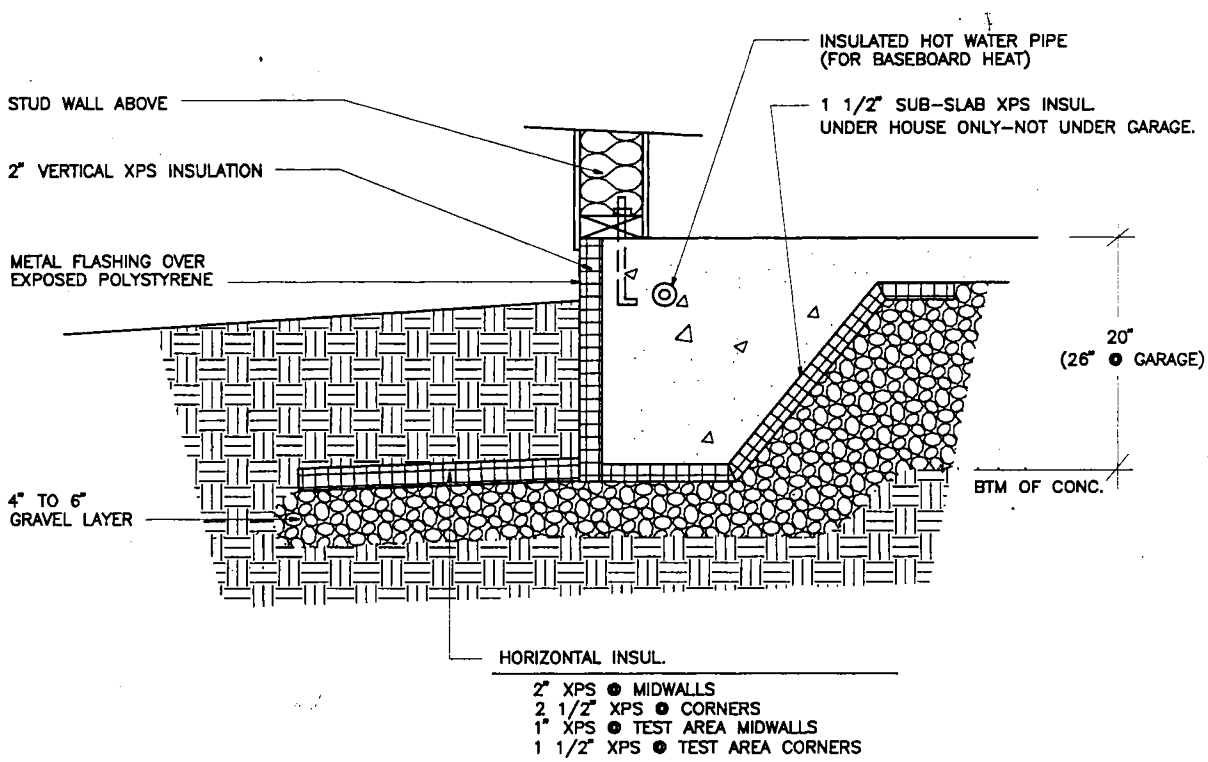
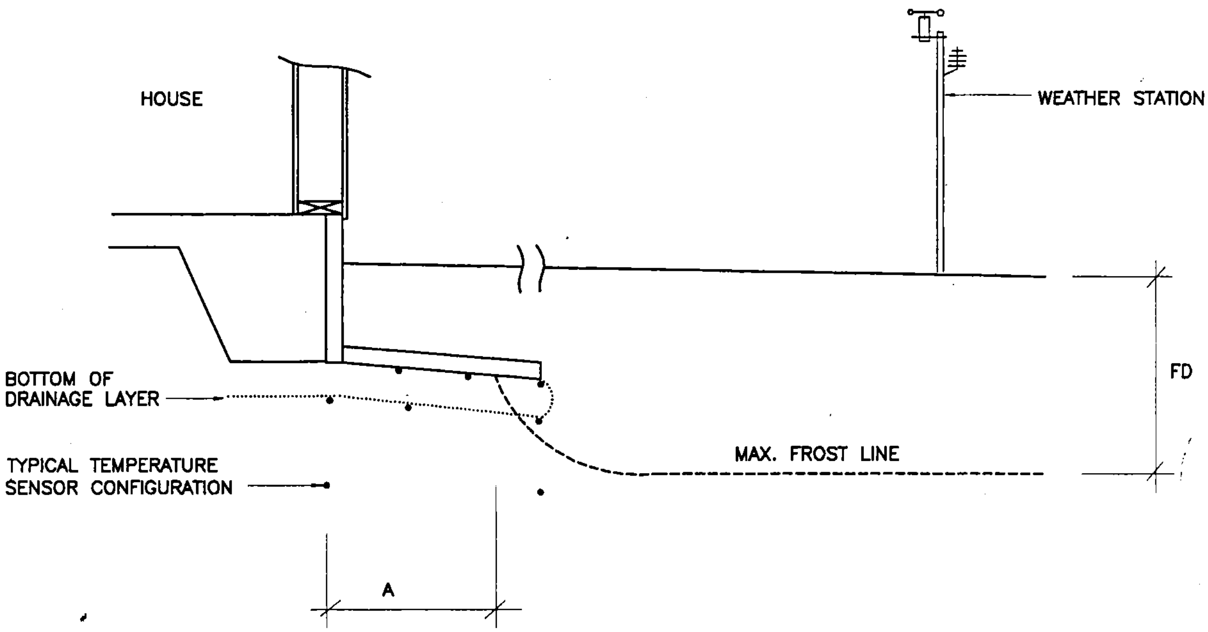


Figure A17. Heated FPSF as-built detail for Palmer, AK.



Winter Season	Frost Depth, FD	Horizontal Distance from Footing to Frost Line (A)		
		@ Test Corner	@ Test Wall	@Normal Wall
1993-94	26"	15"	20"	24"
Comments: Test corner and test wall regions were purposely designed such that an average winter should have resulted in a frost penetration, A, of approximately 0 inches. Frost penetration at the garage was not sufficient to allow measurement. Performance in both test areas and normally designed areas was as expected.				

Figure A18. Frost line penetration @ Palmer, AK.

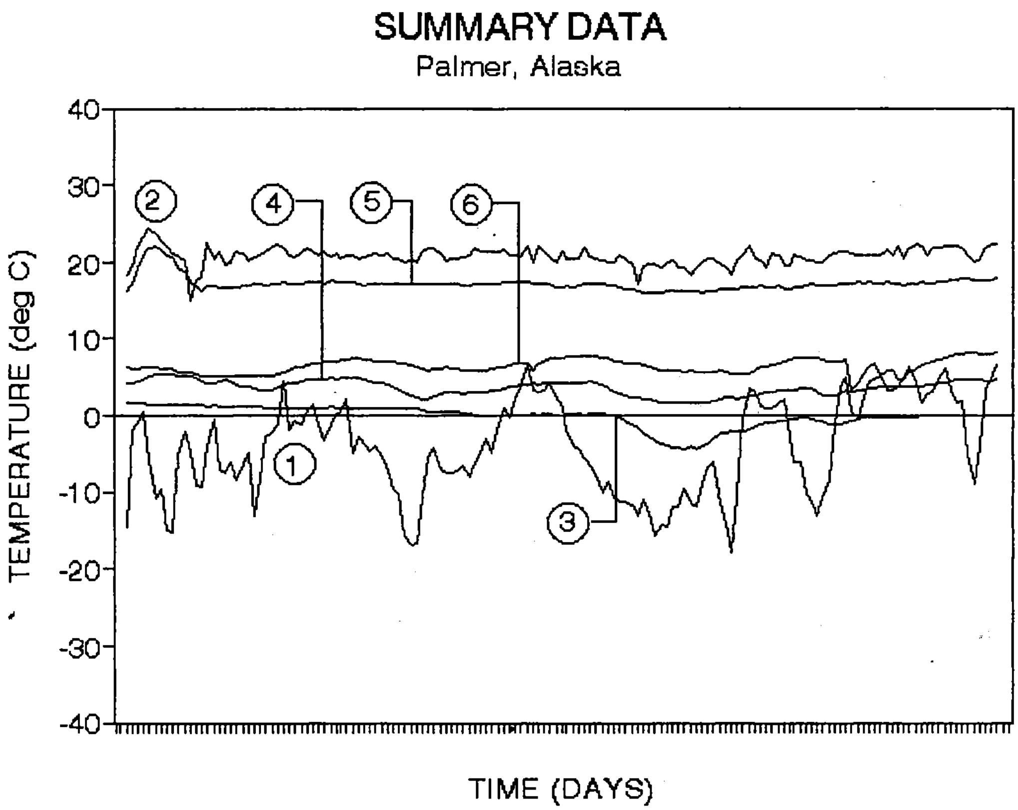


Figure A19. Selected temperature data at the Palmer, AK site.

KEY:

1. Outdoor
2. Indoor
3. Ground, 14" Depth
4. Sub-grade at Test Corner
5. Slab surface, 3' from Edge
6. Subgrade at Garage

PERIOD OF RECORD: 11/23/94 to 4/20/94

FARGO, NORTH DAKOTA (HOME #2)

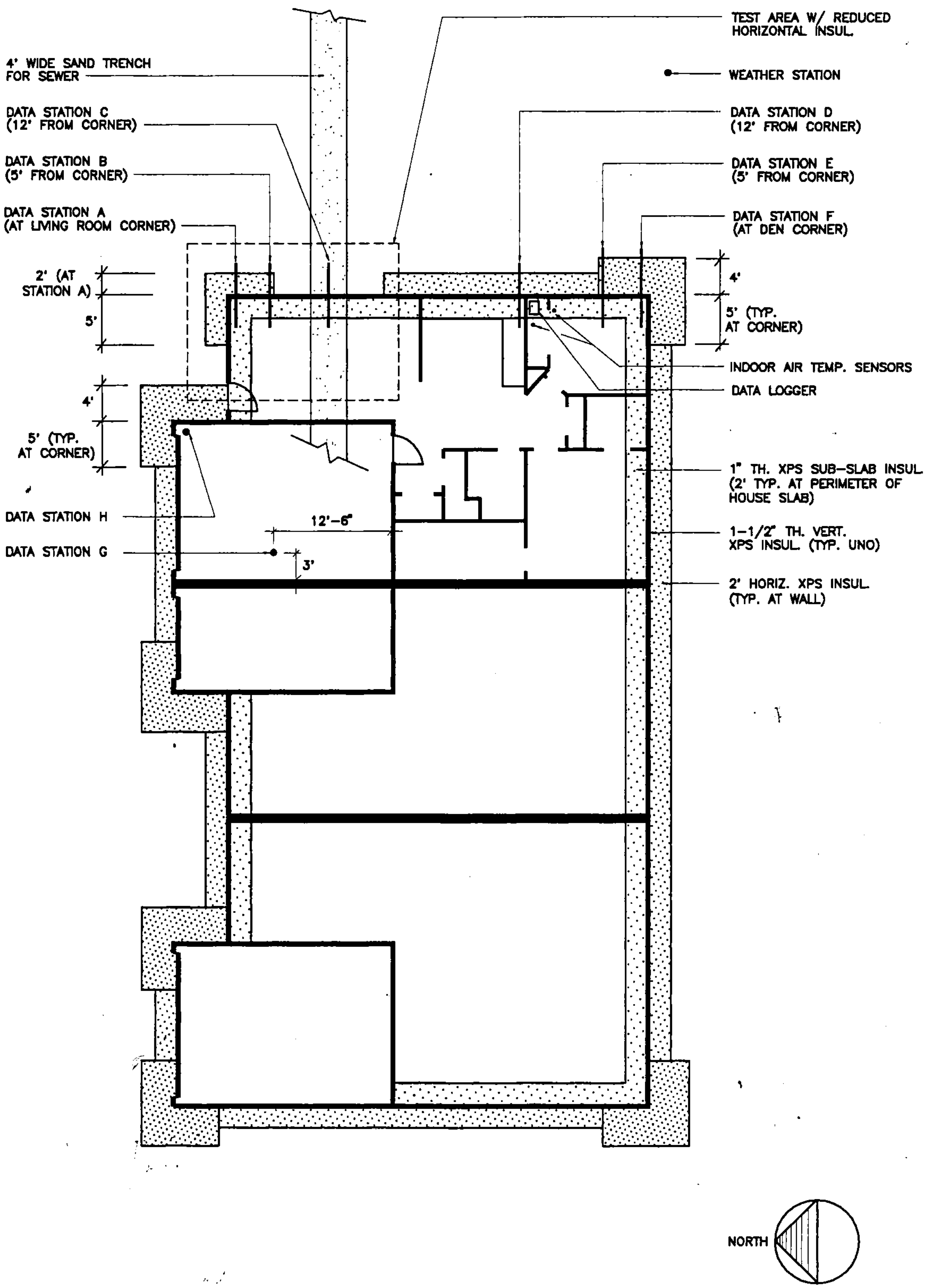


Figure A20. Site plan for house #2 in Fargo, ND.

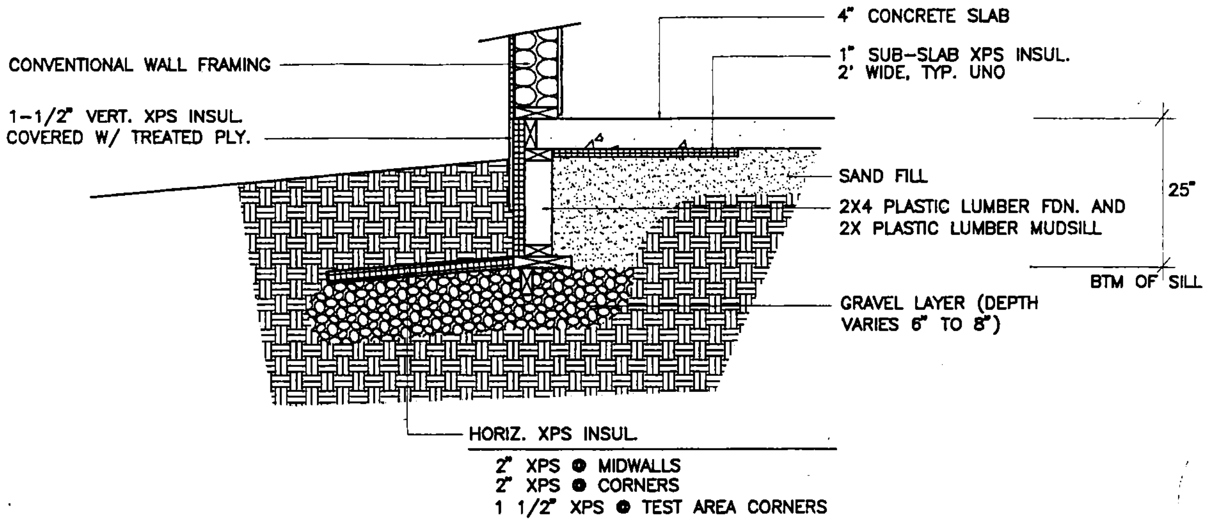
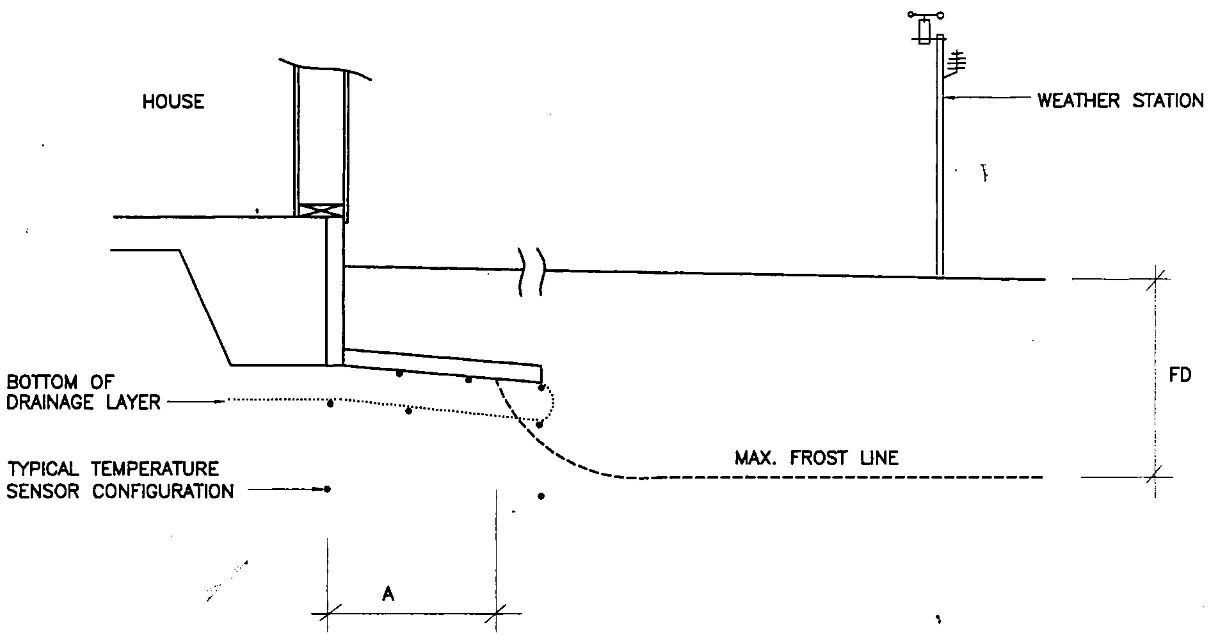


Figure A21. Heated FPSF as-built detail for House #2 in Fargo, ND.



Winter Season	Frost Depth, FD	Horizontal Distance from Footing to Frost Line (A)			
		@ Test Corner	@ Test Wall	Normal Corner	Normal Wall
1993-94	30"	0"	10"	40"	22"
Comments: Test corner and test wall regions were purposely designed such that an average winter should result in a frost penetration, A, of approximately 0 inches. Given the severity of the winter, the test areas and the normally designed regions performed as expected, even at the test wall region where no wing insulation was used.					

Figure A22. Frost line penetration for house #2 in Fargo, ND.

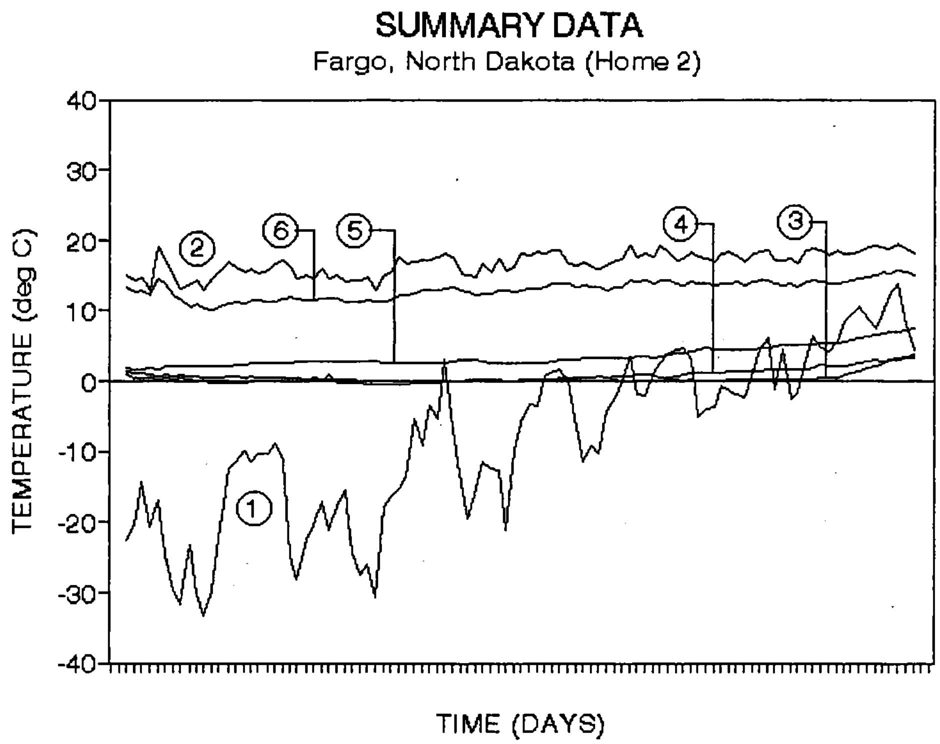


Figure 23. Selected temperature data for house #2 in Fargo, ND.

KEY:

1. Outdoor
2. Indoor
3. Ground, 30" Depth
4. Subgrade at Test Corner
5. Subgrade at Test Wall
6. Slab Surface, 3' from Edge

PERIOD OF RECORD: 1/8/94 to 4/20/94