Frost Protection of a Shallow Building Foundation with Thermal Insulation—A Case Study

D.S. Greeley, P.Eng.

ABSTRACT

In the fall of 1985, the federal mortgage funding and insurance agency requested that instrumentation to record soil temperatures be installed adjacent to the insulated shallow foundation of a 26-unit senior citizens' apartment complex being built in the village of Pefferlaw, Ontario. By examination of soil temperatures above and below a 3-in. (75 mm)-thick horizontal layer of rigid, extruded polystyrene thermal insulation, the effectiveness of the insulation at resisting frost penetration and potential frost heave damage to the shallow buried building footings can be determined. The insulation manufacturer was asked by the foundation engineers to participate in the research to convince the mortgage funding and insurance agency officials that the concept of insulated, shallow foundations was a sound one.

During the 1986-87 and 1987-88 winter seasons, the first two full winters of observation, soil temperatures beneath the 4-ft (1200 mm)-wide insulation layer and adjacent to the shallow footings remained above freezing at all locations, while soil temperatures above the insulation dropped to as low as 10.4 F (-12.0°C). Definite effects of north-facing and south-facing exposures on soil temperatures were found. Lower soil temperatures at foundation corners suggest higher heat losses at these locations and the need for increased insulation thickness.

The design of the insulated shallow depth building footings on this apartment complex proved to be a cost-effective alternative to more conventional deep footing design, saving the owner $219,700.

INTRODUCTION

The construction of a 26-unit senior citizens' complex in the village of Pefferlaw posed an unusual challenge to the foundation consulting engineers. Because of difficult site soils and a tight construction budget, the consulting engineers proposed a cost-effective shallow footing design employing thermal insulation to prevent frost attack. To gain construction funds, the mortgage funding and insurance agency involved had to approve the unique foundation design. As part of the approval process, the funding organization examined the building plans and rejected the foundation design put forth by the consultants as being too unconventional. The officials explained that a more conventional foundation design for the building would be required before they would approve funding.

Knowing they could not provide a more conventional foundation design within the project's budget constraints, the consultants enlisted the help of the research department of the insulation manufacturer to convince officials of the federal funding agency to approve the building's shallow foundation as originally designed. Further discussions ensued, with

D. S. Greeley, P.Eng., is a Project Leader with Construction Materials Technical Service and Development, Dow Chemical Canada Inc., Mississauga, ON.

officials of the funding agency being shown that the design of shallow insulated foundations have been thoroughly investigated in Scandinavia and Canada and have been accepted by the national building code in Canada. They finally accepted the foundation design, as originally submitted, with the provision that the foundation be instrumented and its performance monitored.

This paper documents the performance of the shallow, insulated foundation on the Pefferlaw senior citizens complex during the 1986-87 and 1987-88 winter seasons, its first two full winters in service.

SITE DESCRIPTION

A description of the building location, site soils, shallow foundation, and insulation design follows.

Location

The insulated shallow foundation test site is located in the village of Pefferlaw, Ontario, where the normal air freezing and heating indices are 1322 and 8341 degree-days F, respectively (735 and 4634 degree-days°C, respectively). Pefferlaw is located at latitude 79° 12′ and longitude 44° 15′ , approximately 56 miles (90 kilometers) northeast of the city of Toronto.

Site Soils

Clampitt (1986) characterizes the site as water lain deposits overlying drumlinized till plains. The site is located within the Simcoe Lowlands and bedrock in the area, -- Trenton limestone -- occurs shallowly.

The detailed foundation report from the consulting engineers responsible for the building's foundation design contains the information presented in Table 1. It indicates that the building site soils consist of shallow, loose to dense fine sands underlain by firm to stiff clay, over bedrock. It classifies the site soils as extremely frost susceptible. The groundwater table at the site is found 20 in.(500 mm) below the surface.

Building Foundation Design

Three different foundation designs for the 24,488 square feet (2275 square meter) gross area building were assessed by the consulting engineers. Two involved the use of piled foundations with grade beams while the third examined the use of spread footings. In the first piled foundation design considered, the site would be dewatered and the grade beams placed below the depth of frost penetration. In the second piled design, the site grade would be raised about 3 ft, 3 in. (1000 mm) and the grade beam constructed above the groundwater table. The third design, using spread footings, involved placing the footings as high as possible on a compacted, clean granular fill such that stress influence at the depth of the clay would be within acceptable settlement limits. Insulation, however, would be needed to prevent frost attack on the footings, as the depth of frost penetration expected at the site was 4 ft (1200 mm). Clampitt (1986) reported that the choice of spread footings with insulation to prevent frost penetration proved to be the most economical for the building's owner. Savings of $219,700 (or 68% of the next lowest alternative cost) were possible. This clearly indicated the economic feasibility of the insulated, shallow footing concept where considerations of high-contact stresses and potential long-term consolidation settlements dictated raising the footings above the depth of frost penetration. Costs for the three different foundation design options appear in Table 2.

Insulation Design

To prevent frost attack on the footings, rigid, extruded polystyrene foam plastic insulation conforming to Canadian General Standards Board (CGSB) specification CAN/CGSB-51.20-M87 Type IV was chosen for its excellent performance record in below-grade foundation applications. It has a vertical compressive strength of 30 psi (210 kPa) and was deemed adequate for the loading conditions expected at this foundation site.

The thermal design criteria used for the foundation are given in Figure 1 and are government design curves (Nayyar 1986) which expand on the work reported by Robinsky and Bespflug (1973). Due to the potential for vacancies in the building, a minimum interior building temperature of 55 F (13°C) was assumed and an insulation thickness of 3 in. (75 mm) recommended. The 3-in. (75 mm) - thick insulation [R-value = 15.0 $ft^2 \cdot h \cdot F/Btu$ (RSI = 2.61 $m^2 \cdot C/W$)] was applied to the foundation wall, from the footing level to the top of the wall, located 6 in. (150 mm) above-grade. The above grade portion of the insulation was protected from weathering and physical abuse with a latex-modified cement parging. Insulation was also placed horizontally around the external perimeter of the building at the footing level. It was 3 in. (75 mm) thick and provided an R-value equivalent to 15.0 $ft^2 \cdot h \cdot F/Btu$ (RSI= 2.61 $m^2 \cdot C/W$). It extended out a width of 4 ft horizontally (1200 mm) from the foundation wall and was placed approximately 11 in. (275 mm) below finished grade on a 2 in. (50 mm) bed of sand. It was covered with a sheet of polyethylene and 1/4-in. (6 mm) fiberglass protection board. The ground surface above it was covered with cobblestones to prevent damage to the insulation due to possible tenant gardening activities adjacent to the building perimeter. At all outside corners and for a distance 6 ft (1800 mm) back from the corners along the walls the width of the insulation was increased from 4 ft (1200 mm) to 6 ft (1800 mm). No insulation was placed under the 4-in. (100 mm)-thick slab-on-grade floor.

For an 8 ft (2400 mm) length along approximately the center of the south-facing foundation wall, the insulation thickness (and hence thermal resistance) was reduced from 3 in. (75 mm) to 1.5 in. (40 mm). For half of this 8 ft (2400 mm) length, the insulation applied to the foundation wall did not extend above grade, but was stopped at grade level. These modifications were made to determine the effect of no above-grade insulation and reduced insulation thickness on soil temperatures and heat losses. Figure 2 shows the building plan and the insulation details.

TEST SITES AND INSTRUMENTATION

Six separate areas around the building's perimeter were selected for instrumentation with thermocouples to measure soil temperatures.

North-Facing Sites

Two sites were located on the north-facing side of the building foundation. Thermocouples were installed at the northwest corner (to be called the North Corner Site); here the insulation was 6 ft (1800 mm) wide and 3 in. (75 mm) thick; also, at about 11 ft (3300 mm) along the north-facing wall, east of the northwest corner (to be called the North Standard Site). At this location, the insulation was 4 ft (1200 mm) wide and 3 in. (75mm) thick.

Figure 3 shows the instrumentation at these two northern sites as well as the insulation profiles.

South Facing Sites

Three instrumentation sites were chosen along the center of the south-facing foundation wall of the building. At this location, thermocouples were installed

-- at about 12 ft (3600 mm) west of the southeast corner, along the south-facing wall (to be called the South Above-Grade Site because insulation extended up vertically on the foundation wall above-grade). The insulation width and thickness were 4 ft (1200 mm) and 1.5 in. (40 mm), respectively, at this location.

-- at about 4 ft (1200 mm) west of the South Above-Grade site (to be referred to as the South No Above-Grade Site, as the vertical wall insulation stops at grade level and does not extend above-grade). The insulation width and thickness were 4 ft (1200 mm) and 1.5 in. (40 mm), respectively.

-- at about 41 ft (12,300 mm) west from the southeast corner of the building, along the south-facing wall (to be referred to as the South Standard Site). At this location the insulation width and thickness were 4 ft (1200 mm) and 3 in. (75 mm), respectively.

Figure 4 shows the instrumentation at the three southern sites and the insulation profiles.

East-Facing Site

A sixth instrumented site was installed to the east of the building in an adjacent parking lot. This site was chosen to serve as a control site to show the expected depth of freezing in the area. The site was located in a snow-cleared parking lot area (as opposed to an open field) to provide the maximum depth of freezing. Four thermocouples were installed in a vertical string beneath finished grade. Unfortunately, subsequent construction traffic in the parking lot area damaged the thermocouples and soil temperature readings could not be made. No further discussion of this instrumentation site will be made.

Instrumentation

Thermocouples (used to measure soil temperatures above and below the insulation) were installed at the six major locations around the perimeter of the building. Nylon-coated type "T" calibration thermocouple wire was used to fabricate the thermocouples. The junctions of each thermocouple (the end of the wire placed in the ground to measure soil temperature) were spot welded and coated with epoxy. All thermocouple sets, once installed, were fed into one of two rotary dial switching boxes which facilitate recording of soil temperatures from each thermocouple with just a turn of a dial. Switching boxes were located at the northeastern and southeastern corners of the building, respectively. In total, 48 thermocouples were installed during foundation construction in late 1985; 43 remained operational during the 1986-87 and 1987-88 winter seasons.

The thermocouples were read using a portable digital temperature indicator/calibrator. Its microprocessor-based digital temperature indicator/calibrator with internal cold junction reference accepts the millivolt output of a thermocouple and provides a digital display of the equivalent temperature. Its overall accuracy with type "T" calibration thermocouples is +/- 0.8 F (+/- 0.4°C).

Measurement Frequency

The thermocouples were normally read twice weekly during the frost seasons. During the two monitoring seasons, readings began on October 10, 1986 and December 10, 1987 and they concluded on May 5, 1987 and April 25, 1988; periods of 217 and 208 days, respectively. Most readings were taken in the late afternoon by building maintenance staff and were recorded manually.

METEOROLOGICAL FACTORS

There no longer exists a federal climatological weather station in Pefferlaw, Ontario. However, there was a station located there in the past. Hence, historical climatological data for Pefferlaw, in the form of "normals," does exist (Boyd 1973; Environment Canada Ministry 1973), though recent annual data records do not. Therefore, to obtain the climatological data for the 1986-87 and 1987-88 winter seasons for the Pefferlaw test site, records from the closest meteorological station were used. That station is located in the village of Vallentyne, situated about 8 miles (13 km) southeast of Pefferlaw. Since "normals" do not exist for the Vallentyne station (it is a relatively new station), the records for the 1986-87 and 1987-88 winters in Vallentyne have been compared to the historical "normals" published for Pefferlaw.

Meteorological factors such as air temperature, hours of sunshine, precipitation, and wind velocity all influence soil temperatures and hence the depth of frost penetration (or freezing) into the ground. Air temperature and precipitation,however, are perhaps the most significant factors.

Average Monthly Air Temperatures

In Vallentyne during the 1986-87 winter period, the high and low average monthly air temperatures were 56.9 F (13.8°C) and 18.2 F (- 7.6°C), occuring in September 1986 and February

1987, respectively. During the 1987-88 winter, the high and low average monthly air temperatures were 58.7 F (14.8°C) and 17.2 F (- 8.2°C), occuring in September 1987 and February 1988, respectively. The normals expected for Pefferlaw are 57.3 F (14.1°C) and 18.2 F (- 7.7°C), occuring in September and January respectively. If one plots the average monthly air temperatures for Vallentyne and the normals for Pefferlaw (see Figure 5) one finds that the early winter (December - January) and spring (March - May) periods in Vallentyne during the monitoring periods were milder than the normal for Pefferlaw.

Air Freezing Index And Frost Penetration

Researchers have long related frost penetration into the ground with air freezing index (Chisholm and Phang 1981). Therefore, an understanding of the air freezing index for the test site is desirable. A degree-day is defined as a measure of the departure of the mean daily temperature from a specific reference temperature, in this case, 32 F (0°C). Thus, a day with the mean temperature below freezing will increase the accumulated freezing degree-day total over a specific time period; a mean daily temperature above freezing will decrease the total over the same time period. Air freezing index is defined as the accumulation of degree-days above and below 32 F (0°C) between the highest point in the autumn and the lowest point the next spring on the cumulative degree-day time curve for one freezing season (Boyd 1973).

During the 1986-87 and 1987-88 winter seasons in Vallentyne, the air freezing indices were recorded as 1055 degree-days F (586 degree-days°C) and 1176 degree-days F (653 degree-days ° C), respectively (see Figure 6). The normal expected for Pefferlaw is 1322 degree-days F (735 degree-days°C). Therefore the air freezing indices for the area during 1986-87 and 1987-88 were, respectively, 20% and 11% lower than expected, indicating milder than normal winter seasons.

While frost penetration was not measured at this site due to instrumentation damage, a prediction may be made for the accumulated air freezing index observed during the 1986-87 and 1987-88 winter seasons.

The provincial ministry of transportation in Ontario has studied data relating frost depth to air freezing index in highway pavements throughout the province. The resulting correlation equation is:

$$\underline{P} = -0.328 + 0.0578\ \underline{F}$$

where

$\underline{P}$ = frost penetration in meters

$\underline{F}$ = freezing index in degree-days Celsius

Using this correlation, we find that the expected depth of frost penetration in the paved parking lot area of the site (kept free of snow during the winter) would be 42 in. and 45 in. (1070 mm and 1150 mm), respectively, during the 1986-87 and 1987-88 winters. This would place the high subgrade water table well within the range of possible frost attack.

Precipitation

The amount of precipitation that an area receives, both in terms of rainfall and snowfall, can affect the thermal regime for site soils and thus influence frost penetration into the ground.

During the September 1986 to May 1987 period, Vallentyne received a total of 21.8 in. (554 mm) of precipitation. Of this total, 16.3 in. (414 mm) was rainfall and 5.5 in. (140 mm) was snowfall. During this same period, but in 1987-88, Vallentyne received a total of 23.0 in. (585 mm) of precipitation -- 16.7 in. (425 mm) due to rainfall and 6.3 in. (160 mm) due to snowfall. The normal total precipitation expected over this time period in Pefferlaw is 24.9 in. (633 mm), of which 16.6 in. (422 mm) is rainfall and 8.3 in. (211 mm) is snowfall. Monthly precipitation levels for Vallentyne and Pefferlaw are plotted in Figure 7. Thus it is apparent that the 1986-87 and 1987-88 winters were normal with respect to rainfall and below normal with respect to snowfall.

RESULTS AND DISCUSSION

Soil Temperatures Above And Below Insulation

The shallow foundation design concept works because the presence of thermal insulation prevents freezing temperatures from occurring adjacent to the shallowly placed building footings. As a result, the penetration of frost and the damaging effects it can have on building footings is eliminated. To examine the effectiveness of the thermal insulation design used on the senior citizens' complex discussed here, one should first look at the recorded soil temperatures above and below the thermal insulation.

North And South Standard Sites. The ability of insulation to resist the penetration of freezing temperatures beneath the shallow footings can be seen by examination of Figures 8 and 9. Depicted in Figure 8 are the soil temperature profiles above and below the 4 ft (1200 mm) long, 3 in. (75 mm) thick horizontal layer of rigid, extruded polystyrene insulation at the North Standard Site. Plotted are data collected by the vertical thermocouple string composed of thermocouples N, O, P, and Q located 2 ft (600 mm) from the foundation wall. As can be clearly seen, while soil temperatures above the insulation dropped below freezing (TC# N), temperatures below the insulation remained consistently above freezing at all times during the 1986-87 and 1987-88 monitoring seasons (TCs O, P, and Q). Similar results can be seen in Figure 9 for the South Standard Test Site.

North Corner Site. Soil temperatures above and below the insulation at the North Corner Site (3 in. [75 mm] thick insulation, 6 ft [1800 mm] wide) are plotted in Figure 10. Also shown, as a comparison, are the soil temperatures recorded above and below the insulation at the North Standard Site (3 in. [75 mm] thick insulation, 4 ft [1200 mm] wide). In both cases, temperatures beneath the insulation remained above freezing during the 1986-87 and 1987-88 winter seasons while soil temperatures directly above the insulation dropped to as low as 10.4 F (- 12 °C) in 1986-87. One can see that soil temperatures below the North Corner insulation are lower than those occurring below the insulation at the North Standard Site. This can also be seen in Figure 11, where soil temperatures adjacent to the footings at both sites are shown. Plotted in Figure 11 are the soil temperatures recorded at thermocouples A and C located adjacent to the footing at the North Corner Site and the soil temperatures recorded at thermocouples K and M adjacent to the footing at the North Standard Site. Temperatures adjacent to the footing at the North Corner Site are cooler, averaging about 3.5 F (2.0°C) less than those found at the North Standard Site. This can be explained by the occurrence of three-dimensional heat losses at foundation corners and only two-dimensional heat losses along foundation walls. The observation of these lower soil temperatures at the North Corner Site supports research conducted by Robinsky and Bespflug 1973, which recognized the need for increased insulation thermal resistance at such locations. It is reasonable to assume that the increased length of insulation at the North Corner Site may have had a reducing effect on the noted temperature difference between the two sites; however, to what extent cannot be determined from the data collected.

North Vs. South-Facing Exposures

North-facing walls are often subjected to colder, more severe climatic conditions than south-facing walls. Therefore, one of the reasons for instrumenting standard sites on both the north-and south-facing walls was to determine the effects of different exposures on soil and footing temperatures adjacent to the foundation walls.

Soil Temperatures. Mean soil temperatures observed at the northern test sites were lower than those observed at the southern test sites. For example, over the 217-day monitoring period in 1986-87, the mean soil temperature measured above the insulation at the North Standard Site (TC# N, Figure 8), was 30.3 F (-0.9°C), while above the insulation at the South Standard Site (TC# 4, Figure 9), the mean temperature was 35.4 F (1.9°C) -- a difference of 5.1 F (2.8°C). The same trend, but with a slightly smaller difference in temperatures, can be found in the mean temperatures below the insulation layer at the same two sites during 1986-87. The mean soil temperatures observed directly below the insulation at the North Standard Site (TC# O, Figure 8) and the South Standard Site (TC# 5, Figure 9) were 45.9 F (7.7°C) and 47.4 F (8.5°C), respectively. The temperature below the insulation at the North Standard Site was, on the average, 1.5 F (0.8°C) cooler than that below the insulation at the South Standard Site.

Footing Temperatures. In Figures 12 and 13, one can see the soil temperatures recorded just inside and outside the north- and south-facing footings at the North and South Standard

Sites, respectively.

The observed mean outside footing temperature at the North Standard Site (TC# L, Figure 13) was 48.8 F (9.31°C) and 48.0 F (8.88°C) in 1986-87 and 1987-88, respectively. At the South Standard Site (TC# 2), it was 50.6 F (10.4°C) and 49.9 F (9.9°C) in 1986-87 and 1987-88, respectively. This accounts for an approximate 1.8 F (1 ° C) difference between northern and southern exposures during both monitoring periods.

Correspondingly, mean inside footing temperatures were 49.3 F (9.6°C) and 50.5 F (10.3°C) at the North Standard Site (TC# J), and 52.2 F (11.2°C) and 50.8 F (10.4°C) at the South Standard Site (TC# 1) during the 1986-87 and 1987-88 monitoring periods, respectively (see Figure 12).

Above-Grade Vs. No Above-Grade Insulation

In Figure 14, soil temperatures recorded at the South Above-Grade Site and the South No Above-Grade Site are plotted. As a comparison, those recorded at the South Standard Site are also shown. The plotted data indicate that the presence of above-grade foundation wall insulation appeared to have little effect on soil temperatures beneath the horizontal insulation layer, 1 ft (300 mm) out from the wall (compare TC# 13 and TC# Y). This observation is inconclusive, however, in light of the short length of the test section along the foundation wall (8 ft or 2400 mm) and the small height of foundation wall extending above grade (0.5 ft or 150 mm). A larger test section is recommended to more fully substantiate the effects of above-grade insulation on soil temperatures.

Effect of Insulation Thickness on Soil Temperatures

If one examines the soil and footing temperatures observed at the three southern test sites, one can determine the effect of insulation thickness.

The reader will recall that 3 in. (75 mm) thick insulation was used on the South Standard Site and 1.5 in. (40 mm) thick insulation was used at the South With Above-Grade and South No Above-Grade Sites. There was a difference in soil temperatures observed below the horizontal insulation layers, 1 ft (300 mm) away from the wall at all three sites (Figure 14). Soil temperatures observed below the insulation layers at this location showed a difference in the means of about 2.1 F (1.2°C), with those occurring beneath the 3 in (75 mm) thick insulation being warmer.

Mean outside footing temperatures observed at thermocouples 2, 10, and V (recorded but not plotted here), located at the South Standard, South No Above-Grade, and South Above-Grade Sites, were 50.6 F, 48.2 F, and 48.2 F (10.4°C, 9.0°C, and 9.0°C), respectively, during 1986-87. During 1987-88 they were 49.9 F, 46.4 F, and 45.8 F (9.9°C, 8.0°C, and 7.7°C), respectively. Thus, outside footing temperatures beneath the 3 in. (75mm) thick insulation layer of the South Standard Site were warmer by at least 2.5 F (1.4°C).

These observed differences may have in fact been larger had the South No Above-Grade and South Above-Grade Sites been longer in length along the south foundation wall.

CONCLUSIONS

The shallow depth, insulated building footings of the senior citizens, complex were a cost-effective alternative to more conventional footing design. Placed above the level of expected frost penetration and protected from potential frost damage by rigid, extruded polystyrene thermal insulation, the shallow footing design used on the building saved the owner $219,700, or 68% of the total conventional footing cost.

Observations made during the winters of 1986-87 and 1987-88 showed that while soil temperatures above the 3 in. (75 mm) thick extruded polystyrene insulation layer dropped below freezing, temperatures beneath the insulation remained above freezing (see Figures 8 and 9). Thus, the 4 ft (1200 mm) wide insulation layer placed around the perimeter of the foundation effectively prevented freezing of the soil beneath the shallow footings and hence eliminated potential frost heave damage.

Due to three-dimensional heat losses at building foundation corners, soil temperatures measured beneath the insulation at the North Corner Site were on the average 3.5 F (2.0 °C) cooler than those beneath the insulation at the North Standard Site. To what extent the increased insulation length at the North Corner Site helped reduce this observed temperature difference is unknown.

Soil temperatures measured above and below the insulation layers on the north-facing side of the building were cooler than those recorded on the south-facing exposure. Differences of as much as 5.1 F (2.8°C) were observed.

The effects of above-grade foundation wall insulation on adjacent soil temperatures could not be fully determined. An alternative test site (larger in size) is recommended.

The greater the thermal resistance of the horizontal insulation layer, the warmer the soil and footings beneath it. Mean winter soil and footing temperatures beneath the South Standard Site insulation ($R = 15.0\ ft^2 \cdot h \cdot F/Btu$ or $RSI = 2.61\ m^2 \cdot C/W$) were 2.1 F (1.5°C) and 2.5 F (1.4°C) warmer, respectively, than the corresponding temperatures beneath the South Above-Grade Site insulation ($R = 7.5\ ft^2 \cdot h \cdot F/Btu$ or $RSI = 1.3\ m^2 \cdot C/W$).

REFERENCES

Boyd, D.W. 1973. "Normal freezing and thawing degree-days for Canada, 1931-1960." Environment Canada. Atmospheric Environment Service. Downsview. CLI 4-73.

Chisholm, R.A., and Phang, W.A. 1981. "Aspects of prolonged exposure of pavements to sub-zero temperatures, part 1: measurement and prediction of frost penetration in highways." Ontario Ministry of Transportation and Communications. ISBN 0-7743-7096-3. Downsview, Ontario.

Clampitt, J.K. 1986. "Frost prevention below footings using insulation." Geotechnical Engineering Division. Paper presented at American Society of Civil Engineers Annual Fall Convention, Boston.

Environment Canada Ministry. 1973. "Canadian normals: precipitation, 1941-1970." Atmospheric Environment Service, Vol.2. Downsview, Ontario.

Nayyar, B.K. 1986. Personal communications with C. Mirza of Strata Engineering Corp.

Robinsky, E.I., and Bespflug, K.E. 1973. "Design of insulated foundations." Journal of the Soil Mechanics and Foundations Division. Proceedings of the American Society of Civil Engineers, Vol. 99, No. SM9, Proc. Paper: 10009, pp. 649-667.

BIBLIOGRAPHY

Associate Committee on the National Building Code. 1985. "National building code of Canada: 1985." National Research Council of Canada. NRCC No. 23174. ISSN 0700-1207. Ottawa.

Burn, K.N. 1972. "Frost action and foundations." National Research Council of Canada. Division of Building Research. Canadian Building Digest No. 182. Ottawa.

Figley, D.A., and Snodgrass L.J. 1984. "The effect of basement insulation on the depth of frost penetration adjacent to insulated foundations." Journal of Thermal Insulation, Vol. 7, April.

Hamilton, J.J. 1968. "Effects of environment on the performance of shallow foundations." Paper presented at 21st Canadian Soil Mechanics Conference, Winnipeg, Manitoba. September 12-13.

Morris, R.A. 1988. "Frost-protected shallow foundations: current state-of-the-art and potential application in the U.S." NAHB National Research Center, Maryland.

Penner, E. 1967. "Performance of insulated shallow footings under an elevated cottage." National Research Council of Canada. Division of Building Research. Technical Note No. 497. Ottawa.

Penner, E., and Burn, K.N. 1970. "Adfreezing and frost heaving of foundations." National Research Council of Canada. Division of Building Research. Canadian Building Digest No.128. Ottawa.

Penner, E., and Crawford, C.B. 1983. "Frost action and foundations." National Research Council of Canada. Division of Building Research. DBR Paper No. 1090. ISSN 0381-4319. Ottawa.

Slusarchuk, W.A., and Theakston, F.H. 1971. "Frost heave protection for shallow foundations using vertical perimeter insulation." Transactions of the American Society of Agricultural Engineers. Vol. 14, No. 4, pp. 642 - 646.

ACKNOWLEDGMENTS

The assistance of Strata Engineering Corp. representatives C. Mirza, K. Ahmad, and J. Clampitt with all aspects of this project is greatly appreciated. S. Budgen of Dow Chemical Canada Inc. braved freezing temperatures to help install the instrumentation and her extra effort is acknowledged with thanks. The dedication of B. Kibble, the building maintenance engineer who collected the soil temperature data throughout the monitoring period, is recognized. The inspiration of the late Mr. Rixon, who foresaw the need for senior citizen housing in Pefferlaw and who collected our soil temperature data initially, will long be remembered.

DEPTH BELOW GRADE FEET (meters)	DESCRIPTION	"N" VALUES	SHEAR STRENGTH	ATTERBERG LIMITS W	W	W
0.0 (0.0)	Ground level	-	-	-	-	-
0.0 (0.0)	Topsoil	-	-	-	-	-
0.65 (0.20)	Sand - fine to medium - brown - compact - saturated	11	-	-	21	-
1.66 (0.50)	Ground water table					
7.54 (2.03)	Silt - grey - loose to compact - moist to wet	20	-	-	18	-
13.45 (4.10)	Silty clay to Clay - grey - stiff - wet	6	86	19	31	59
33.46 (10.20)	Limestone bedrock					

* as determined by foundation consulting engineers

Table 1. Typical soil conditions across the site

OPTION ONE: A piled foundation with site dewatering. Grade beams are below the depth of frost.

ITEMS	COST ($)	CUMMULATIVE ($)
1. Piling	119,100.00	119,100.00
2. Grade beams	93,900.00	213,000.00
3. Floor slab	61,500.00	274,500.00
4. Site dewatering	40,000.00	314,500.00
5. Excavation	5,000.00	319,500.00

OPTION TWO: A piled foundation without dewatering the site. Grade raised 3.33 ft (1000 mm) with granular fill.

ITEMS	COST ($)	CUMMULATIVE ($)
1. Piling	119,100.00	119,100.00
2. Grade beams	93,900.00	213,000.00
3. Floor slab	61,500.00	274,500.00
4. Excavation	5,000.00	279,500.00
5. Fill	50,000.00	329,500.00

OPTION THREE: A shallow insulated spread footing design. The grade is raised with granular fill.

ITEMS	COST ($)	CUMMULATIVE ($)
1. Site drainage	3,300.00	3,300.00
2. Foundation wall	13,600.00	16,900.00
3. Slab-on-grade	12,200.00	29,100.00
4. Footings	6,800.00	35,900.00
5. Insulation	13,900.00	49,800.00
6. Granular fill	50,000.00	99,800.00

* Canadian dollars

Table 2. Foundations cost estimates

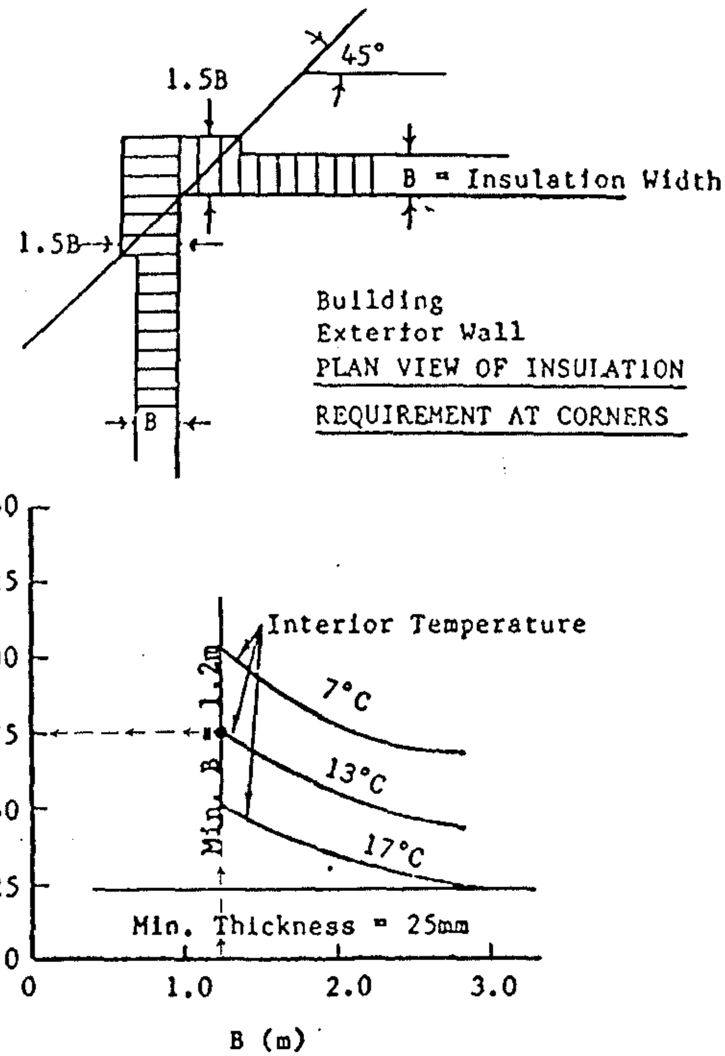

Figure 1. Foundation thermal design criterion

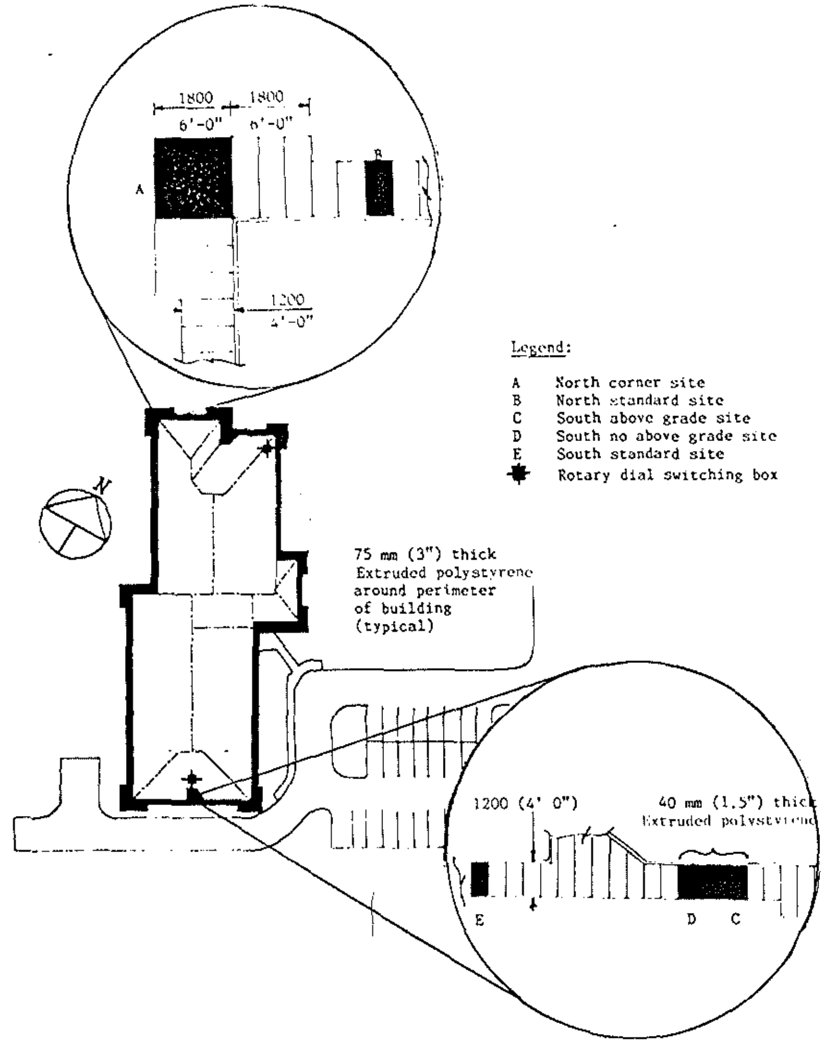

Figure 2. Building plan and insulation configuration

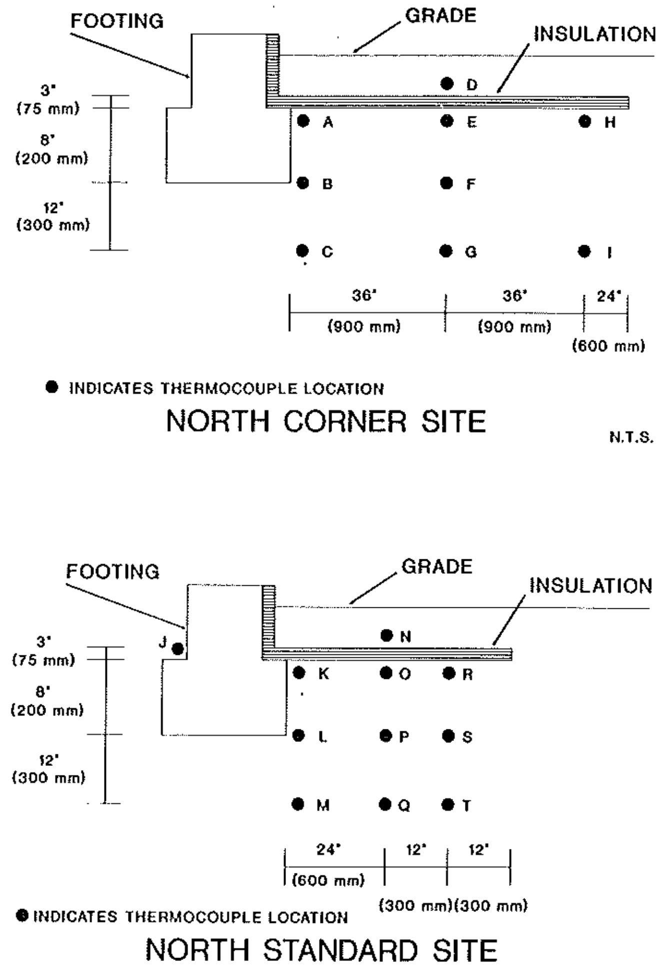

Figure 3. Northern sites—insulation and instrumentation

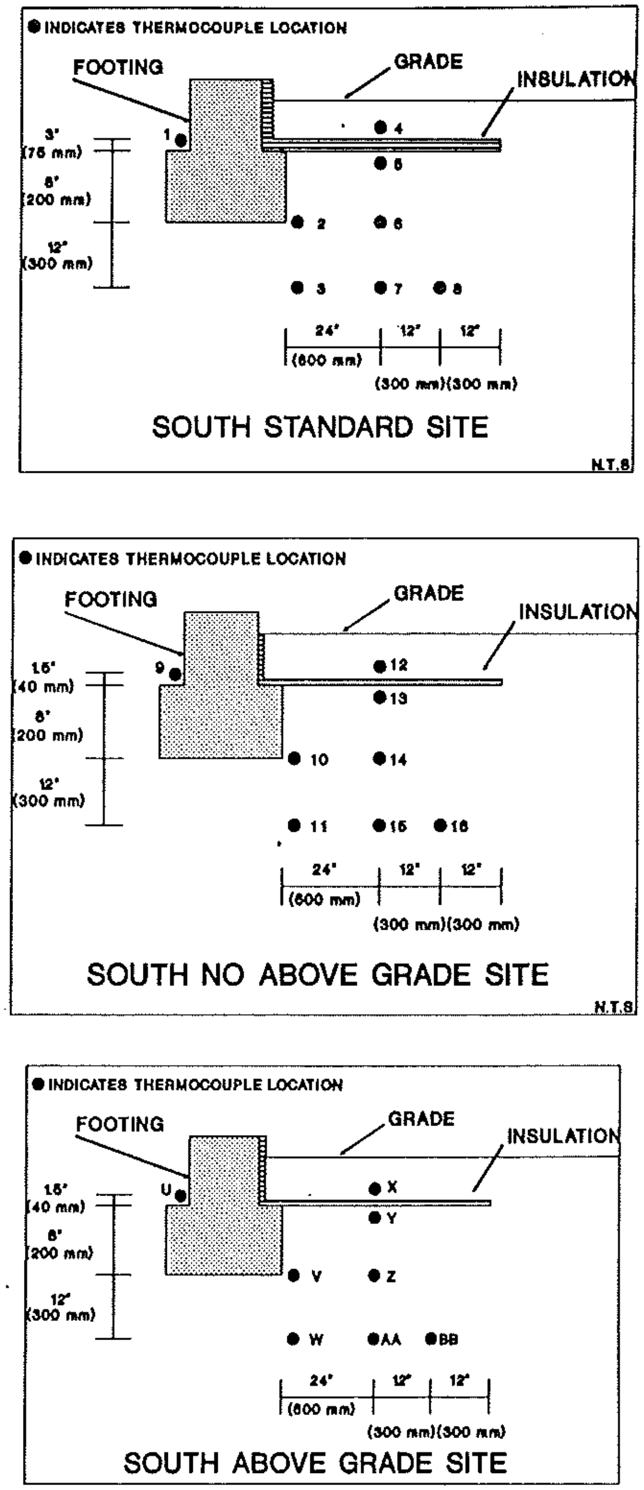

Figure 4. Southern sites—insulation and instrumentation

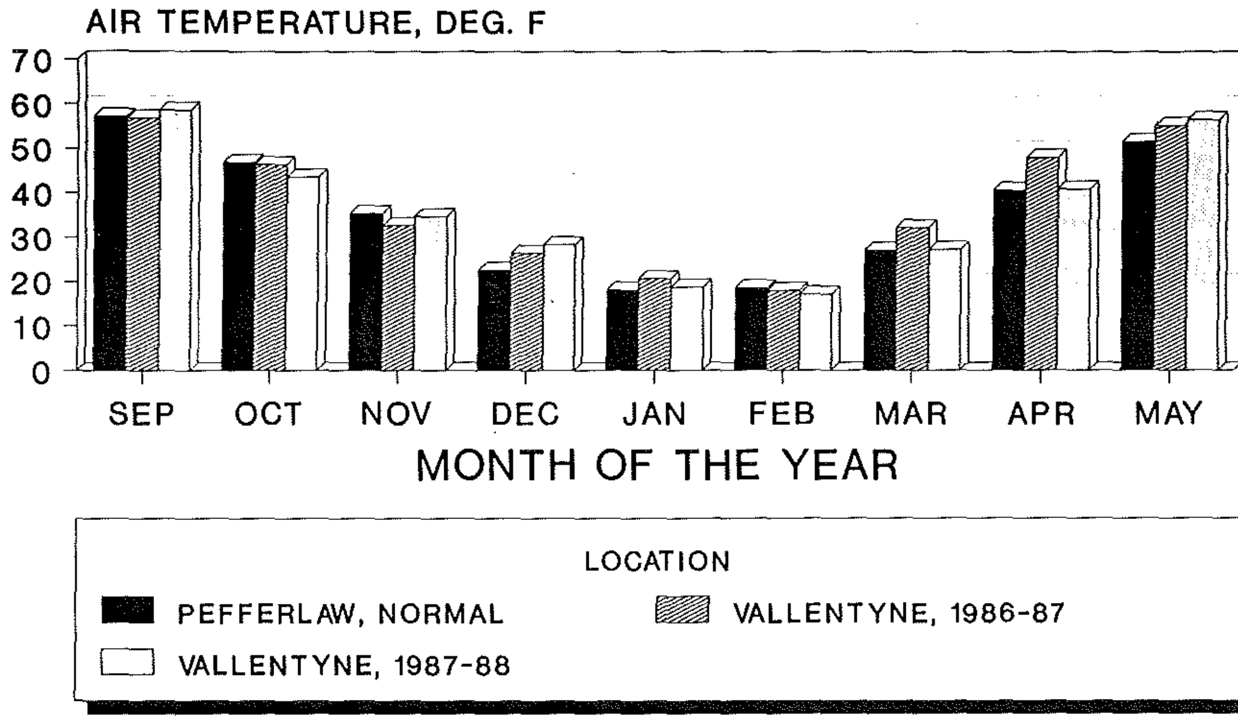

Figure 5. Average monthly air temperatures

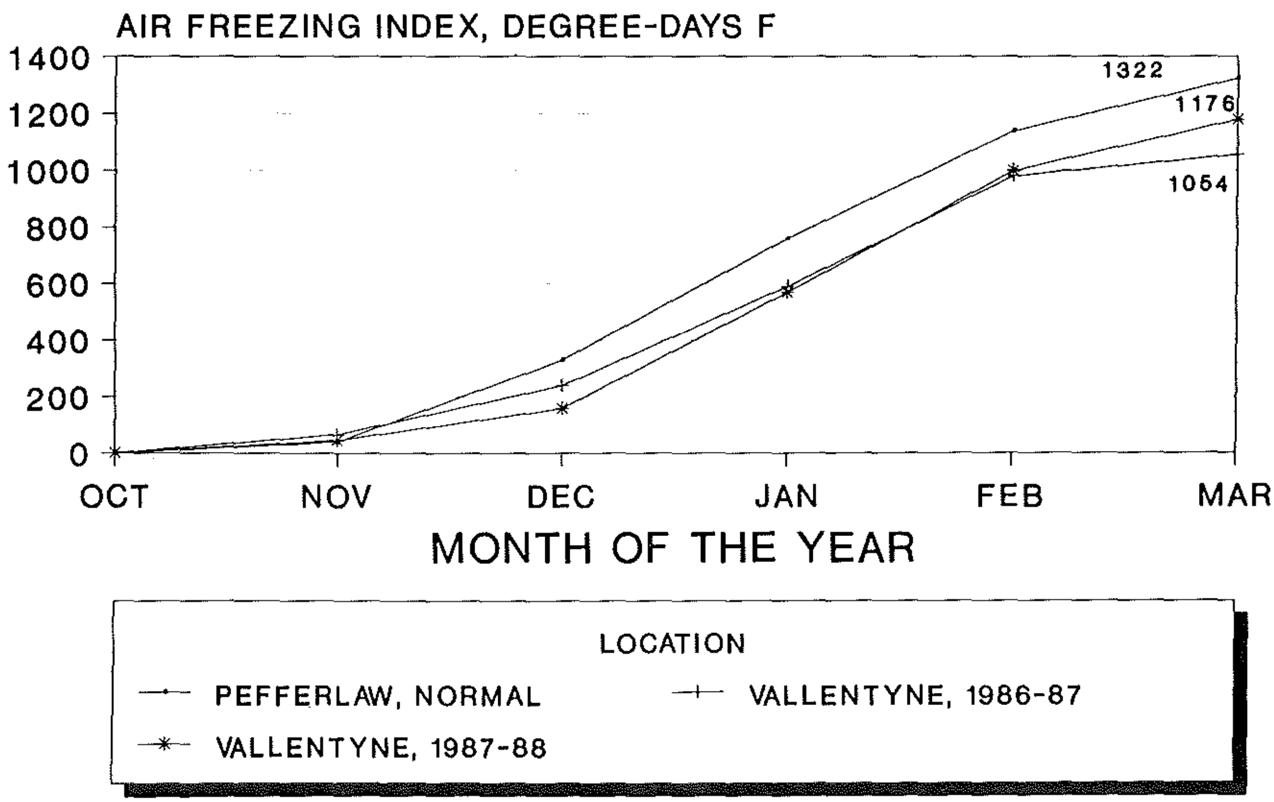

Figure 6. Air freezing index

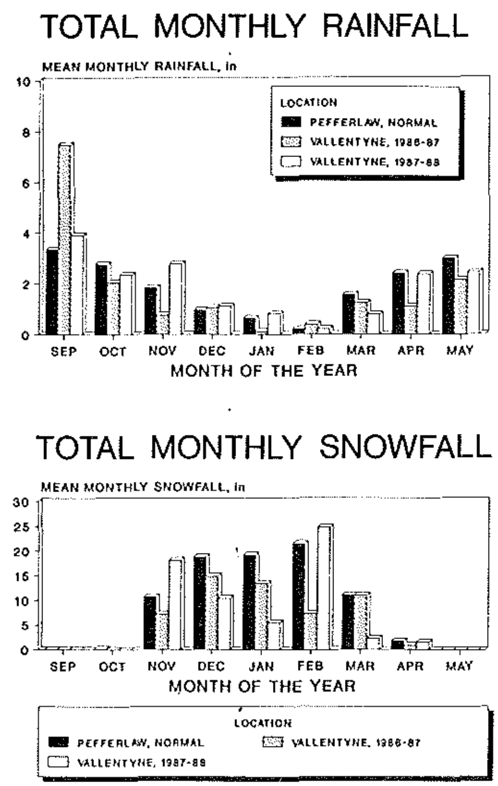

Figure 7. Monthly precipitation

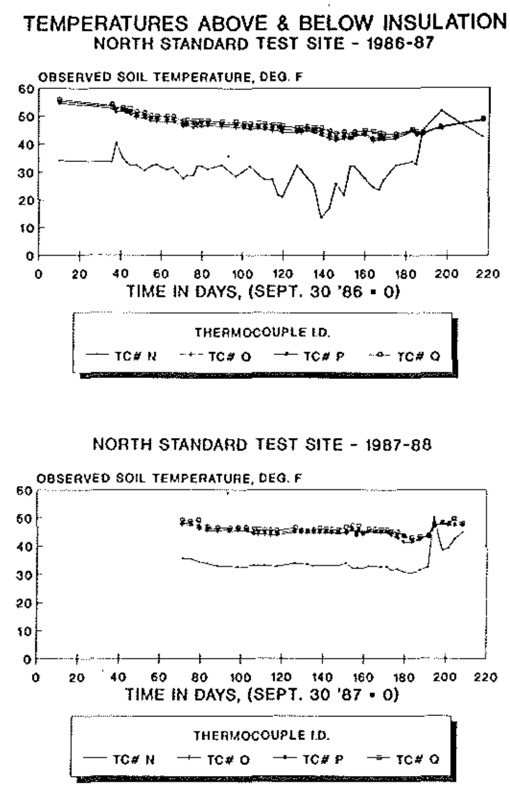

Figure 8. Temperatures above and below insulation—north standard test site

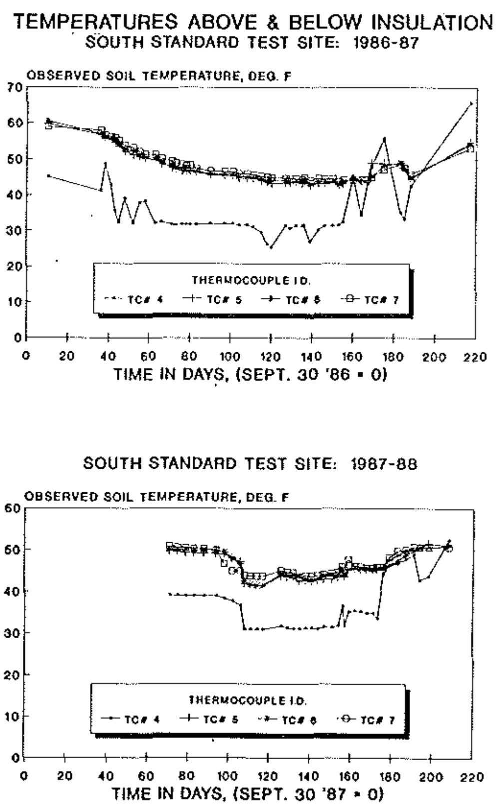

Figure 9. Temperatures above and below insulation—south standard test site

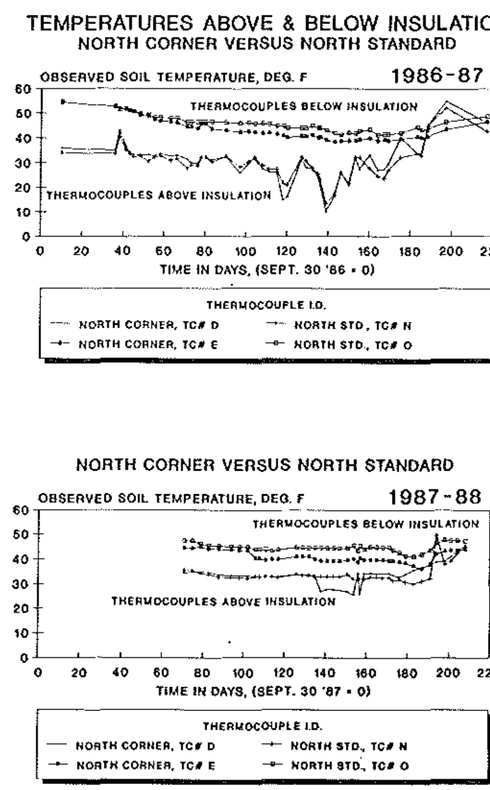

Figure 10. Temperatures above and below insulation—north corner vs. north standard

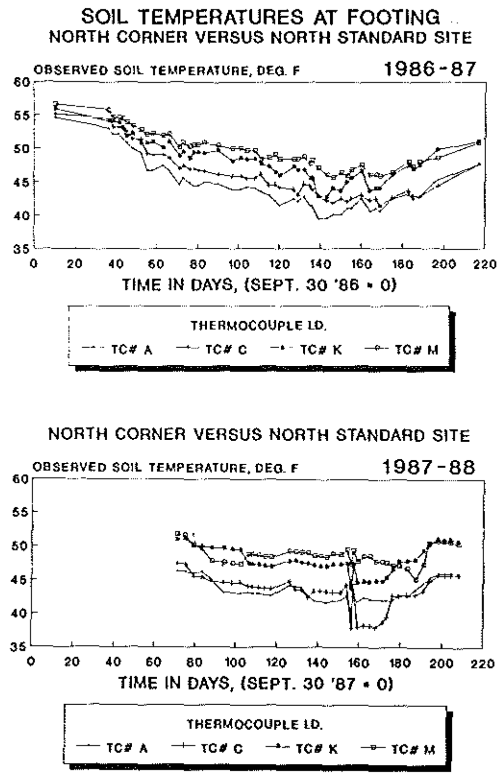

Figure 11. Soil temperatures at footing—north corner vs. north standard site

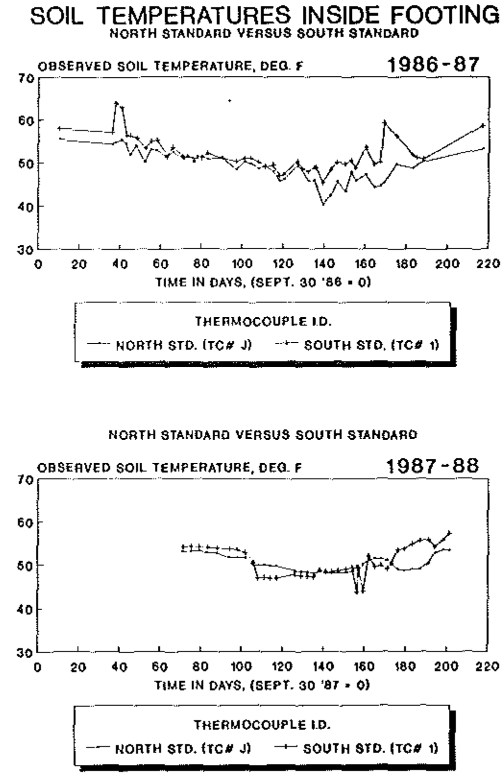

Figure 12. Soil temperatures inside footing—north standard vs. south standard

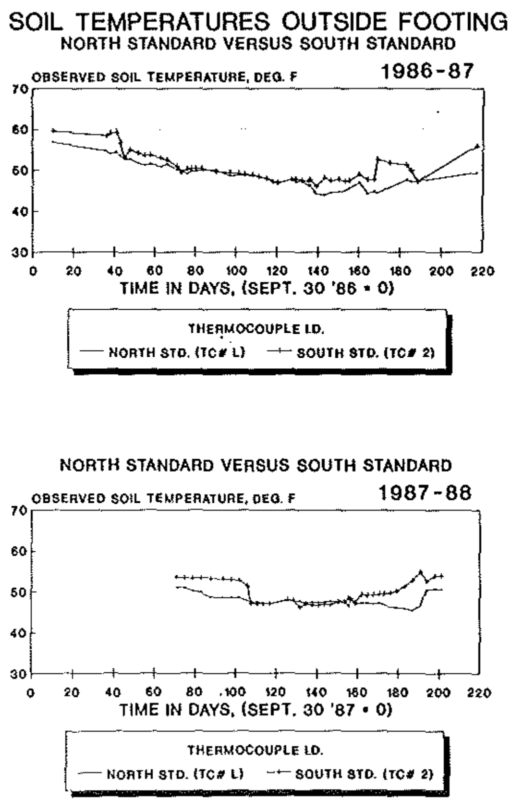

Figure 13. Soil temperatures outside footing—north standard vs. south standard

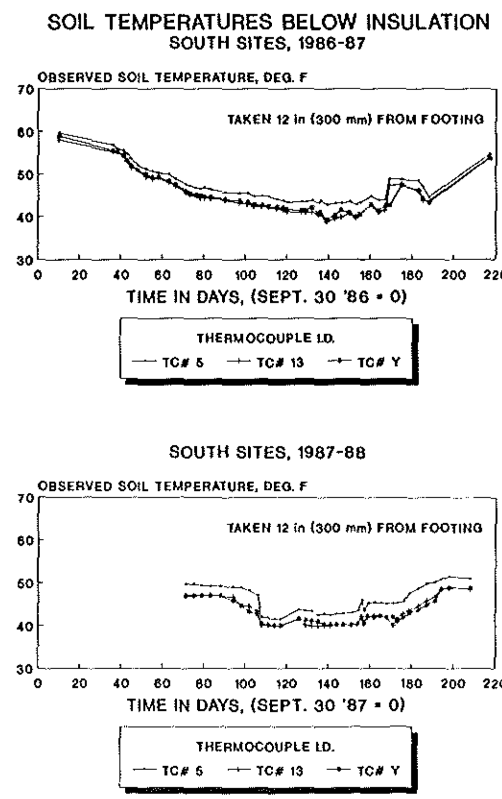

Figure 14. Soil temperatures below insulation—southern sites, 12" from footing