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THE EFFECT OF BASEMENT INSULATION ON THE DEPTH OF FROST PENETRATION ADJACENT TO INSULATED FOUNDATIONS

by D.A. Figley and L.J. Snodgrass

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RÉSUMÉ

L'isolation des sous-sols est une technique de plus en plus utilisée pour réduire la consommation d'énergie nécessaire au chauffage des locaux et rendre les sous-sols moins froids. L'isolation du sous-sol empêche la chaleur de se dissiper dans le sol environnant, ce qui entraîne un abaissement de la température du sol et un accroissement de la profondeur de pénétration du gel. Les techniques d'isolation doivent donc être sérieusement étudiées car les fondations qui reposent sur des sols soumis à des variations de volume produites par le gel peuvent se déplacer et causer des dommages au bâtiment.

Cette étude présente les résultats des mesures de la pénétration du gel effectuées à proximité de neuf maisons ayant des sous-sols de configurations différentes. On y indique la profondeur maximale de pénétration du gel contre les murs des sous-sols et à 1,5 m de distance, pour plusieurs hivers, à des indices de gel variant entre 1249°C-jours et 2409°C-jours (2248°F à 4336°F-jours).

Les premières observations ont montré que la profondeur de gel s'étendait au-delà des semelles seulement dans les cas où les sous-sols étaient partiellement enfouis et fortement isolés (plancher et murs).

The Effect of Basement Insulation on the Depth of Frost Penetration Adjacent to Insulated Foundations

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ABSTRACT

Insulating house basements is becoming a popular method of reducing space heating energy consumption and improving the basement environment. With a reduced heat flow to the surrounding soil, the soil temperatures are lowered and the depth of the frost penetration increases. Insulation strategies must be considered carefully, otherwise foundations bearing on soils that experience volume changes upon freezing can be shifted and building damage may occur.

This study reports on frost penetration measurements adjacent to nine different house basement configurations. The maximum depth of frost penetration against the exterior wall and 1.5 m (5 ft.) from the wall are reported for a number of winters with a range of freezing indices from 1249°C days to 2409°C days (2248°F days to 4336°F days).

Initial observations show that only shallow, highly insulated basements with both wall and floor insulation have frost depths extending below the footings.

KEY WORDS

Insulation, basement, foundation, frost, frost depth, house, soil, temperature.

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INTRODUCTION

*During the last decade, the rising cost of energy has created an in-*terest in improving the energy efficiency of housing. In most new constructions and many existing houses, the foundations and basement walls have been insulated in an attempt to reduce heat loss from the structure.

In the Canadian prairies, the most common foundation (new and existing) is a cast-in-place concrete basement. The insulating methods for this type of basement include:

1. Strapping the interior of the wall with wood framing and insulating with glass fibre batts (≅ RSI 1.4 to 7.1) (≅ R 8 to 40).
2. Installing high density glass fibre or polystyrene insulation on the exterior of the foundation wall before backfilling (≅ RSI 1.1 to 2.6) (≅ R 6 to 15).

In most retrofit cases, excavation of the foundation wall is not practical, thus the first method is normally used.

Advantages of the interior insulation system include easily finished basement walls and the ability to install relatively inexpensive batt insulation. Also, since the moisture barrier behind the stud wall isolates the concrete from the house, moisture transfer to the living space will be reduced. Disadvantages of this system include a reduction in usable floor area, and the loss of the thermal mass of the concrete as a heat storage medium.

Insulating the outside of the basement wall eliminates the disadvantages of the first method, however the economic optimum thermal resistance is reduced since the insulation costs are much higher. Additional interior insulation can also be added when the basement area is developed.

Another basement foundation wall system [1] that has become increasingly popular uses preserved wood wall studs and plywood sheathing. This system has walls that are readily insulated and finished from the interior, since additional framing is not required.

Any increase in the amount of insulation on the interior of a foundation wall will decrease the exterior wall surface temperature. Depending upon the interior space temperature, the insulation configuration, and the soil properties (including grain size distribution and water content), the soil may freeze to the exterior of the wall. If the soil "expands" upon freezing, significant loads can be imposed on the wall and structural problems can arise.

Fortunately, proper design of the wall, the insulation layout, and the drainage system can eliminate most of the potential problems associated with adfreezing. Several authors [2,3,4] have discussed this phenomena and outlined the basic engineering principles. They also suggest some design details (including the use of a drainage layer) that will prevent this problem from occurring. The use of high density glass fibre as an insulation-drainage layer has been reported by Tao [5]. The results indicated that this system could be used to prevent adfreezing and should be considered for locations where conditions require adfreeze protection.

Increasing the thermal resistance of the below grade portion of the wall will also reduce heat loss to the surrounding soil, resulting in lower adjacent soil temperatures. The effect on soil temperature is of particular interest, since some types of soil experience volume changes upon freezing. Foundations in these soils can experience substantial displacements causing problems ranging from minor wall cracking and window breakage to serious structural failures.

The accurate prediction of temperatures surrounding a heated basement is complex and involves many factors, including non-uniform local soil properties, foundation depth, basement geometry and insulation values, snow cover, vegetation, incident solar radiation, outside air temperature, precipitation, drainage, and proximity to other structures. Since many of these factors vary with time and location, each case must be considered separately.

Goodrich [6] has reviewed numerical methods for ground temperature calculations. The problem associated with these numerical methods is that, in addition to the assumptions in heat transfer mechanisms, soil properties must be specified. Farouki [7] has evaluated a number of techniques currently used to predict the thermal properties of specific soils and it is recognized that substantial variations can occur.

The current literature contains analytical models for basement heat loss and soil temperature profiles that require large amounts of field data to yield accurate results. When making comparisons with field measurements, seasonal and short-term variations in factors impose large bands of uncertainty on current models, some of which are already complex and costly to execute.

This paper discusses field measurements of soil temperature profiles around insulated basements. The maximum depths of frost penetration adjacent to and 1.5 m (5 ft.) from the foundation are reported for twelve locations in the Saskatoon area. The measurements were taken for a number of winters with a cumulative freezing index range of 1249°C days to 2409°C days (2248°F days to 4336°F days).

Future studies by NRC/DBR may be undertaken to compare these data with analytical model predictions.

METHOD

Thermocouples were installed around a number of typical foundations with different insulation configurations. Detailed descriptions of the individual sites are given in Appendix A.

The soil temperatures were measured using 0.4049 mm (0.016 in.) type T (copper-constantan) thermocouples. The thermocouples were soldered and then sealed with lacquer to prevent corrosion of the wiring and erroneous readings [8]. The thermocouple strings were inserted down 38 mm (1.5 in.) diameter augered holes and the holes were backfilled with existing soil.

Temperatures were calculated from voltages measured with a voltmeter (resolution 0.004 mv) using an ice bath as reference. With this equipment, soil temperature measurements are estimated to be accurate to ±0.3°C (±0.5°F).

The freezing index (FI) is defined as "the cumulative total of degree days of air temperature below freezing during the entire winter. The FI is calculated using the mean daily temperatures with subtractions for days above freezing" [9].

The wall thermal resistance values are the nominal insulation values of the insulating materials and do not include corrections for framing, concrete or other construction materials. The RSI units are $m^2\,°C/W$ and the R values are hr $ft^2\,°F/BTU$.

RESULTS

The data for each location include a written description of the site giving the construction date and building style, insulation configuration, general soil type, heating system, monitoring period and a plot plan and cross section of the foundation wall. The thermocouple locations are shown as solid dots (·) on the cross sections.

The vertical temperature distributions were calculated by linear interpolation between the vertical data points. Straight line isotherms were then drawn using the vertical temperature profiles as end points. The isotherms for the days with the greatest frost depths were used to determine the maximum frost depths adjacent to and 1.5 m (5 ft.) from the foundation.

Snow cover was measured "as is" at the time the monthly temperature measurements were made. These measurements may not accurately describe the prevailing snow cover conditions.

For reference purposes, the average monthly air temperature and soil temperature at various depths for the years 1977 to 1983 [10] are presented in Figure 1. The freezing index for Saskatoon for the same years is given in Figure 2.

DISCUSSION

Table 1 summarizes the basic insulation configurations for the houses. The annual maximum depth of frost penetration at each location for the nine houses is summarized in Figures 3 to 6. Since the maximum depth of frost penetration varies with distance from the foundation, values are given at a distance of 1.5 m (5 ft.) from the foundation and adjacent to the wall. Due to transient heat transfer effects, these maximums do not always occur simultaneously. The depth to the top of the

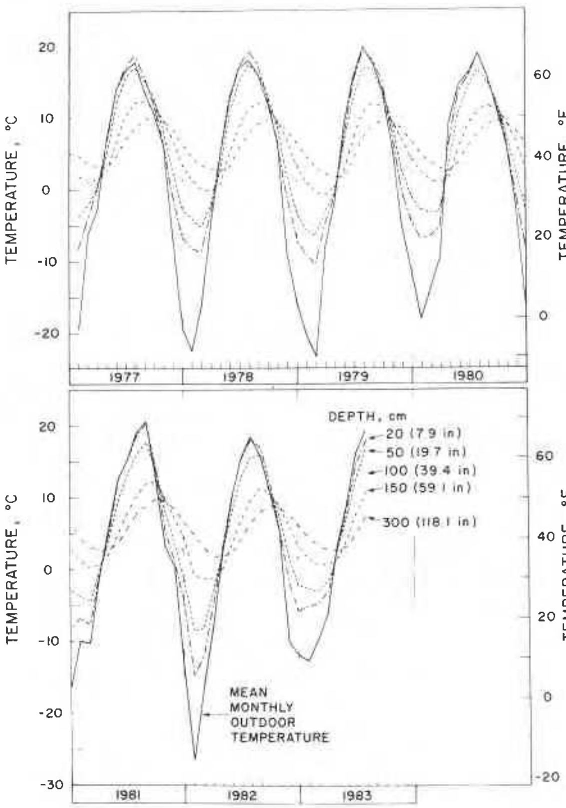

Figure 1. Soil temperature at various depths 1977–83 (Saskatoon).

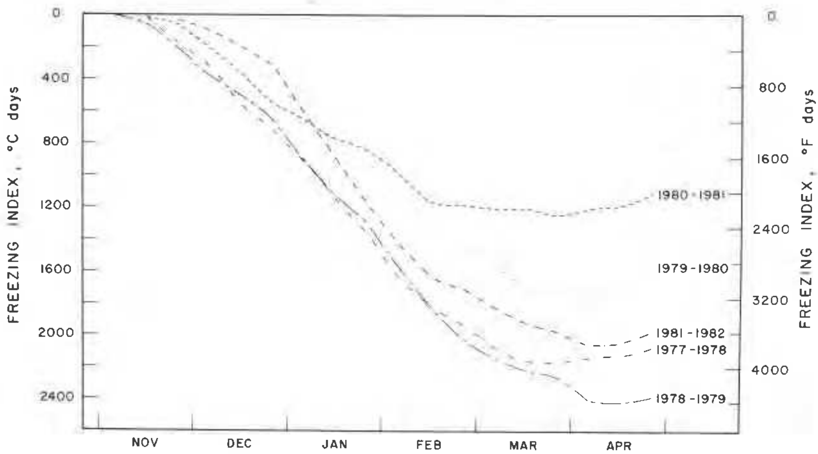

Figure 2. Cumulative freezing index for 1977–83 (Saskatoon)

footing below grade is shown. Open field frost penetration with naturally occurring snow cover [10] is also plotted. In some cases, frost penetration depths lower than the open field data were recorded. Variations in snow cover and soil conditions could cause these local differences.

Figures 3 to 6 clearly indicate that increasing the thermal resistance of the floor/wall system below grade will increase the depth of frost penetration. In practical terms, however, only extremely well insulated foundations such as houses 1 and 5 have frost penetration levels near the footing depth.

Considering house 5S, the zero degree isotherm adjacent to the foundation went just below the top of the footing, even during a relatively mild winter, 1980–81 (FI = 1249°C days) (FI = 2248°F days) yet did not go below the bottom of the footing even during a severe winter, 1978–79 (FI = 2409°C days) (FI = 4336°F days). This illustrates the effectiveness of horizontal insulation in preventing frost from reaching the footings

In the prairies, the majority of existing basements are cast-in-place concrete with top of footing depths ranging from approximately 1 m (3.3 ft.) (bi-level or split level) to 3 m (10 ft.) (bungalow) below finished grade.

Houses 2, 3, 6, 8, and 9 have "deep" foundations (top of footing depth ≥1.8 m (6 ft.)) with moderate levels of insulation. All of the data for these houses indicate that much higher levels of basement wall insulation could be used without causing potentially serious frost penetration. It is probable that the heat loss from the uninsulated concrete floor slab alone would be sufficient to prevent frost penetration to the footing

Table 1. House Detail Summary.

House Code	Soil Type	Depth of Footing Below Grade m (ft)	Below Grade Wall Insulation RSI (R)	Floor Insulation RSI (R)
1	Sand 50% Silty Clay 50%	2.02 (6.63)	7.7 (44)	3.5 (20)
2	Sand 98% Silt 2%	1.83 (6.00)	3.5 (20)	0
3	Sand 10% Silt 60% Clay 30%	2.83 (9.28)	3.5 (20) from 150 mm to 760 mm below grade level (5.9 in. to 30 in.)	0
4	Silty Sand	1.30 (4.26)	1.9 (11)	0
5S	Sand 94% Silt 6%	0.92 (3.02)	7.7 (44)	3.5 (20) (plus horizontal rigid insulation outward at top of footing)
5E	Sand 94% Silt 6%	1.22 (4.00)	7.7 (44)	3.5 (20) (plus horizontal rigid insulation outward at top of footing)
6	Sand 70% Silt 15% Clay 15%	1.86 (6.10)	1.2 (7)	0 (plus horizontal rigid insulation outward at top of footing)
7	Sand	0	N/A	1.8 (10) (rigid insulation on edge of a slab and 0.6 m horizontally under slab)
8	Sand 5% Silt 53% Clay 42%	2.34 (7.68)	3.5 upper 1.22 m (20 upper 4 ft.) 1.4 lower 1.22 m (8 lower 4 ft.)	0
9N	Fine Sand	1.86 (6.10)	1.1 (6)	0
9W	Fine Sand	1.86 (6.10)	1.1 (6)	0

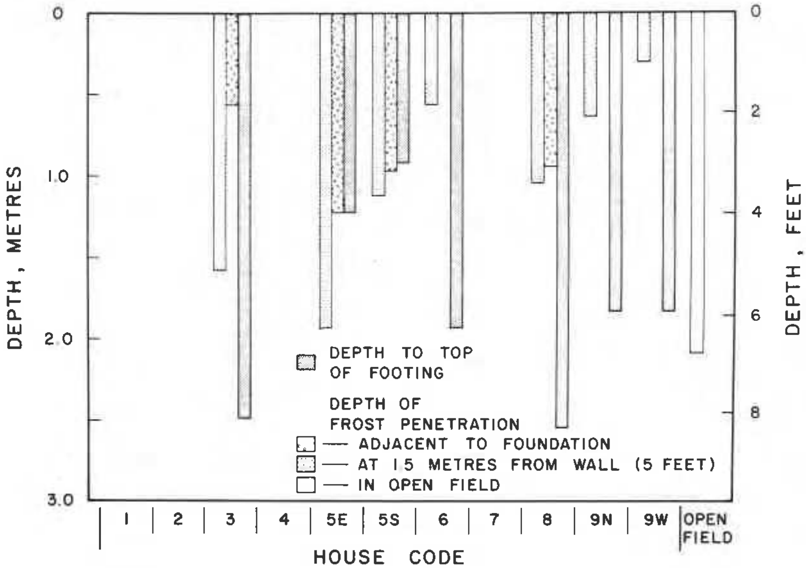

Figure 3. Depth of frost penetration for 1978–79. FI = 2409°C days (FI = 4336°F days).

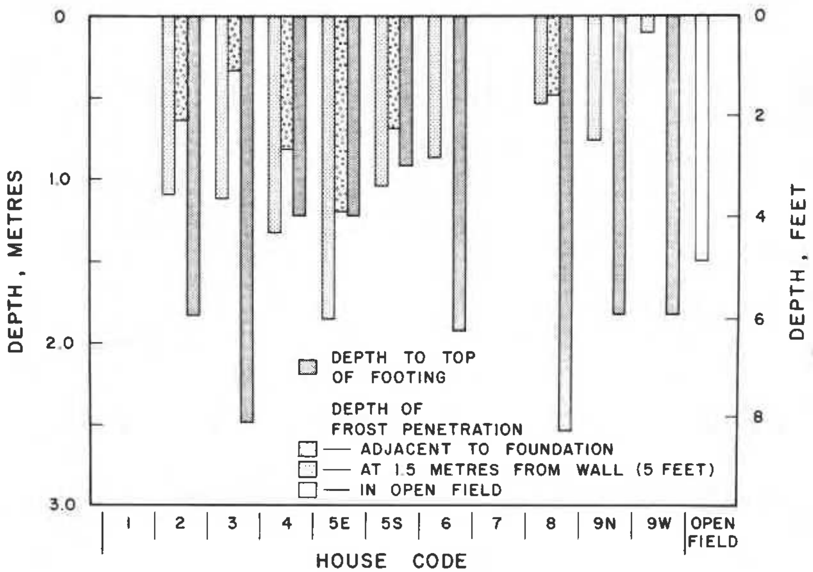

Figure 4. Depth of frost penetration for 1979–80. FI = 1757°C days (FI = 3163°F days).

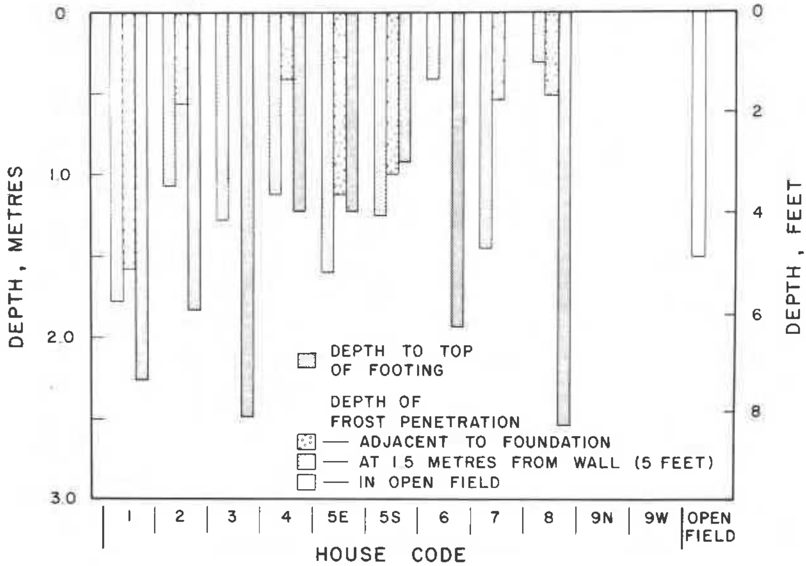

Figure 5. Depth of frost penetration for 1980–81. FI = 1249°C days (FI = 2248°F days).

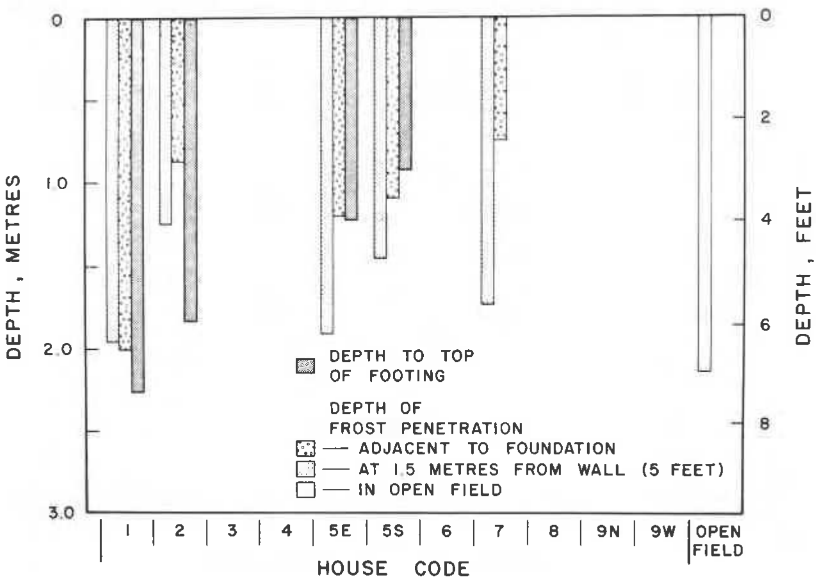

Figure 6. Depth of frost penetration for 1981–82. FI = 2073°C days (FI = 3731°F days).

depth. In house 8, the lower wall insulation was reduced to RSI 1.4 (R 8) to allow additional heat loss because the owner (a structural engineer) was concerned about frost heaving of the footings. For this house, Figure 3 shows that during a cold winter (FI = 2409°C days) (FI = 4336°F days) the frost penetration adjacent to the wall was less than 1 m (3.3 ft.).

In "shallow basement" constructions (top of footing depth ≤1.8 m (6 ft.)), very high levels of wall and floor insulation can result in potentially harmful frost penetration, as in the case of house 5. In the majority of cases where a cast-in-place, uninsulated concrete floor slab is used, the floor slab provides a substantial heat source; the amount of wall insulation that can be safely used will be related to the backfill depth. In house 4, a wall insulation level of RSI 1.9 (R 11) resulted in a frost penetration of 0.8 m (2.6 ft.) in a moderate winter (FI = 1757°C days) (FI = 3163°F days), with very light (0 to 50 mm) (0 to 2 in.) snow cover, so it is possible that the frost could reach footing depth during a severe winter.

House 7 is a slab on grade construction with perimeter in-slab forced air heating. This is not a common house foundation but a large number of commercial/light industrial and farm livestock buildings use foundations of this type. Although temperatures under the slab are not reported, it is expected that freezing isotherms would extend well under the foundation. For this location, a low water table and sandy soil prevented any foundation heaving, but this insulation system is not recommended.

The depth of frost penetration is strongly dependent upon the thermal conductivity and the volumetric heat capacity of the soil, that depend on many variables, primarily water content. Although an infinite number of possible combinations exist, Goodrich [11] has shown that in general, sands and gravels experience deeper frost penetrations than fine grained soils.

When analyzing frost penetration data, designers and researchers often refer to the Design Curve [9,12,13] which relates the maximum depth of frost penetration to the freezing index. This curve was originally developed from observed frost penetration under snow cleared airport runways in the northern United States and is based on a granular soil type and a limited range of FI. Although useful for estimations under similar conditions, it has been shown to be less reliable for other applications [14].

For estimating frost penetration near basements, it is proposed that the design curve be modified to account for heat input. As the thermal resistance of the insulation increases, the influence of the basement on

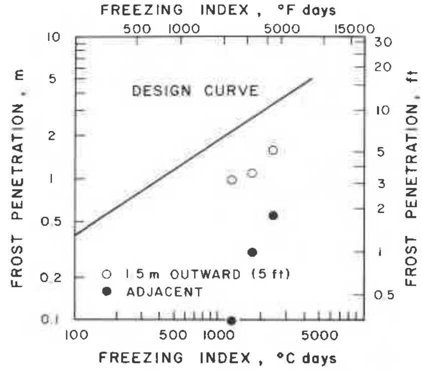

Figure 7. Frost penetration vs. freezing index—House 3.

the soil temperature profile decreases and the profile will converge toward open field conditions.

Since different foundation geometries and insulation configurations will affect the overall soil heat input, a separate "modified design curve" would be required for each case. These foundations represent a large portion of prairie residential designs, therefore these data should apply to many of them.

An example of a modified curve is shown in Figure 7. For house 3, the maximum frost penetration depth adjacent to the foundation and at a distance of 1.5 m (5 ft.) from the foundation are plotted for the three years data were available. Although the range of FI is limited, a relationship appears to exist. Since this site was kept snow cleared, the data are more consistent than some of the other sites where snow cover was allowed to accumulate naturally.

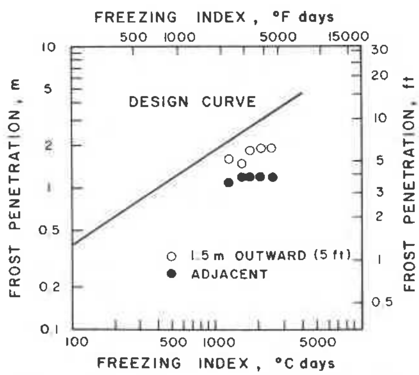

Figure 8. Frost penetration vs. freezing index—House 5 East.

Another example of a modified curve is shown in Figure 8. The data for maximum frost penetration at a distance of 1.5 m (5 ft.) from the foundation follows a relationship similar to the design curve but is vertically offset to account for heat supplied by the basement. The observations adjacent to the basement wall are almost independent of FI, showing the effectiveness of the horizontal insulation skirt in preventing frost penetration. At lower FI values where the frost penetration does not reach the footing, the values begin to decrease.

Further measurements of these soil temperature profiles are being made under snow cleared conditions over a sufficient period of time (range of FI) to develop modified design curves.

CONCLUSIONS

Although these data were collected from a limited number of sites, a number of generalizations can be made. Additional data are needed to support these observations.

1. Observations around house 1 with a deep foundation show that even with RSI 7.7 (R 44) wall and RSI 3.5 (R 20) floor insulation, frost did not penetrate to the depth of footing during a cold winter (FI = 2073°C days) (FI = 3731°F days) with minimal (75 mm) (3 in.) snow cover.
2. Observations around house 5S with a heavily insulated shallow foundation, RSI 7.7 (R 44) wall and RSI 3.5 (R 20) floor, shows that frost can penetrate to the footing level even during a mild winter (FI = 1249°C days) (FI = 2248°F days) with no snow cover. The additional 0.3 m (1 ft.) of backfill, 1.22 m (4 ft.) above footing on the east side, seems to be the minimum necessary to prevent frost penetration to the footing. The horizontal insulation thickness and width should be increased on new constructions of this type.
3. New and existing basements with uninsulated concrete floor slabs can safely use much higher levels of wall insulation than was previously assumed.
   - For deep basements, the thickness of wall insulation may become an economic decision since frost penetration to the footings is very unlikely.
   - For shallow basements, consideration should be given to the maximum insulation level, although the economic optimum (≅ RSI 2 to 4) (R 11 to 22) can normally be used. For new constructions, perimeter insulation over the footings will allow the safe use of higher levels of wall insulation.
4. To prevent the soil under a surface slab from freezing, vertical insulation on the outside edge of the slab extending downward is required.

Determination of the thickness, and more importantly, the depth of the insulation is beyond the scope of this study.

ACKNOWLEDGEMENT

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APPENDIX A HOUSE CODE 1–9

USC UNIT CONVERSIONS FOR APPENDIX A

Thermal Resistance

RSI 1 ($m^2\,°C/W$) = R 5.678 ($hr\ ft^2\,°F/BTU$)
RSI 2.1 = R 12
RSI 3.5 = R 20
RSI 4.9 = R 28
RSI 7.0 = R 40
RSI 7.7 = R 44

Density

1 kg/m^3 = 0.0624 lb/ft^3
14.5 kg/m^3 = 0.90 lb/ft^3
48 kg/m^3 = 3 lb/ft^3
112 kg/m^3 = 7 lb/ft^3
144 kg/m^3 = 9 lb/ft^3

Length

1 meter (m) = 3.28 ft. = 39.37 in.
12 mm = 1/2 in.
15.9 mm = 5/8 in.
19 mm = 3/4 in.
25.4 mm = 1 in.
38 mm = 1 1/2 in.
100 mm = 4 in.
150 mm = 6 in.
203 mm = 8 in.
228 mm = 9 in.
305 mm = 12 in.
406 mm = 16 in.
610 mm = 24 in.

150 μm = 6 mil = 0.006 in.

Framing Lumber

38 × 89 mm = 2″ × 4″
38 × 140 mm = 2″ × 6″
38 × 184 mm = 2″ × 8″
38 × 235 mm = 2″ × 10″

House 1

This structure, built in 1980, is a continuously heated wood framed double stud wall house on a full height (2.44 m) double stud preserved wood foundation and crawl space (Figure a).

To support the soil pressure, the basement wall system incorporates 38 × 140 mm studs, 406 mm o.c. with 15.9 mm plywood sheathing on the exterior. The backfill is 1.42 m above the top of the basement floor. The inner vertical load bearing wall uses 38 × 89 mm studs, 406 mm o.c. for an overall wall thickness of 330 mm. Both walls bear on a wood footing set on 150 mm of crushed rock.

The stud spaces and cavity are filled with glass fibre batt insulation (14.5 kg/m^3) with an overall thermal resistance of RSI 7.7. The inside of the wall above the floor is sheeted with 12 mm drywall.

The basement floor is 38 × 235 mm joists topped with 15.9 mm plywood bearing on the inner load bearing wall. The cavity between the floor joists is insulated to RSI 3.5 using glass fibre batts.

The crawl space (0.84 m from the underside of floor joists to top of grade) is not heated or ventilated. 150 μm polyethylene sheeting was placed on the ground surface to reduce moisture transmission from the soil.

Soil from the original excavation was used to backfill the basement. The general soil type is 50 percent silty clay and 50 percent sand.

An electric forced air furnace is used to heat the house.

Monthly temperature measurements were taken from January 1981 to April 1983. Seventeen thermocouples were used to measure soil temperatures at various locations on the north side of the house.

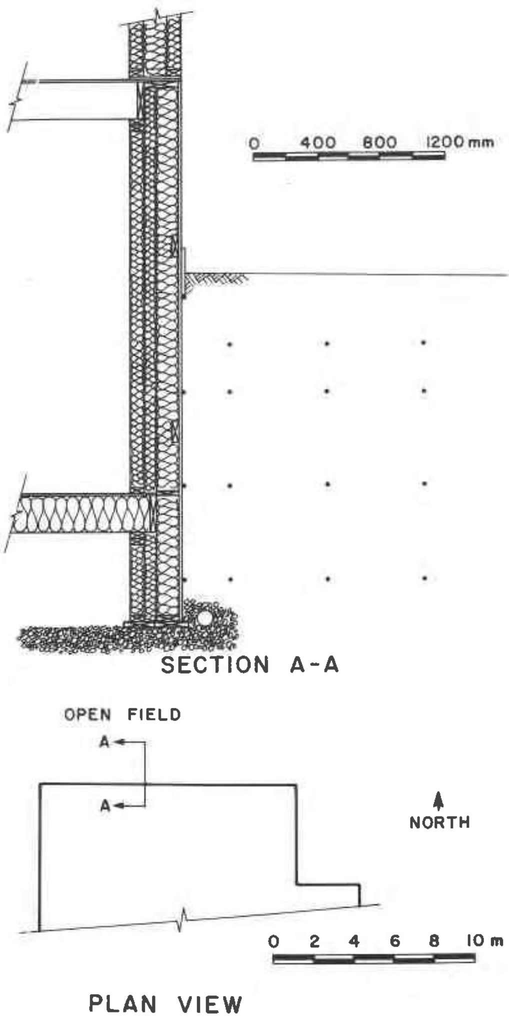

Figure a. Plot plan and foundation cross section—House 1.

House 2

This structure, built in 1955, is a continuously heated wood frame house on a full height (2.36 m) cast in place 228 mm thick concrete basement with 0.64 m above grade (Figure b).

The floor slab is 100 mm thick uninsulated concrete cast over a 100 mm gravel pad placed on undisturbed soil. The top surface of the slab is bare concrete.

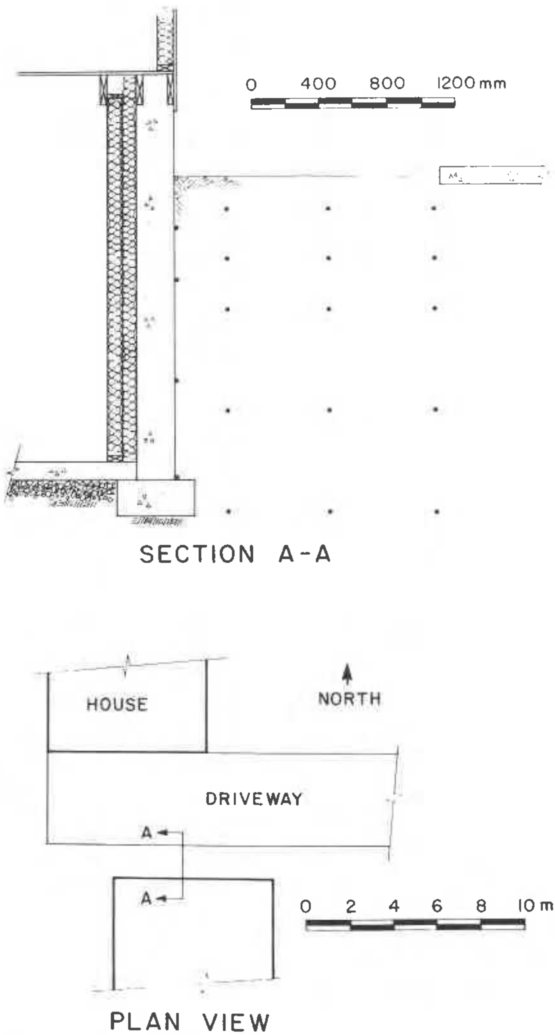

Figure b. Plot plan and foundation cross section–House 2.

During the fall of 1979, the interior of the wall from the subfloor to the underside of the floor joists was framed with 38 × 89 mm studs 610 mm o.c. set out 75 mm from the concrete. The back space was insulated with RSI 1.4 glass fibre batts and the space between the studs was filled with RSI 2.1 glass fibre batts yielding a total wall thermal resistance of RSI 3.5. The glass fibre batt insulation density was 14.5 kg/m^3. The entire inside wall was sheeted with 12 mm drywall.

The basement excavation was backfilled with soil from the site. The general soil type is 2 percent silt and 98 percent sand.

The heating system is natural gas fired forced air furnace with automatic fan operation.

Monthly temperature measurements were taken from December 1979 to March 1983. Nineteen thermocouples were used to measure ground temperatures on the north side of the house.

House 3

This structure, built in 1976, is a continuously heated wood frame house on a full height (2.32 m) preserved wood basement (Figure c).

The top of the basement wall extends 100 mm above the top of the 100 mm thick concrete patio slab. The basement wall system used 38 × 140 mm studs, 305 mm o.c. with 15.9 mm plywood sheathing on the exterior. The walls bear on uninsulated concrete footings cast on undisturbed soil. The basement floor is a 100 mm thick concrete slab cast over 150 mm of gravel on undisturbed soil. The top surface of the slab is bare concrete.

The cavities between the studs are filled with 14.5 kg/m^3 glass fibre batt insulation RSI 3.5 for 0.60 m down from the top plate. The lower portion of the wall is uninsulated. The inside of the stud wall is sheeted with 12 mm drywall.

Soil from the original excavation was used to backfill the basement. The general soil type is 30 percent clay, 60 percent silt, and 10 percent sand.

A natural gas fired forced air furnace is used to heat the house.

Soil temperature measurements were taken monthly from September 1976 to April 1981. Thirteen thermocouples were used to measure soil temperatures at various locations on the west side of the house under the concrete patio slab.

House 4

This structure, built in 1979, is a continuously heated wood frame house on a full height (2.44 m) corrugated steel panel basement with

1.22 m above grade (Figure d). The wall panels are 16 ga. galvanized steel with 76 mm deep corrugations and rest on 3 mm × 203 mm steel plate footings on a 200 mm gravel pad.

The floor slab is 75 mm thick uninsulated concrete cast over a 200 mm gravel pad placed on undisturbed soil. The top surface of the slab is bare concrete.

The exterior of the wall from the underside of the floor joists to the

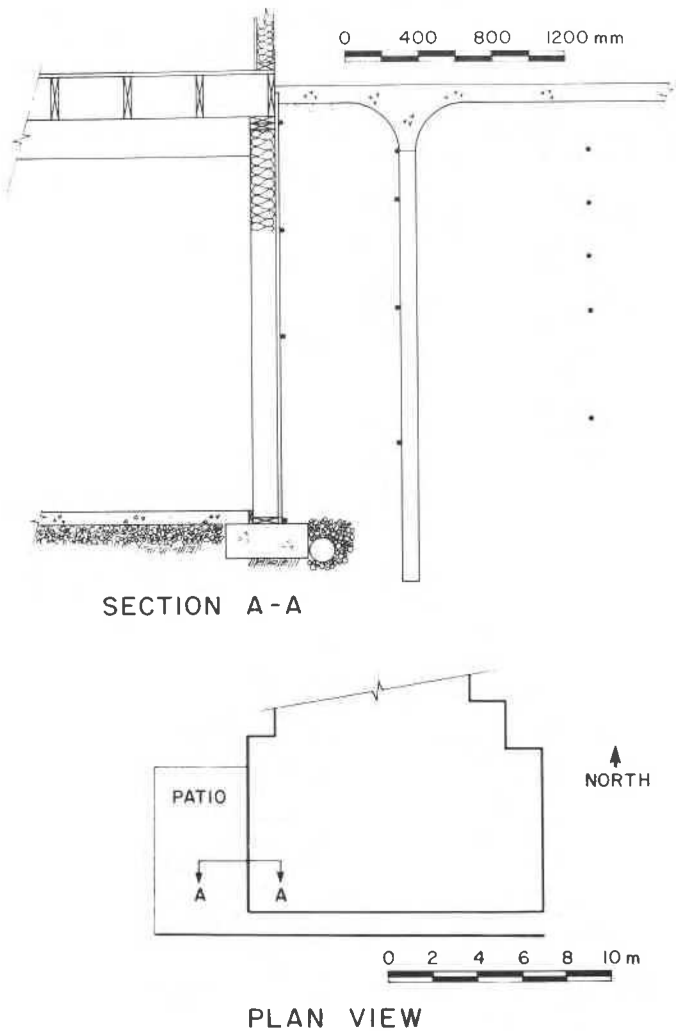

Figure c. Plot plan and foundation cross section—House 3.

top of the footing is insulated with 68 mm thick asphalt coated rigid glass fibre insulation with a density of 144 kg/m³ having a nominal (dry) thermal resistance of RSI 2.0. The exterior of the insulation above grade was covered with metal lath and parged.

The basement excavation was backfilled with soil from the original excavation. The general soil type is silty sand to a depth of 1.52 m and soft clay below that level.

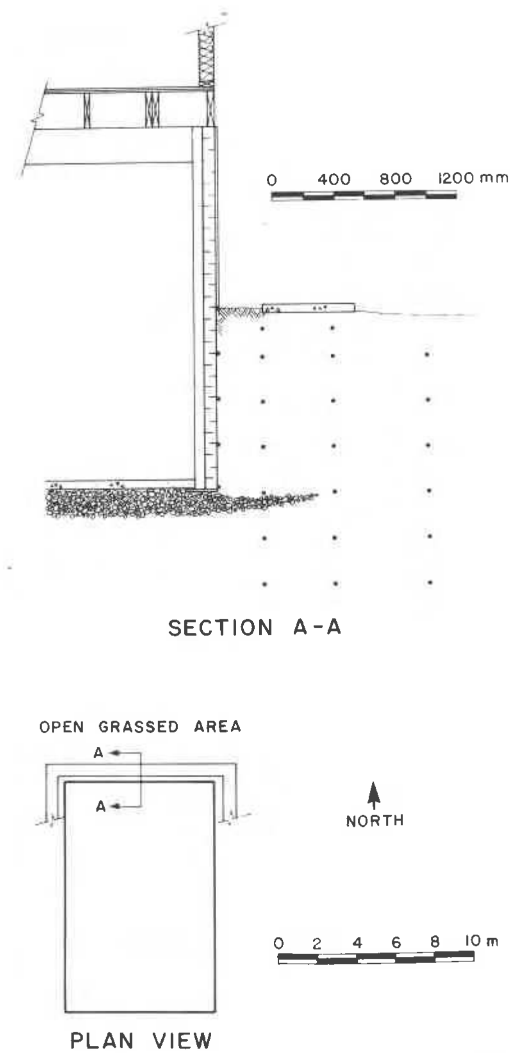

Figure d. Plot plan and foundation cross section—House 4.

The heating system is a natural gas fired forced air furnace with automatic fan operation.

Monthly temperature measurements were taken from October 1979 to April 1981. Twenty-five thermocouples were used to measure ground temperatures on the north side of the house.

House 5

This structure, built in 1978, is a continuously heated wood framed double stud wall house on a full height (2.44 m) double stud preserved wood foundation (south side Figure e.1 and east side Figure e.2).

To support the soil pressure, the basement wall system uses 38 × 89 mm studs, 406 mm o.c. with 19 mm plywood sheathing on the exterior. The inner wall uses 38 × 89 mm studs, 406 mm o.c. for an overall wall thickness of 305 mm.

The stud spaces and cavity are filled with glass fibre batt insulation with an overall thermal resistance of RSI 7.7. The inside of the wall is sheeted with 12 mm drywall.

The basement floor is 38 × 140 mm joists topped with 15.9 mm plywood. The main wall and the floor joists are supported by a 200 × 600 mm concrete footing placed on undisturbed soil. The spaces between the floor joists are insulated with glass fibre batt insulation to RSI 3.5. All of the glass fibre batt insulation had a density of 14.5 kg/m^3.

The crawl space (0.28 m from the underside of floor joists to top of grade) is not heated or ventilated. 150 μm polyethylene sheeting was placed on the soil surface to reduce moisture transmission from the soil.

The concrete footings were cast on undisturbed soil and are insulated with two 38 mm layers of SM (STYROFOAM™ RSI 1.3 per layer) extending horizontally from the top of the footing. The lower layer extends outward 0.92 m and the upper layer 0.61 m.

Soil from the original excavation was used to backfill the basement. The south side backfill height is 0.92 m above the top of the footing and the east side backfill height is 1.22 m above the top of the footing. The general soil type is 6 percent silt and 94 percent sand.

The house is heated with an electric forced air furnace.

Monthly temperature measurements were taken from October 1978 to April 1983. One string of 23 thermocouples was installed on the east side of the house. The second string of 20 thermocouples was installed on the south side of the house.

House 6

This structure, built in 1976, is a continuously heated wood frame house on a full height (2.36 m) cast in place 203 mm thick concrete basement with 0.6 m above grade (Figure f). The floor slab is 100 mm thick uninsulated concrete cast over a 100 mm thick gravel pad placed on undisturbed soil. The top surface of the slab is bare concrete.

The exterior perimeter of the foundation wall from the underside of the subfloor to the top of the footing is insulated with 38 mm of 144 kg/m³ rigid glass fibre insulation having a nominal thermal resistance of RSI 1.2. An additional 1.22 m high layer of 12 mm rigid glass fibre insulation (SOUNDSTOP™) was installed from 60 mm below the subfloor

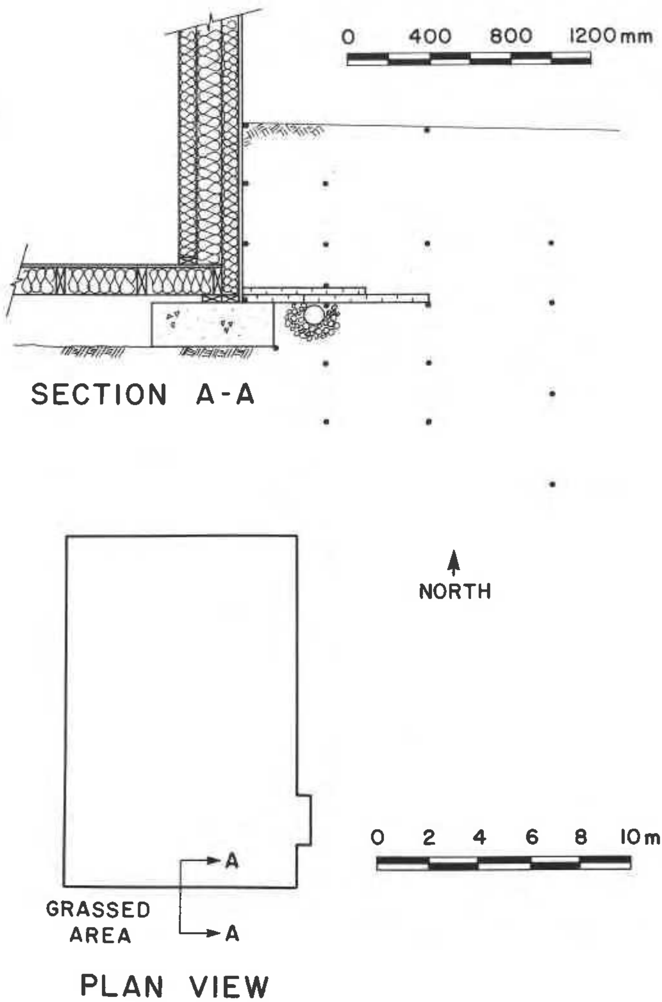

Figure e.1. Plot plan and foundation cross section—House 5 South.

downwards. The exterior of the SOUNDSTOP was covered with expanded metal lath and parged to provide mechanical protection. Thirty-eight mm thick 133 kg/m³ rigid glass fibre insulation, extending horizontally outward 0.30 m, was installed over the concrete footing.

The basement excavation was backfilled with soil from the site. The general soil type is 15 percent clay, 15 percent silt, and 70 percent sand.

The heating system is a natural gas fired forced air furnace with automatic fan operation.

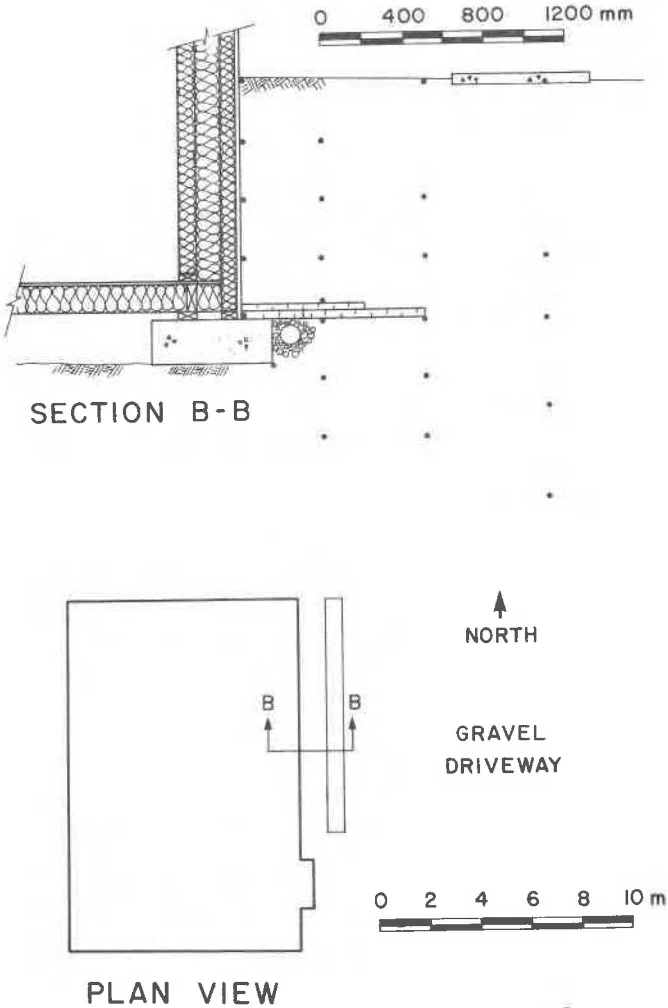

Figure e.2. Plot plan and foundation cross section–House 5 East.

Temperature measurements were taken monthly from January 1977 to April 1981. Nineteen thermocouples were used to measure soil temperatures at various locations on the west side of the house.

House 7

This structure, built in 1980, is a continuously heated wood framed single story garage/workshop with a slab on grade foundation (Figure g).

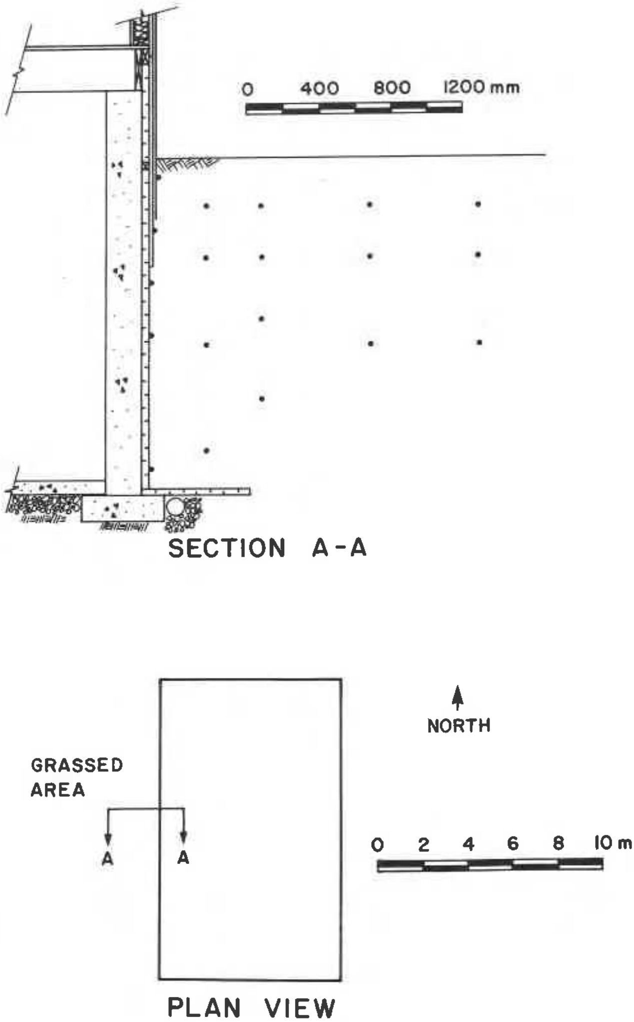

Figure f. Plot plan and foundation cross section–House 6.

The concrete slab is nominally 100 mm thick with the 0.50 m perimeter strip thickened to 305 mm for structural support and to accommodate in-slab services. The slab was cast on a 200 mm gravel pad on undisturbed soil. The top surface of the slab is bare concrete.

Fifty mm (STYROFOAM™ RSI 1.75) was installed on the vertical edge of the slab and under the slab extending from the perimeter inward for 0.61 m.

The soil type is 100 percent sand from the underside of the slab to 2.0 m below grade. No soil testing was done below that depth.

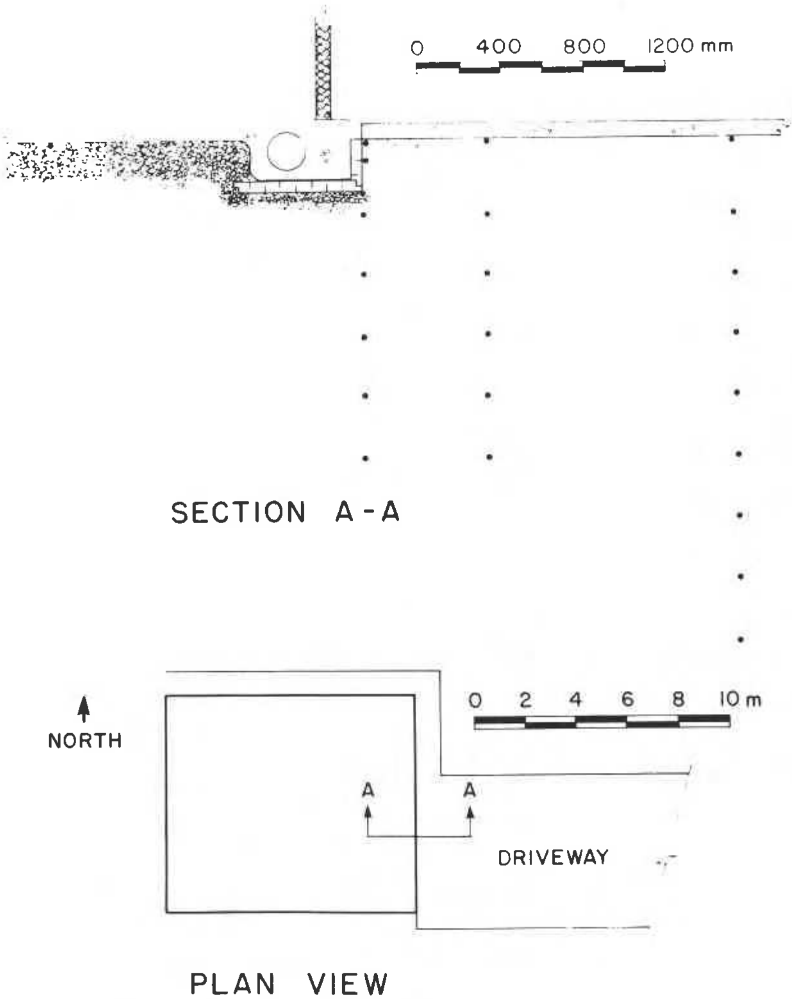

Figure g. Plot plan and foundation cross section—House 7.

The heating system is a natural gas fired forced air furnace with the warm air supplied to a perimeter in-slab duct system. The furnace fan is operated continuously and the circulating air temperature varies from approx. 60°C with the furnace firing to 20°C (normal room temperature) during fan only operation.

Temperature measurements were taken monthly from October 1980 to March 1983. Twenty-three thermocouples were installed at various locations in the floor slab and soil adjacent to the concrete driveway.

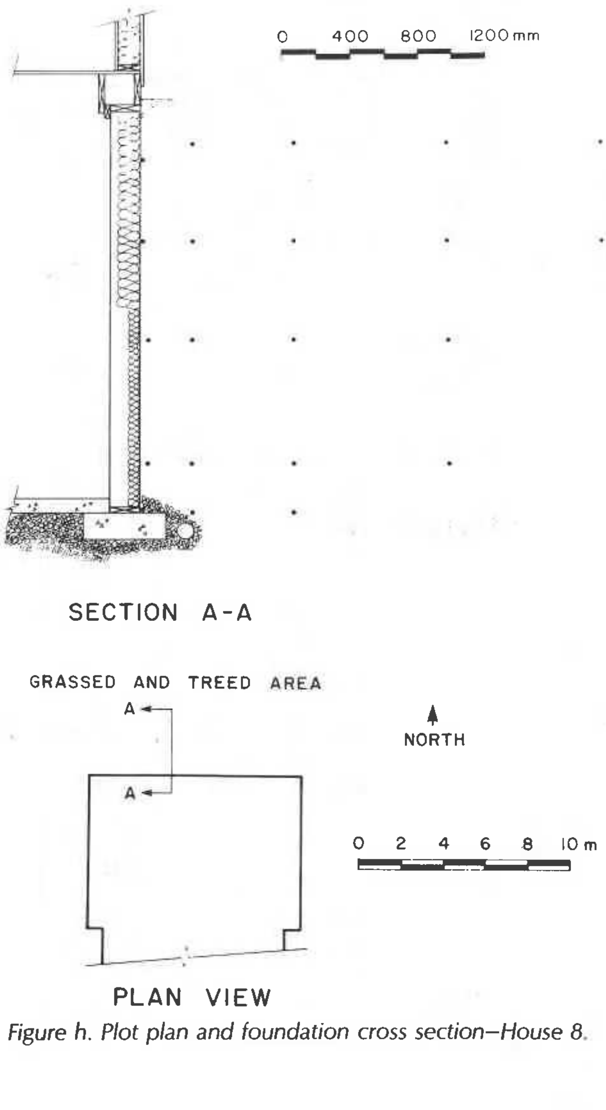

Figure h. Plot plan and foundation cross section–House 8.

House 8

This structure, built in 1977, is a continuously heated wood frame house on a full depth (2.44 m) preserved wood basement (Figure h).

The top of the basement wall extends 200 mm above grade level. The basement wall system uses 38 × 184 mm studs, 406 mm o.c. with 15.9 mm plywood sheathing on the exterior. The walls bear on uninsulated concrete footings cast on 50 mm granular fill. The basement floor is a

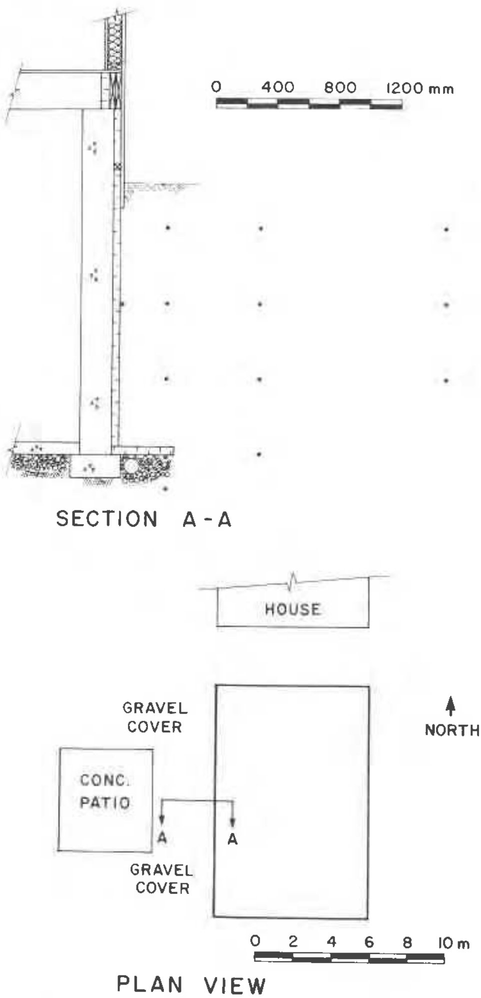

Figure i.1. Plot plan and foundation cross section—House 9 West.

100 mm thick concrete slab cast over 200 mm of gravel on undisturbed soil. The top surface of the slab is bare concrete.

Glass fibre batt insulation (14.5 kg/m^3) was installed in the stud spaces, the upper 1.22 m of the wall has RSI 3.5 batts and the lower 1.22 m portion has RSI 1.4 batts. The interior of the wall is sheeted with 12 mm drywall.

Soil from the original excavation was used to backfill the basement.

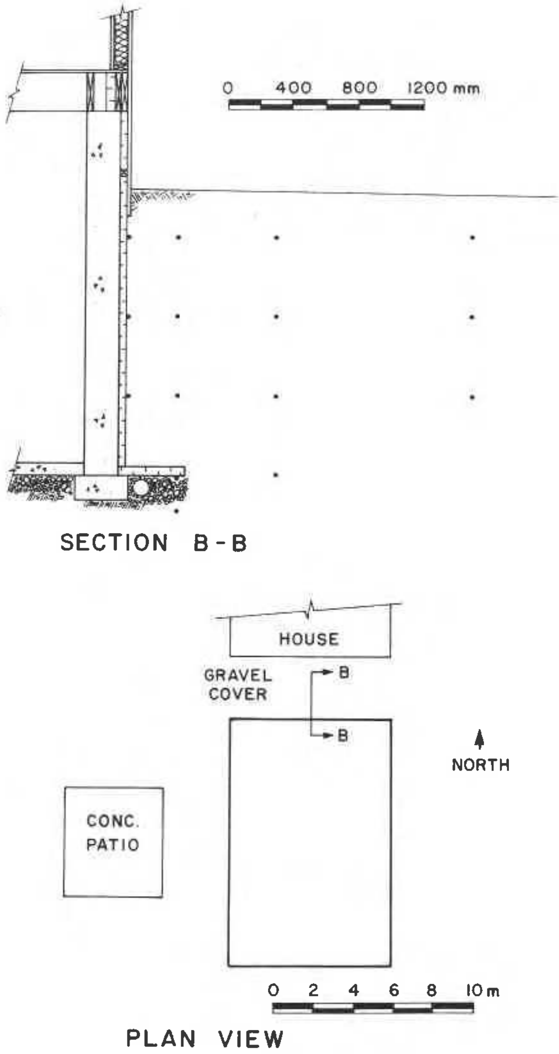

Figure i.2. Plot plan and foundation cross section–House 9 North.

The general soil type is 42 percent clay, 53 percent silt, and 5 percent sand.

The space heating is provided by a forced air electric furnace.

Temperature measurements were taken monthly from August 1977 to April 1981. Twenty-one thermocouples were used to measure soil temperatures at various locations on the north side of the building.

House 9

This structure, built in 1976, is a continuously heated wood frame house on a full height (2.29 m) cast in place 203 mm thick contrete basement with 0.53 m above grade (west wall Figure i.1 and north wall Figure i.2).

The floor slab is 100 mm thick uninsulated concrete cast over a 100 mm gravel pad placed on undisturbed soil. The top surface of the slab is bare concrete.

The exterior perimeter of the north foundation wall from the underside of the subfloor downwards 0.37 m is insulated with 38 mm of 112 kg/m^3 rigid glass fibre insulation. A 38 $\times$ 38 mm nailer strip was placed below the insulation and the remainder of the wall from below the nailer strip to the top of the footing was insulated with 38 mm of 144 kg/m^3 rigid glass fibre insulation.

The west wall insulation configuration is the same as the north wall; however, the rigid glass fibre insulation has a density of 48 kg/m^3. Rigid glass fibre insulation, extending horizontally outward 0.30 m, was installed over the top of the concrete footings.

Soil from the original excavation was used to backfill the basement. The general soil type is fine sand.

A natural gas fired forced air furnace with automatic fan operation is used to heat the house.

Monthly temperature measurements were taken from November 1976 to January 1980. Fifteen thermocouples on the north wall and 13 thermocouples on the west wall were used to measure soil temperatures at various locations.