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Effect of Insulating Crawlspace Walls in Residential Structures

T.L. Moody C. Jennings D. Lamb
ASHRAE Member

ABSTRACT

The purpose of this study was to make in situ evaluations of the effects of insulating crawlspace walls of residential structures. The evaluation included (1) the effect of heating loss or gain through the floor for the winter and summer months, (2) the effect of eliminating crawlspace ventilation, (3) the effect of locating a central heating duct in the crawlspace, and (4) the effect of the crawlspace walls above or below grade. Homes chosen for the study were located in the same neighborhood and were of approximately the same size. In all the houses but one, used as a control, .6-mil (0.15mm) polyethylene covered the crawlspace walls and the ground. This covering was followed by a 2-in. (50.8mm) thick foil-backed duct wrap on the crawlspace walls. All the homes, including the control, were instrumented with two heat-flux transducers, having an approximate sensitivity of 0.9 Btu/ft^2·mV) 2.84 W/m^2·mV, under the floor. Humidity and crawlspace temperatures, as well as outdoor temperature, were monitored and recorded continuously. In addition, the moisture content of the floor joists was measured weekly. The results of this study have revealed that, (1) heat loss through the floor is significantly reduced in the winter, (2) heat was conducted through the floor to the crawlspace even during the summer, and (3) the moisture content of the floor joists was not adversely affected.

INTRODUCTION

Since 1977, the Tennessee Valley Authority (TVA) has conducted a large home-weatherization effort, called the Home Insulation Program (HIP), that provides free home energy audits and no-interest financing for approved weatherization measures. These measures include adding attic insulation, weather stripping, caulking, and floor insulation. Of the nearly 600,000 living units that have been surveyed, more than 100,000 have had floor insulation installed. The floor insulation is the most expensive and difficult of the weatherization measures.

Floor insulation, which usually consists of some form of mineral fiber, presents special installation difficulties. Some areas under floors are difficult to reach because of obstacles such as, heating and air-conditioning ducts, water pipes, hot water heaters, air-handling units, foundation pillars, etc.

In most of the Tennessee Valley area, the winter design temperature is 15 °F (-9 °C). These conditions are mild enough that heat loss from floor to crawlspace is adequate to prevent water pipes from freezing if the foundation vents are closed (which is common, though not recommended). Therefore, water lines must be insulated, thus increasing the total cost of floor insulation.

Thomas L. Moody
Middle Tennessee State University, P.O. Box 273, Murfreesboro, Tennessee

Charles W. Jennings
Tennessee Valley Authority, 330 401B-C, Chattanooga, Tennessee

David B. Lamb
Tennessee Valley Authority, 330 401B-C, Chattanooga, Tennessee

A major factor in the success of HIP has been the 100% reinspection by the TVA energy advisers. Unlike in attic and other weatherization inspections, the energy adviser expends considerable time and labor in inspecting floor insulation. As might be expected, this area is where the poorest quality of work is generally found.

The cost relative to energy savings has been one of the more controversial aspects of floor insulation. In the middle Tennessee area, the cost of floor insulation is approximately \$0.42/ft.^{2} (\$4.52 /m^2). Adding water-pipe insulation places the cost for both of these insulation measures for the average home between 600 and \$800.

It is difficult to determine the amount of energy saved by the use of floor insulation. In such determinations, it is usually assumed that the crawlspace is adequately ventilated. However, in the Tennessee Valley area, the water pipes are not normally insulated and, as a result, the foundation vents are closed during the winter to prevent freezing and rupture of these pipes.

Because of the difficulties in installation and the low cost-to-benefit ratio, an alternative method of reducing heat loss through floors was sought. A promising method consists of insulating the crawlspace walls of the structure. This concept is not new but, as with floor insulation, very little data is available. It does, however, offer several advantages over the more traditional floor insulation:

1. Ease of installation

2. 50 to 70% reduction in labor and material costs

3. Elimination of water-pipe insulation

4. Facilitation of reinspection.

The method does require eliminating ventilation to the crawlspace area. This practice is contrary to established TVA policies, and approval of this insulation method has been withheld until the benefits and consequences can be established.

EXPERIMENTAL PROGRAM

The present investigation consisted of in situ measurements taken at four homes in Murfreesboro, Tennessee. These homes were in the same neighborhood, with the same general terrain, and of approximately the same size. The primary objectives of the program were to determine the heat loss or gain through the floors with the crawlspace walls insulated and how these losses were affected by

1. Height of the crawlspace walls above and below grade

2. Type of floor covering

3. Location of the central heating duct in the crawlspace

4. Amount of insulation on crawlspace walls

5. Elimination of crawlspace ventilation.

The four homes are shown in Figs. 1-4. Each will be referred to by the home owner's last name. Pertinent information for each home is given in Tab. 1. All four were instrumented and monitored, but only three homes (Monk, Hall, and Kimbell) were insulated. The fourth home (Wyatt) was used as a control to determine existing heat losses through an uninsulated floor. Here, it is important to point out that the Kimbell and Wyatt homes are on adjacent lots, are of approximately the same size and age (17 years), and were constructed by the same builder. Each had radiant ceiling heat and central air conditioning, with the duct work located in the crawlspace. Under the subfloor was a foil-backed vapor barrier. The only substantial difference between these two homes is that all of the floor in the Kimbell home was carpeted, while only part of the Wyatt home had carpeting.

INSTALLATION OF INSULATION

The Monk, Hall, and Kimbell homes had a polyethylene vapor barrier 6-mill thick (0.15 mm), covering the ground under the crawlspace as well as the concrete block crawl space walls, Fig. 5. During the installation of the vapor barrier, the polyethylene was temporarily stapled to the floor sill. The polyethylene was approximately 10 ft (3 m) wide. All joints were overlapped 6 in. (152 mm) and taped with a polyethylene tape. A 4 ft wide by 2 in. thick (1.219 m wide by 7.87 mm thick) foil-backed fiberglass duct wrap was attached to the crawl space walls, Fig. 6. The insulation was mounted so that the foil-backed faced the inside of the crawlspace. The duct wrap was fastened to the concrete blocks by means of a hardened concrete nail and washer driven through the duct wrap near the top of the crawlspace wall. The nails were spaced about every 3 to 6 ft (3 to 6 m) where the wall height was less than duct wrap width, the excess duct wrap was allowed to extend over the earth on top of the ground cover. The insulating material was extended to approximately 2 ft (60) cm either vertically, horizontally, or in combination below grade level so that the heat-flux would have to pass through 2 ft (60 c)m of earth before reaching the outside surface.

After the duct wrap was installed, the polyethylene, which had been attached to the floor sill, was detached and folded back over the top of the duct wrap and taped. As a result, the duct wrap was enclosed on both sides by a vapor barrier, important in preventing the insulation from absorbing moisture penetrating the foundation walls. Such absorption would not only deteriorate the insulating property of the duct wrap, but also can result in the insulation becoming detached (by virtue of the added weight of the moisture). A study being conducted by the authors has shown that, in some cases, placing a vapor barrier only on the ground in the crawlspace does not prevent mositure accumulation when crawlspace walls are below grade. Moisture penetrates the block, ultimately condensing on surfaces in the crawlspace and collecting on top of the vapor barrier. Although this problem appears primarily in summer, it is essential that, in cases in which the ventilation to the crawl space is being eliminated, all sources of water vapor be removed. Although the effect of eliminating crawl space ventilation is not yet conclusive, it would be prudent to recognize that homes having unusual moisture problems from groundwater would not be good candidates for this insulation technique.

INSTRUMENTATION AND DATA ACQUISITION

All four homes were instrumented with two heat-flux transducers, each 4.5 in. (114 mm) square and 0.125 in. (3.2 mm thick), and mounted on the crawlspace side of the floor. The locations of these tranducers are indicated by a "T" in the floor plans of the homes. Transducers were placed midway between two adjacent floor joists. In the Wyatt and Kimbell homes, the transducers were placed under the foil-backed vapor barrier. The approximate sensitivity of the transducers was .9 Btu/ft^2·mV (2.8 W/m^2·mV). The output of each transducer was passed through a multiplexer to a strip chart recorder with a full-scale sensitivity of 10 mV.

The multiplexer cycle consisted of four phases. It would switch in one transducer for approximately 1000 seconds. Next, it would switch in a zero Volt input, by shorting the input leads to the recorder, for approximately 200 seconds. The multiplexer would then switch in the second heat-flux transducer for a period of approximately 800 seconds, and finally would switch in zero input again for approximately 200 seconds. The cycle would then repeat. This procedure allowed each transducer to be identified on the strip chart and also provided a check for any zero drift of the recorder.

At the time of data collection (generally, once a week), the calibration of the strip chart recorder was checked. A 7-day hygrothermograph was placed approximately at the middle of each crawl space 1 ft (300 mm) above the ground. The moisture content of the floor joists was measured, using a Delmhorst moisture meter, at four areas of each home, once a week. In addition to these data, the average outdoor temperature for each hour was recorded.

RESULTS

The heat-flux data were analyzed by averaging the readings of the heat-flux transducers by the hour, day, week, month, winter heating season, and summer cooling season.

Hourly Heating Average

Heat flux for each of the homes and outdoor temperatures for a 78-hr period are shown in Fig. 7. This period began at 6 p.m., January 27, 1982, and ended at 6 p.m., January 30, 1982. The graph is representative of a typical winter period and reveals some of the characteristics of heat loss through the floors for each home.

Monk Home. The Monk home showed the largest fluctuation in the heat-flux. The values in

Fig. 7 for the Monk home are from the transducer under the vinyl covered floor. These extreme fluctuations were apparently the result of three factors:

1. Night setback of the thermostat, a general practice in the Monk home. This observation is suggested by the fact that, from approximately 11 p.m. to 6 a.m., dropping

2. The larger area of crawlspace walls above grade, resulting in fluctuations that were correlated with the outdoor temperature to a greater degree than in the two other homes having also had crawlspace wall insulation. This effect is obscured by the hourly averaging used in plotting Fig. 7, however, it was generally apparent during periods of continuous recording by the strip chart recorders (during test periods in which the multiplexer was disabled)

3. A noticeable reduction in heat-flux when the central heating system was on for extended periods, e.g., during periods of recovery from the night setback. During these periods, both heat-flux transducers would indicate heat-flux from the crawlspace into the living area, probably the result of warm air leakage from the duct work in the crawlspace. In general, these periods were relatively short with a relatively small heat-flux, and contributed very little to the overall flux throughout the heating season.

Hall Home. The values in Fig. 7 for the Hall home were for the den area's heat-flux transducers. The Hall home, which has a central heating system, generally demonstrated to a lesser degree the same heat-flux fluctuations as the Monk home. This is believed to result from the smaller crawlspace wall area and the larger portion of walls below grade.

Kimbell Home. The Kimbell home demonstrated the smallest hourly fluctuation because of the absence of a central heating duct in the crawlspace and the total carpeting of the floors. Carpeting appreciably reduced heat-flux in this home (as in the two other homes with carpeted areas). The Kimbell home also had a smaller crawlspace wall area, with approximately 50% being below grade. See Tab. 2 for a summary of the data from all the heat-flux transducers.

Wyatt Home. The Wyatt home, which served as the control, had neither insulation nor vapor barrier, resulting in the largest heat losses through the floor (which was expected). The weekly averages of heat-flux from January through the first two weeks of August 1982 are shown in Fig. 8 (with the exception of the Monk and Wyatt homes for which sufficient data for August were not available to give a reliable average). These plots present some surprising and unexpected results. For the total winter period, similarity is seen between the Monk and Hall homes. During January through February, heat-flux through the floor is relatively uniform, so the longer averaging period obscures the fluctuations of the hourly and daily averaging.

The most surprising data point for the winter period was obtained the week beginning March 13, in which there was a sudden warming trend. The previous week's average outdoor temperature was 46°F(8°C) but for the week of March 13 the average weekly temperature was 63°F(17°C), dropping to 52°F(11°C) the following week. A decrease in the heat-flux, as occurred in the uninsulated Wyatt home, would be expected, but a very pronounced increase in heat-flux during this period was seen for the three insulated homes. An explanation for this effect has not been found. The Wyatt home followed the trend that was generally expected for the heat-flux through the floors, in that it peaked during the coldest part of the winter and decreased as the weather turned warmer. The heat-flux was markedly larger than in the insulated homes. However, the most surprising results occurred in the summer, during which heat-flux from the living area into the crawlspace continued. A similar result has been reported by Burch and Hunt in a study conducted by the National Bureau of Standards.[1]

These results were expected during the early summer, although the heat-flux was not expected to be so large. The pattern continued through the first part of August, the final period of data collection for this paper. From the crawlspace temperatures shown in Fig. 9, it is evident that the average crawl space temperature is always lower than the indoor air temperature. This result is important when floors are insulated. It is reasonable to assume that insulating the floor to achieve an R-value of 11 $f \cdot Ft^2 \cdot h/Btu$ (1.94 $C \cdot m^2/W$) or greater would reduce the heat-flux through the foor to a negligible amount during both winter and summer and would substantially reduce the cost effectiveness of floor insulation.

From Tab. 2, the effect of insulating the crawlspace of each of the homes for the winter months can be assessed if it is assumed that the Wyatt home is representative of the heat loss that would occur through uninsulated floors with the foundation vents closed:

1. The carpeting in the Wyatt home reduced the heat loss through the carpeted area by 27% and in the Monk home the carpeting reduced the heat loss by 67%.

2. Heat losses through the carpeted floors of the Kimbell and Monk homes was reduced 60% and 84% respectively, when compared to the carpeted area of the Wyatt home.

3. Heat losses through the vinyl-covered floors of the Monk and Hall homes are 65% less than that through the vinyl-covered floors of the Wyatt home.

Moisture Measurements

The moisture measurements obtained from the floor joists indicated that, in the early winter, before the vapor barriers were installed, all four homes had a moisture content of about 16%. This value slowly dropped in the crawlspaces where the vapor barriers were installed, reaching a low of about 8% during February. The value remained relatively steady at this value for the remainder of the winter, increasing to about 12 to 13% by mid-August.

Moisture content in the Wyatt home dropped to 14% in the floor joist in mid-winter and increased to about 18% by mid-August. The average monthly moisture, as a percentage of water by weight of the weight of oven-dried wood, Tab. 3.

INSULATION COST COMPARISON

Homes with heat pumps having approximately the same Coefficient of Performance (cop) for heating and cooling would realize little, if any, savings from floor insulation. Homes with electrical resistance heat and an effective heating and cooling period of 2800 hours per year, and an effective floor area (net area less floor joists, furniture, etc.) of 70%, would result in an annual energy savings (with vinyl floors) of 1.07 kWh/ft^2 (11.5 kWh/m^2). The insulation cost of \$0.51/ft^2 (\$5.50/m^2)(including water pipe insulation) and fuel cost of \$0.05/kWh result in an insulation-cost to fuel-cost saving ratio of 9.56. In the case of crawlspace wall insulation the annual winter fuel saving would be (for vinyl floors) 1.95 kWh/ft^2 (21 kWh/m^2) for electric resistance heat and approximately 1.02 kWh/ft^2 (11 kWh/m^2) for a heat pump. The insulation cost to fuel dollars saved ratios would be 2.14 and 4.1, respectively.

CONCLUSION

The following conclusions can be drawn from this study:

1. Crawlspace wall insulation is between 2 and 3 times as cost effective as floor insulation during heating periods.

2. The energy saved by insulating floors for winter will be lost by additional energy consumption in the summer, reducing the overall effectiveness of the floor insulation. This problem does not occur when the crawlspace walls are insulated.

3. The effect of removing crawlspace ventilation did not detrimentally affect the structure and, in fact, reduced moisture content to a more acceptable value.

REFERENCES

1. Douglas M. Burch, and C. M. Hunt, "Retrofitting an Existing Wood-Frame Residence for Energy Conservation--An Experimental Study," NBS Building Science Series 105, U.S. Government Printing Office Washington: 1978.

TABLE 1

General Information Concerning Test Structure

	Monk	Hall	Kimbell	Wyatt
Structure type	Split Level	One Level	One Level	One Level
Floor area over crawl Space ft^2 (m^2)	775 (72)	1690 (157)	1938 (180)	1734 (162)
Heat type	heat pump	heat pump	radiant ceiling	radiant ceiling
Heating duct location	crawlspace	crawlspace	none	none
Air conditioning location	crawlspace	crawlspace	crawlspace	crawlspace
Crawlspace wall height ft (m)				
Above grade	4.5 (1.37)	1.5 (0.45)	1.5 (0.45)	1.5 (0.45)
Below grade	3.0 (0.9)	1.5 (0.45)	1.5 (0.45)	1.5 (0.45)

TABLE 2

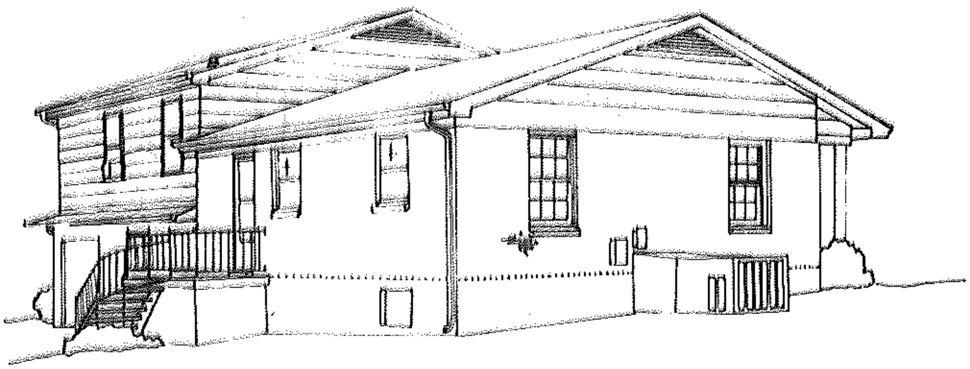
Summary of Average Monthly Heat-Flux Through Floors Btu/ft^2·hr (W/m^2)

	Monk		Hall		Kimbell		Wyatt	
Month	Carpet	Vinyl	Vinyl	Vinyl	Carpet	Carpet	Carpet	Vinyl
Jan	0.3 (1.0)	1.5 (4.7)	1.5 (4.7)	1.3 (4.1)	2.0 (6.2)	1.1 (3.6)	3.7 (11.7)	4.6 (14.5)
Feb	0.4 (1.3)	1.1 (3.5)	1.2 (3.8)	1.3 (4.2)	1.1 (3.5)	1.2 (3.8)	2.7 (8.5)	4.0 (12.7)
Mar	0.6 (2.0)	1.2 (3.8)	1.3 (4.0)	1.2 (3.8)	0.7 (2.1)	0.9 (2.7)	2.4 (7.6)	3.2 (10.1)
Apr	0.3 (1.2)	1.5 (4.7)	1.2 (3.8)	1.4 (4.4)	0.7 (2.1)	0.9 (2.7)	1.9 (6.0)	3.0 (9.5)
Winter average	0.4 (1.4)	1.3 (4.1)	1.3 (4.1)	1.3 (4.1)	1.1 (3.5)	1.0 (3.2)	2.7 (8.5)	3.7 (11.7)
May	0.7 (2.1)	1.4 (4.4)	1.7 (5.3)	2.0 (6.3)	0.7 (2.4)	0.8 (2.5)	1.1 (3.5)	2.1 (6.7)
June	0.6 (1.8)	1.1 (3.6)	1.0 (3.3)	1.7 (5.1)	0.6 (2.0)	0.5 (1.7)	1.3 (4.0)	2.2 (6.9)
July	0.5 (1.5)	0.9 (2.8)	1.1 (3.5)	1.5 (4.7)	0.6 (2.0)	0.5 (1.6)	0.7 (2.3)	1.3 (4.0)
Aug	----	----	0.9 (2.8)	1.3 (4.1)	0.5 (1.6)	0.3 (1.1)	---	---
Summer average	0.6 (1.8)	1.1 (3.6)	1.2 (3.7)	1.6 (5.0)	0.6 (2.0)	0.5 (1.7)	1.0 (3.3)	1.9 (5.9)

TABLE 3

Moisture Content Of Floor Joists
Percentage of water by weight of the weight of oven-dried wood

Month	Monk	Hall	Kimbell	Wyatt
Jan	9	9	12	14
Feb	8	8	11	14
Mar	8	10	11	15
Apr	7	10	10	15
May	8	9	11	14
June	11	11	12	16
July	12	13	13	17
Aug	12	14	14	18
Sept	12	14	14	18
Oct	13	13	13	17



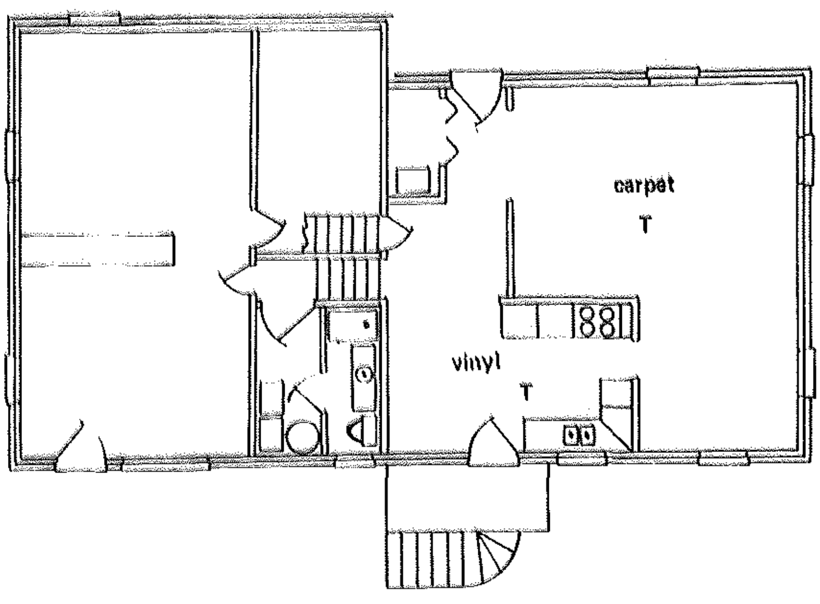
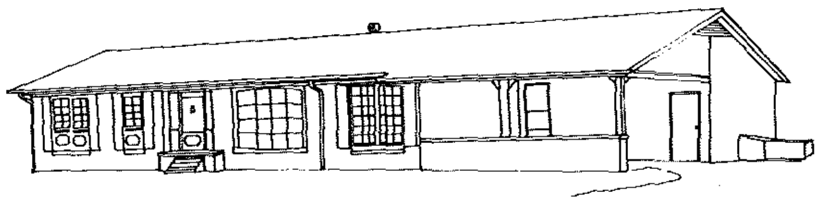


Figure 1. Nonk home. Type of structure: split level; type of heating: heat pump; duct in crawlspace



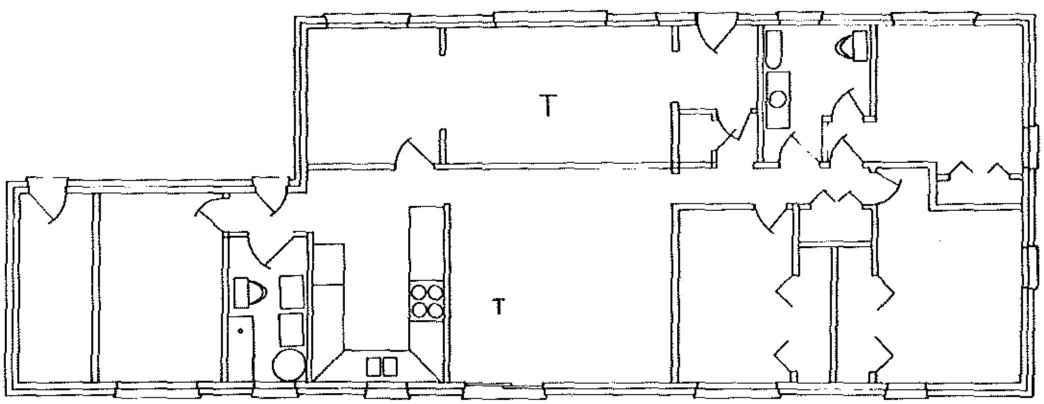
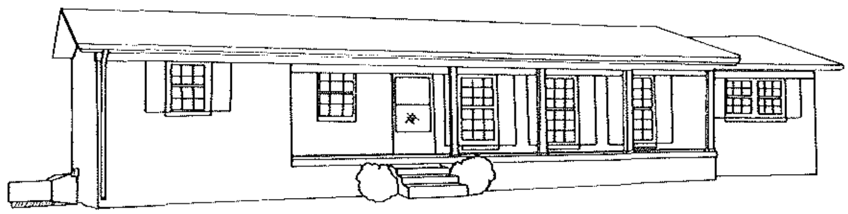


Figure 2. Hall home. Type of structure: one level; type of heating: heat pump; cooling: central; duct in crawlspace



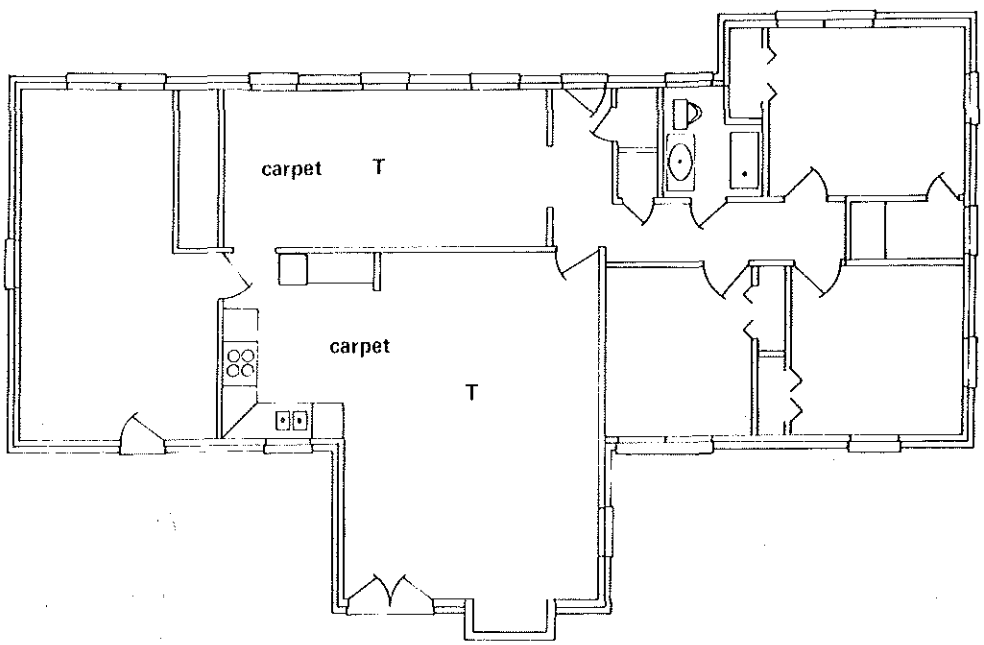
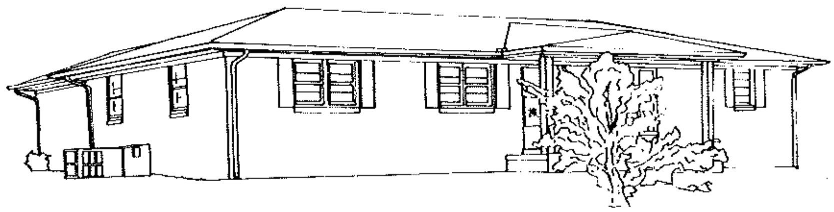


Figure 3. Kimbell home. Type of structure: ove level; type of heating: ceiling radiant; cooling: central; duct in crawlspace



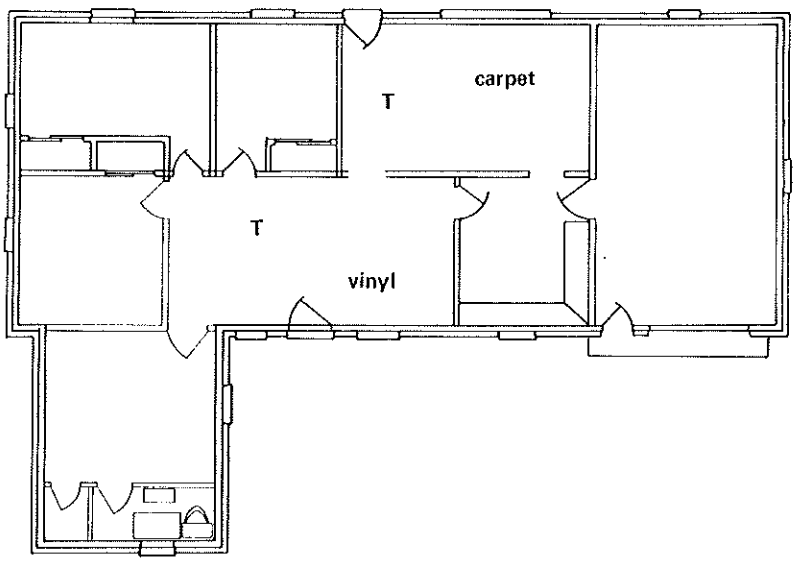


Figure 4. Wyatt home. Type of structure: one level; type of heating: ceiling radiant; cooling: central; duct in crawlspace

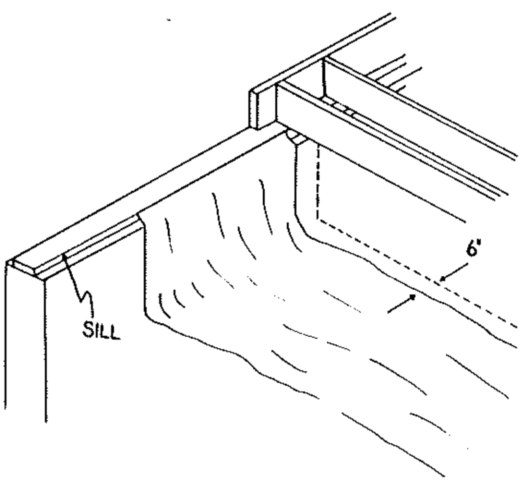


Figure 5. Installation of polyethylene vapor barrier

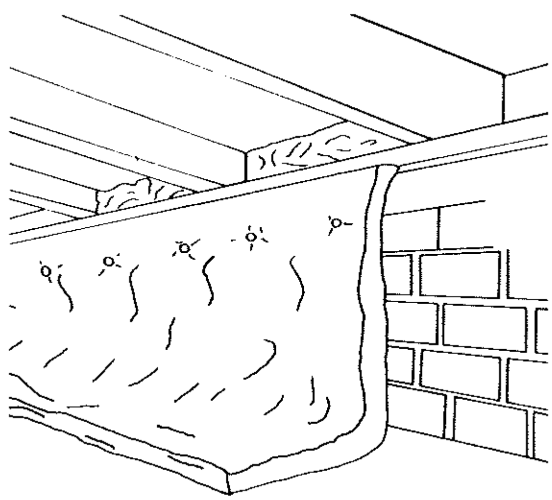


Figure 6. Installation of two-inch, foil-backed duct wrap

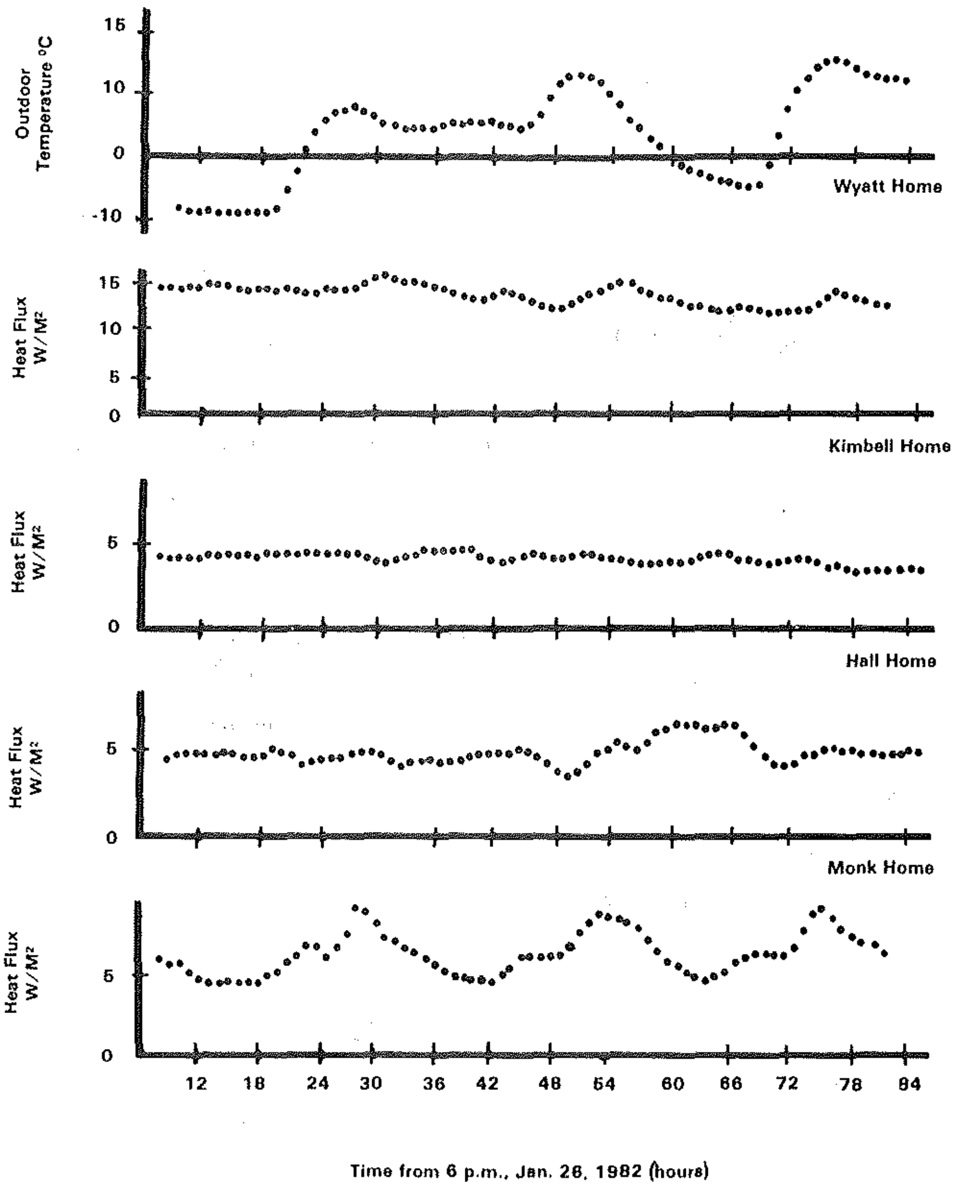


Figure 7. Typical hourly heat flux through floors of test homes

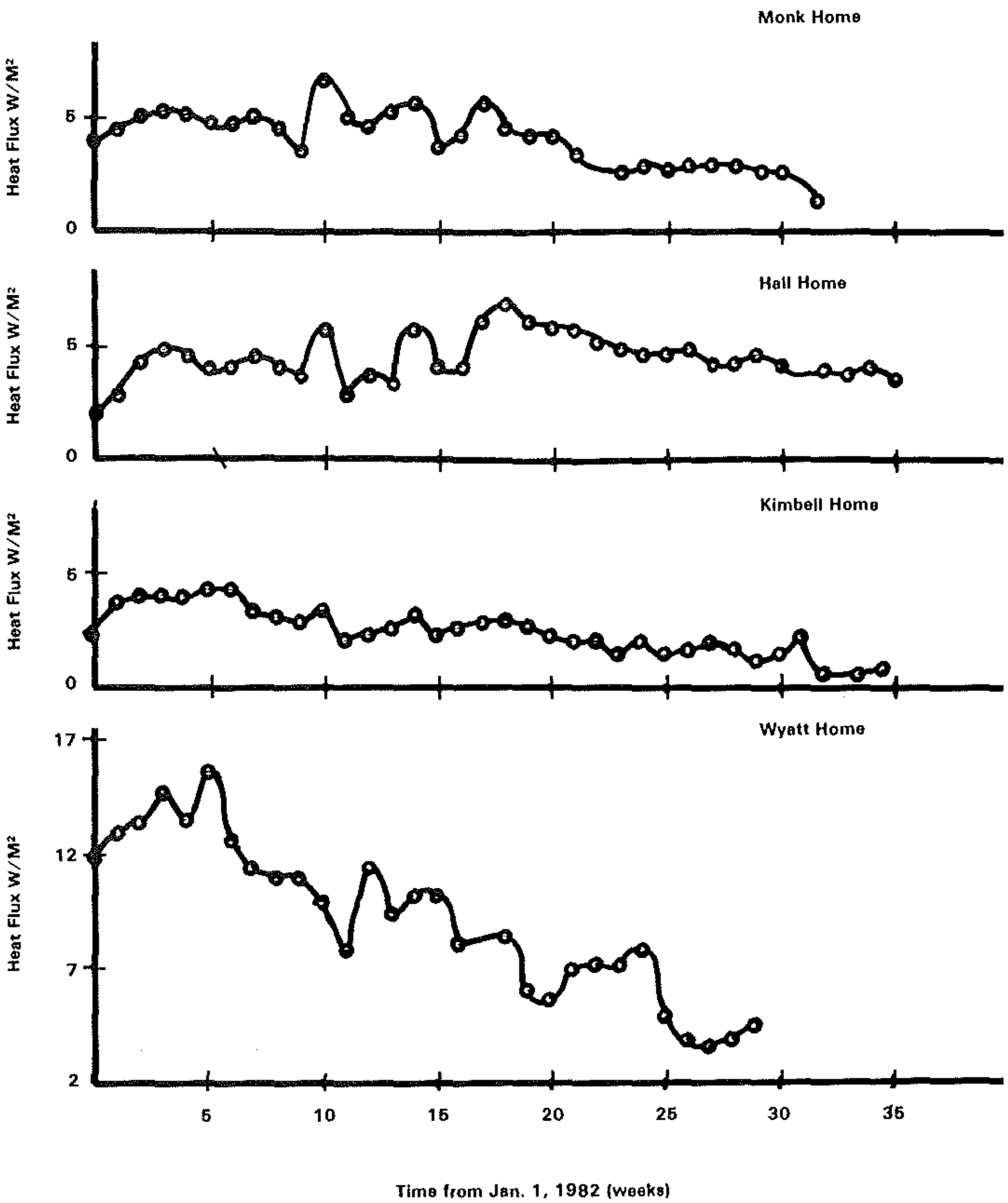


Figure 8. Average weekly heat flux through floors of test homes

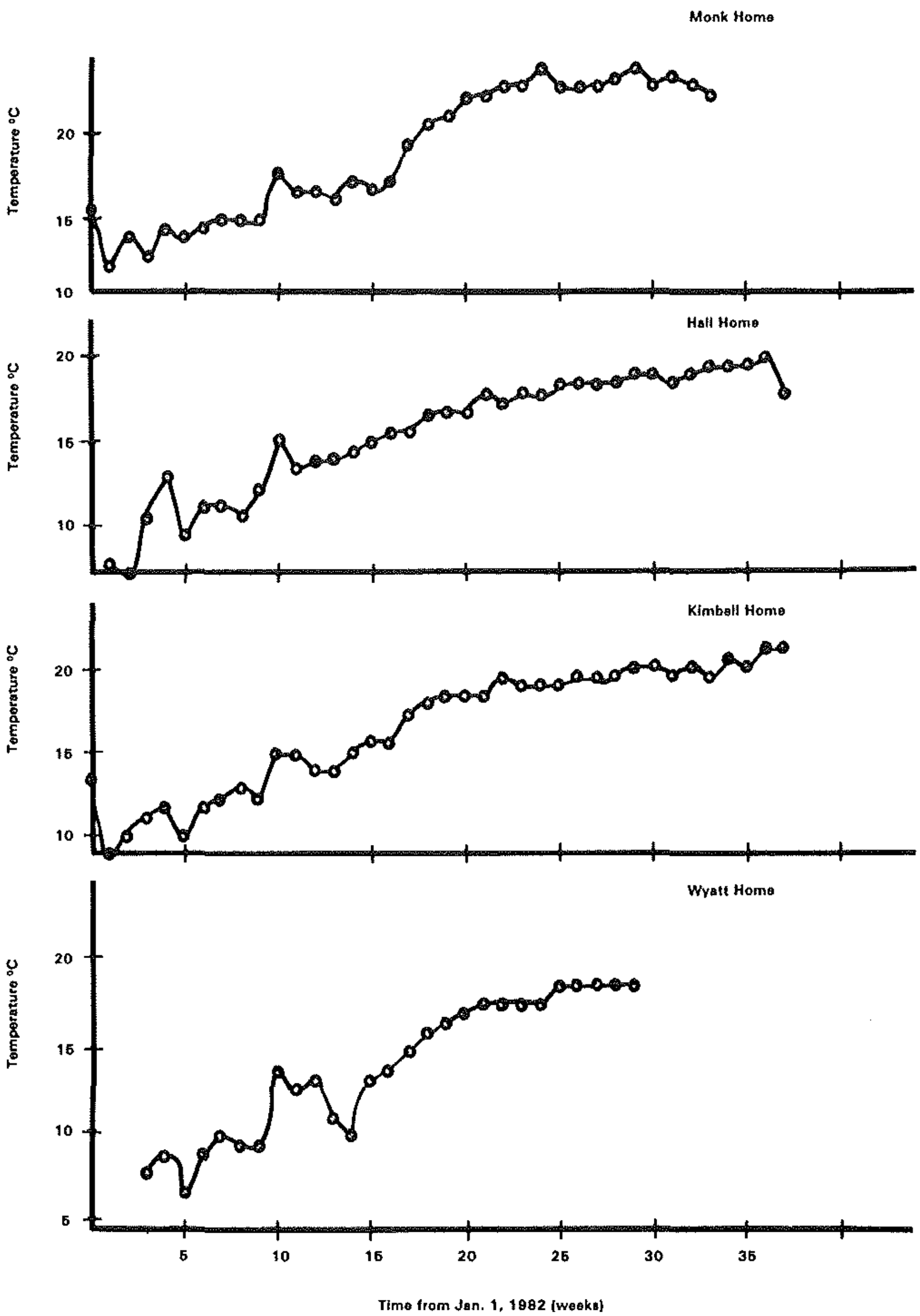


Figure 9. Average weekly crawlspace temperature of test homes