The Experimentally Determined Effectiveness of Insulation Added to the Exterior of Residential Foundations

K.J. Wolfgram

ABSTRACT

Calculations based on ASHRAE methodology suggest that an uninsulated basement wall can account for a significant portion of the overall heat loss in a typically insulated home. To determine the energy-saving effectiveness of foundation insulation, a small group of homes in Newark, OH, were retrofitted with extruded polystyrene insulation on the exterior, from 1 ft (0.30 m) below-grade up to the existing frame wall finish.

The objectives of the study included determining (1) the impact on energy usage per degree-day, (2) the effect on savings of limited accessibility to the perimeter, (3) how actual savings compare with those predicted by ASHRAE methodology, and (4) the cost-effectiveness of foundation retrofitting.

Savings of up to 26% were measured, and payback periods of three to four years were estimated, even though an average of only 70% of the perimeter was insulated. Surprisingly, ASHRAE methodology severely underestimates actual savings. Possible explanations for this understatement are discussed.

INTRODUCTION

As energy costs continue to rise, homeowners are looking for cost-effective ways to reduce or control their heating and cooling expenses. Many have already added storm windows, caulking, and weatherstripping. The most common retrofit practice has been, perhaps, the installation of additional attic insulation.

The thermal effectiveness of these retrofit options is limited, however, by the law of diminishing returns. The first layer of attic insulation, for example, does the most work. Each additional layer results in successively smaller reductions in heat flow. In other words, doubling the amount of insulation will not double energy savings (see Tab. 1).

This fact suggests, then, that installing some insulation everywhere is better than heavily insulating any one area. Fig. 1 illustrates the point by comparing heat-loss distribution in two homes--one uninsulated and the other well-insulated by current standards. Reducing heat loss in the uninsulated home should begin with attic insulation, caulking, and weatherstripping so that the major components of heat loss are addressed. Insulating the foundation of an otherwise uninsulated home should not have a high priority because the foundation accounts for such a small percentage of the overall heat loss. However, in the well-insulated home, insulating the foundation would be much more effective than adding insulation to the attic, because the foundation accounts for a greater percentage of overall heat loss.

Kathy J. Wolfgram, Sr. Research Chemist, Dow Chemical U.S.A., Foam Products TS&D Granville, OH.

Theoretically, the foundation may be the least understood component in heat loss in a home, but the number of research efforts in this area is increasing. Recent studies have concluded that: (1) exterior application of the insulation is more effective, (2) extruded polystyrene foam is the preferred insulation in below-grade environments, and (3) the heat flow paths are more complex than the concentric circular paths assumed by ASHRAE in current handbooks.[1,2,3,4] Current ASHRAE methodology is limiting, therefore, because it is based on rather simplified heat flow models and does not differentiate between interior and exterior application of the insulation.

Large-scale field research has also been limited. Although there have been several studies comparing energy efficient residential construction to conventional construction, this author is unaware of any U.S. field research conducted to isolate the energy-saving effectiveness of foundation insulation.[5,6]

With this in mind, the objectives of the study described here are:

1. to determine the savings in energy usage per degree-day attributable to the addition of rigid insulation around the exterior top few feet of residential foundation walls

2. to determine how closely actual savings compare to those predicted by current ASHRAE methodology

3. to determine the effect of limited accessibility to the perimeter on savings

4. to determine the cost-effectiveness foundation retrofitting offers the homeowner, i.e., the payback period.

EXPERIMENTAL

Test Home Selection

Residents of the Newark, OH, area were invited to volunteer their homes for use in the experiment. Factors considered in selecting the test homes included:

1. type of foundation (a full basement was preferred)

2. existing insulation levels of attic, frame wall, foundation wall (homes were disqualified if there was insulation in the ceiling area above the basement)

3. type of heating equipment (e.g., woodburning stoves were not allowed)

4. exposure of the foundation wall above-grade

5. accessibility to the foundation perimeter

6. recent history of home improvements (preferably no energy-saving improvements were added during the previous year).

It was also emphasized to each applicant that no other energy-saving practices or measures were to be added during the year of the study so that the effect of foundation insulation alone could be isolated.

Six homes were selected for the study. Attempts were made to include a range of existing insulation levels, exposures above-grade, and perimeter accessibility among the samples.

Details of the homes selected are shown in Tab. 2. The existing insulation levels were based on inspections of the attic and wall areas by the homeowner. Plan drawings of each home are shown in Fig. 2. The drawings highlight the portion of the perimeter accessible for retrofitting.

In calculating the percentage of accessibility, it was assumed that the total effective perimeter is that which bounds conditioned space. For example, only the portion of the attached garage that is adjacent to the living area was included in the perimeter calculations. A sample calculation is shown in Fig. 3.

Installation of Insulation System

Extruded polystyrene foam board was selected as the insulation material, based on previous laboratory and field evaluations that revealed its superiority to molded expanded polystyrene, polyurethane, and polyisocyanurate in the below-grade environment.[7] The extruded polystyrene used was 1 in (2.54 cm) thick, had an average density of 2 lb/ft^3 (32.0 kg/m^3), and had an average insulating value of R-5.4 hr/ft^2·°F·Btu (R-1.0 m^2·K/W) at a mean test temperature of 40°F (4.4°C).

Before the insulation was installed, a trench approximately 1 ft (0.3 m) deep was dug around the foundation wall wherever it was reasonably accessible. In most cases, a J-channel (similar to those used in the re-siding industry) was mechanically fastened underneath the existing siding to receive the insulation. The foam insulation was then installed from approximately 1 ft (0.3 m) below-grade up to the existing exterior finish. The foam was attached using mechanical fasteners long enough to penetrate 1 in (2.54 cm) into the masonry wall.

There were some exceptions to this installation method:

1. Insulation was installed only below-grade at basement windows

2. That portion of the foundation wall occupied by unremovable window wells was left uninsulated

3. Only the above-grade portion of a foundation wall directly adjacent to a driveway was insulated

4. Insulation was installed only below-grade where the exterior finish consisted of face brick extending at least to the grade line.

Once all the insulation had been installed, a self-adhering fiberglass mesh tape was applied over every joint and mechanical fastener in the foam as well as over exposed edges around windows. A latex-modified cementitious coating was then brush applied to that part of the insulation exposed above grade. In some cases, a pebble finish was hand "seeded" into the brush-on coating and, finally, the dirt was replaced.

Labor times and material costs were recorded for use in estimating the installed cost for each house.

Data Collection

No attempts were made to control thermostats in the homes involved in the experiment. However, homeowners were instructed to maintain conditions as closely as possible to those in effect before the addition of foundation insulation. Data collection consisted solely of fuel-usage comparisons corrected for differences in weather.

The homes were retrofitted during the first week of December 1981. The ratios of fuel usage per degree-day for the 1980-81 and 1981-82 heating seasons were compared, using fuel records provided by the utility companies and weather data provided by the National Weather Service office at the Port Columbus airport. (Newark is approximately 30 miles east of the weather station and at about the same elevation.)

Note that in the case of house B, the frame walls had been insulated with blown cellulose during the summer of 1981. Therefore, three fuel-usage/degree-day ratios were compared so that the effects of the cellulose and the foundation insulation could be separated.

Theoretical Considerations

The energy savings attributable to foundation insulation can be estimated using the following equation which is based on methodology presented in the ASHRAE Handbook--1981 Fundamentals Volume.[8]

$$\Delta E = \frac{\Delta U \times P \times D \times 24}{k \times V} (C_D) \left[\frac{ti - (ta - A)}{ti - to}\right] * \tag{1}$$

where

- ΔE = savings in fuel or energy consumption for the estimate period, Btu or kWh
- ΔU = reduction in the heat transfer coefficient calculated on a lineal ft (m) basis, Btu/hr·ft^2·°F (W/m·K)
- P = perimeter; ft (m)
- D = number of 65°F (291°K or 18.3°C) degree-days for estimate period
- 24 = hours per day
- k = correction factor that includes the effects of rated full-load efficiency, part-load performance, oversizing, and energy-conservation devices
- V = heating value of fuel
- C_D = empirical correction factor for heating effect versus 65°F (18.3°C) degree-days(value is based on graph of C_D versus annual degree-days in ASHRAE Handbook)
- ti = indoor design temperature, °F (°C)
- $\underline{to}$ = winter design temperature, assuming 99% frequency level, °F (°C)
- $\overline{ta}$ = mean annual air temperature, °F (°C)
- A = amplitude(the difference between mean air temperature and the lowest ground temperature at a depth of 4 in (100 mm))

$\frac{ti - (\overline{ta} - A)}{ti - to}$ = correction factor that adjusts degree-days based on indoor-to-outdoor air temperature differences to degree-days based on indoor air-to-ground temperature differences*

In using this equation, the U values before and after retrofitting must first be compared. This, in turn, requires establishing the insulating value of the surrounding soil. Based on field measurements, current ASHRAE methodology assumes that heat flow through an uninsulated basement wall follows concentric circular paths centered at the intersection of the grade line and the wall (see Fig. 4). Path lengths through the soil at various depths have been calculated on this basis. For example, at a depth of 0 to 1 ft (0 to 0.30 m), the heat flow path length through the soil averages 0.68 ft (0.20 m)[9]. Assuming a soil R-value of R-1.25/ft (R-0.72/m), the insulating value of soil 0 to 1 ft (0 to 0.30 m) below-grade is R-0.85 (0.14).

With this value in hand, it is now possible to proceed with the calculation of ΔU-value. A sample calculation based on house C follows.[†]

Before retrofit:

	IP Units		SI Units	
Component	R(above)	R(below)	R(above)	R(below)
Inside air film	0.68	0.68	0.12	0.12
Concrete block	1.11	1.11	0.20	0.20
Earth	0	0.85	0	0.14
Outside air film	0.17	0.17	0.03	0.03
R	1.96	2.81	0.35	0.49
1/R = U	0.5102	0.3559	2.857	2.041

*Applies only to the below-grade heat loss

[†]Slight discrepancies between IP and SI units may occur throughout this paper because of rounding off

After retrofit:

Component	IP Units R(above)	IP Units R(below)	SI Units R(above)	SI Units R(below)
Inside air film	0.68	0.68	0.12	0.12
Concrete block	1.11	1.11	0.20	0.20
Extruded polystyrene insulation	5.41	5.41	0.95	0.95
Earth	0	0.85	0	0.14
Outside air film	0.17	0.17	0.03	0.03
R	7.37	8.22	1.30	1.44
1/R = U	0.1357	0.1217	0.769	0.694
U-value	$\frac{0.3745\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{0.2342\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{2.088\ \text{W}}{\text{m}^2\cdot\text{K}}$	$\frac{1.346\ \text{W}}{\text{m}^2\cdot\text{K}}$

Next, U-values are converted to a lineal ft (m) basis:

$$\frac{\text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}\left(\frac{\text{W}}{\text{m}^2\cdot\text{K}}\right) \times \text{ft (m) height or depth} = \frac{\text{Btu}}{\text{hr}\cdot\text{ft}\cdot{}^\circ\text{F}}\left(\frac{\text{W}}{\text{m}\cdot\text{K}}\right) \quad (2)$$

Therefore, in the case of house C, where height exposures insulated were 7 in (0.18 m) and 11 in (0.28 m), and depths insulated were 1 ft (0.30 m), the U-values convert to:

	IP Units ΔU	X Height or Depth	= ΔU(lineal)	SI Units ΔU	X Height or Depth	= ΔU(lineal)
Above	0.3745	X (7/12) ft	= 0.2185	2.088	X 0.18 m	= 0.376
Above	0.3745	X (11/12) ft	= 0.3433	2.088	X 0.28 m	= 0.585
Below	0.2342	X 1 ft	= 0.2342	1.346	X 0.30 m	= 0.404

These values can now be inserted into Eq. 1, assuming other values are:

P = 68 ft (20.7 m) of 7 in (0.18 m) height exposure
  = 23 ft (7.0 m) of 11 in (0.28 m) height exposure
  = 97 ft (29.6 m) of 1 ft (0.30 m) depth
D = 5600°F days (3111°C days); the average for Newark, OH
k = 0.65 (gas forced air); 1.6 (heat pump)
V = 3413 Btu/kWh electricity or 100,000 Btu/therm gas
C_D = 0.61
ti = 70°F (21.1°C); assumed equal for all homes
$\overline{to}$ = 0°F (-17.8°C)
$\overline{ta}$ = 52°F (11.1°C)
A = 20°F (11.1°C)

$$\text{Let } N_a = \frac{D \times 24}{k \times V} C_D \qquad \text{Let } N_b = \frac{D \times 24}{k \times V} C_D \frac{ti - (\overline{ta} - A)}{ti - to} \quad (3)$$

Therefore:

$$E = [(\Delta U(\text{lineal}) \times P \times N_b)] + [(\Delta U(\text{lineal}) \times P \times N_a)] \quad (4)$$

Substituting the specified values defining N_b and a factor for converting Btu/hr to Watts in SI units:

$$N_a = \frac{1.26\,{}^\circ\text{F}\cdot\text{hr}\cdot\text{therm}}{\text{Btu}} \qquad N_b = \frac{0.681\,{}^\circ\text{F}\cdot\text{hr}\cdot\text{therm}}{\text{Btu}} \quad \text{IP Units} \quad (6)$$

$$N_a = \frac{0.7007\ \text{K}\cdot\text{hr}\cdot\text{therm}}{\text{Btu}} \times \frac{\text{Btu/hr}}{0.293\ \text{W}} \qquad N_b = \frac{0.378\ \text{K}\cdot\text{hr}\cdot\text{therm}}{\text{Btu}} \times \frac{\text{Btu/hr}}{0.293\ \text{W}} \quad (5)$$

$$N_a = \frac{2.39\ \text{K}\cdot\text{therm}}{\text{W}} \qquad N_b = \frac{1.29\ \text{K}\cdot\text{therm}}{\text{W}} \quad \text{SI Units}$$

The annual energy savings attributable to adding insulation to the two above-grade components at different height exposures and the below-grade component of fairly uniform depth can now be separately calculated and then summed:

	IP Units				SI Units			
	ΔU(lineal)	X P	X N	= ΔE	ΔU(lineal)	X P	X N	= ΔE
Above	0.2185	X 68	X 1.26	= 18.7	0.376	X 20.7	X 2.39	= 18.6
Above	0.3433	X 23	X 1.26	= 9.9	0.585	X 7.0	X 2.39	= 9.8
Below	0.2342	X 97	X 0.681	= 15.5	0.404	X 29.6	X 1.29	= 15.4
Total therms saved per year				= 44.1				= 43.8

Therefore, using ASHRAE methodology, the predicted annual savings resulting from the addition of insulation to the foundation of house C is approximately 44 therms. (Similar calculations for the other homes are included as Appx A.

How might the savings estimates compare with actual savings? Several factors suggest that the estimates significantly understate savings. Discussion of these factors follows.

1. The concentric circular path does not recognize a significant heat-loss path that occurs vertically, through the conductive concrete wall. Fig. 5 illustrates this neglected heat-loss path. The ASHRAE model, therefore, severely underestimates the heat loss occurring through an uninsulated wall and, in turn, the effect of added insulation applied on the exterior.

2. The model does not recognize convective heat transfer that may occur through cores in concrete block. The overall effect is the same as above: the heat loss through the uninsulated wall is understated, as are the savings from insulation applied to the exterior. The insulation lessens the temperature differential across the block and, thereby, minimizes the driving force for convective looping.

3. The model neglects the diagonal heat-loss path that occurs at every wall-to-wall and wall-to-floor corner (see Fig. 6).

4. The C_D factor was designed for use in furnace sizing calculations, not in energy savings calculations. When used in sizing the furnace, the C_D adjusts degree-days to compensate for the heat provided by solar effects and internal heat gains (appliances, water heater, people, etc.)--heat that the furnace need not supply. However, when C_D is used in energy-savings calculations, the added insulation is not given credit for reducing the loss of internal heat gains and, thereby, further reducing the demand on the furnace. Added insulation will reduce heat loss whether that heat is provided by the furnace or by solar effects, hot water, appliances, or other sources. As insulation is added, the internal gains simply provide a greater percentage of the overall demand.

There are also some factors that suggest that the savings estimates would overestimate savings:

1. There are interruptions in the continuity of the insulation. For example, no insulation was installed where windows, slabs, fireplace chimneys, and so forth, occurred. This suggests that the heat may bypass the insulation and find an easier way out.

2. Heat loss may occur through thermal short-circuits. In the case of brick ledges, e.g., the heat may travel up through the foundation wall, through the brick ledge, into the brick, and out, bypassing the insulation placed on the exterior of the foundation wall.

3. The amplitude, which is used to estimate soil temperature, is based on measurements of soil at only a 4 in (100 mm) depth.[10] Undoubtedly, deeper soil is warmer. Therefore, the indoor air-to-ground temperature difference is smaller than that used in the calculations. With a lower driving force, heat loss will be less.

4. Moisture in the soil will decrease the insulating value of the soil and, possibly, that of the insulation. This factor is of less concern when a material of high moisture resistance, such as extruded polystyrene, is used as the insulation.

No attempts were made in this study to determine the relative weight each of these factors has on actual results.

Results

Note: House A was disqualified from the study because of several substantial changes in lifestyle and heat-pump efficiency. The owner was at home in the daytime ten weeks during the winter of retrofitting; previously, the home had been unoccupied in daytime. The heat-pump efficiency was also suspect; therefore the heat pump was serviced during the study. These two changes were enough to drop the home from the study. From this point on, only the results from homes B through F will be discussed.

The ratio of fuel usage per degree-day of the test homes is summarized in Tab. 3. The time period is noted for each of the homes. Whenever possible, only months that had at least 100 IP unit degree-days (55 SI unit degree-days) were considered. However, exceptions were made so that actual rather than estimated meter readings could be used. The percent-savings column represents the reduction in total fuel usage per degree-day. (Note that in the case of house B, three ratios of fuel usage to degree-days are compared to separate the effects of foundation and frame wall insulation.)

In Tab. 4, the difference in the ratios of gas usage per degree-day before and after retrofitting has been multiplied by the annual number of degree-days to determine the annual therms saved. The annual savings are then compared to those predicted using current ASHRAE methodology (see discussion under "Theoretical Considerations" and Appx A).

Tab. 5 summarizes the annual therms saved, the annual dollars saved, and the simple payback periods by using installed cost estimates given in Appx B.

DISCUSSION OF RESULTS

In Tab. 6, the annual therms saved and the percentage savings attributable to foundation retrofitting are compared with the existing insulation levels, exposures, and accessibility of each of the test homes. Studying the table will reveal several points about the relative percentage of savings:

1. Four of the five homes realized significant savings, ranging from 8 to 26% of their total gas usage per degree-day.

2. These savings were measured even though an average of only 70% of the perimeter was accessible for retrofitting.

3. House F realized no savings. The house is more than 50 years old and may have been built using balloon-style framing techniques. If so, the empty wall cavities may have created a "chimney" for any heat conducted up through the foundation wall to bypass the added insulation, travel up the frame wall cavity into the attic, and then move out. (Note that the R-4 (R-0.7) existing frame wall insulation referred to consists of rigid foam that had been installed under new siding about five years ago.)

4. Houses C and E had very similar exposures and percentages of accessibility, yet their percentages of savings were considerably lower than that of house C. The higher existing insulation level of house E would seem to indicate the opposite. However, the foundation wall of E was already insulated to R-4 (R-0.7) and any added insulation would have less effect than if the wall was previously uninsulated, as in case C.

5. The comparatively low percentage of savings measured for house D is most likely due to the limited access (53%) to its perimeter.

6. Houses B and F had similar accessibilities; however, B had a greater exposure and was better insulated in the frame wall area. These two differences are a likely explanation for the great disparity in percentages of savings. (See also point 3.)

7. Houses B and C experienced similar savings, yet B had much better accessibility and almost four times the exposure. It appears that the relatively high insulation levels in its attic and frame wall were more important factors than access and exposure in determining the percentage of savings.

The comparison of actual to ASHRAE-estimated savings in Tab. 4 is very surprising. In four of the five cases, the ASHRAE estimates are substantially below actual savings measured. The ASHRAE model is therefore inadequate. Most likely, the inadequacies relate to its (1) misuse of the C_D factor, (2) neglect of the vertical path of heat flow up the concrete wall, and (3) neglect of the diagonal path of heat flow at each wall-to-wall and wall-to-floor corner. Computer modeling of these effects has been attempted and should serve as the basis for more complete representative ASHRAE models in the future.[11]

In addition to significantly reducing energy usage in four of the five cases, foundation retrofitting also proved to be an economically sound investment. As shown in Tab. 5, payback periods range from three to four years, assuming current gas costs remain constant. (As a rule, payback periods less than seven years are judged favorably, for this is the average residence time in a home.)

CONCLUSIONS

The foregoing observations lead to the following tentative conclusions:

1. Addition of insulation to the top few feet of the exterior of the foundation wall is an effective way to significantly reduce heat loss in a home that otherwise is fairly well insulated, i.e., attic insulation levels are at R-13 (R-2.3) or above, and frame walls are insulated to at least R-11 (R-1.9).

2. Foundation retrofitting is an economically sound investment. For the Newark, OH, area of 5600°F days (3111°C days), estimated payback periods range from three to four years.

3. Significant energy savings are achievable even if accessibility is limited to 70% or less.

4. Percentage of energy savings will generally correlate to the existing insulation levels, the exposure, and the accessibility.

5. The current ASHRAE model for estimating foundation heat loss and savings is inadequate--it seriously understates actual savings measured. The understatement is likely attributable to incorrect use of C_D factors, neglect of vertical heat loss up the foundation wall, and neglect of diagonal heat loss at corners.

6. Foundation retrofitting may not be effective when frame wall cavities are uninsulated, particularly if balloon construction techniques were used in framing. Cavities may create a thermal bypass for heat loss from the foundation.

The sample size is too small and the results too scattered for general savings claims to be based on this study. However, the results are certainly encouraging enough for the experiment to be expanded by another 15 homes. This effort is now under way, and savings data should be available soon.

ADDENDUM

The author recently learned that house F (which measured 0% savings with the addition of foundation insulation) suffered from lack of controlled conditions before and after retrofitting. The homeowners just recalled that two rooms had been shut off to heat the winter before retrofitting but that the entire house was heated after retrofitting. Had conditions remained constant, a 10%-plus reduction in fuel usage per degree-day might have been measured. The tentative conclusion that foundation retrofitting may not be effective for homes without frame wall insulation may therefore have been premature. The second phase of the experiment includes several homes which do not have frame wall insulation. Results from this study should determine how effective foundation retrofitting can be in otherwise poorly insulated homes.

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APPENDIX A
Estimated Energy Savings*

House B

Same foundation configuration as house C; therefore:

ΔU-Value

IP Units Above	IP Units Below	SI Units Above	SI Units Below
$\frac{0.3745\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{0.2342\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{2.088\ \text{W}}{\text{m}^2\cdot\text{K}}$	$\frac{1.346\ \text{W}}{\text{m}^2\cdot\text{K}}$

Converting U-values to a lineal ft (m) basis:

	IP Units ΔU	X Height or Depth	= ΔU(lineal)	SI Units ΔU	X Height or Depth	= ΔU(lineal)
Above	0.3745	X (26/12) ft	= 0.8114	2.088	X 0.66 m	= 1.378
Below	0.2342	X 1 ft	= 0.2342	1.346	X 0.30 m	= 0.404

Calculating ΔE when P = 132 ft (40.4 m) of 26 in (0.66 m) height exposure
P = 93 ft (28.3 m) of 1 ft (0.30 m) depth

	IP Units ΔU(lineal)	X P	X N	= ΔE	SI Units ΔU(lineal)	X P	X N	= ΔE
Above	0.8114	X 132	X 1.26	= 134.9	1.378	X 40.4	X 2.39	= 133.1
Below	0.2342	X 93	X 0.681	= 14.8	0.404	X 28.3	X 1.29	= 14.7
Total therms saved per year				= 149.7				= 147.8

House D

Same foundation configuration as house C; therefore:

ΔU-Value

IP Units Above	IP Units Below	SI Units Above	SI Units Below
$\frac{0.3745\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{0.2342\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{2.088\ \text{W}}{\text{m}^2\cdot\text{K}}$	$\frac{1.346\ \text{W}}{\text{m}^2\cdot\text{K}}$

Converting U-values to a lineal ft (m) basis:

	IP Units ΔU	X Height or Depth	= ΔU(lineal)	SI Units ΔU	X Height or Depth	= ΔU(lineal)
Above	0.3745	X (8/12) ft	= 0.2497	2.088	X 0.20 m	= 0.418
Below	0.2342	X 1 ft	= 0.2342	1.346	X 0.30 m	= 0.404

Calculating ΔE when P = 68 ft (20.7 m) of 8 in (0.20 m) height exposure
P = 89 ft (27.1 m) of 1 ft (0.30 m) depth

	IP Units ΔU(lineal)	X P	X N	= ΔE	SI Units ΔU(lineal)	X P	X N	= ΔE
Above	0.2497	X 68	X 1.26	= 21.4	0.418	X 20.7	X 2.39	= 20.7
Below	0.2342	X 89	X 0.681	= 14.2	0.404	X 27.1	X 1.29	= 14.2
Total therms saved per year				= 35.6				= 34.8

*Slight discrepancies between IP and SI units occur because of rounding off

House E

Calculating ΔU-value above- and below-grade:

Before retrofit:

Component	IP Units R(above)	IP Units R(below)	SI Units R(above)	SI Units R(below)
Inside air film	0.68	0.68	0.12	0.12
Paneling	0.35	0.35	0.06	0.06
Drywall	0.45	0.45	0.08	0.08
Foam/furring	3.75/0.93	3.75/0.93	0.66/0.16	0.66/0.16
Poured concrete	0.64	0.64	0.11	0.11
Earth	0	0.85	0	0.14
Outside air film	0.17	0.17	0.03	0.03
R	6.04 /3.22	6.89 /4.07	1.06 /0.56	1.20 /0.70
1/R = U	0.1656/0.3106	0.1451/0.2457	0.9434/1.786	0.8333/1.429
Framing factor	X 0.9 X 0.1	X 0.9 X 0.1	X 0.9 X 0.1	X 0.9 X 0.1
	0.1490+0.0311	0.1306+0.0246	0.8491+0.1786	0.7500+0.1429
System U	0.1801	0.1552	1.028	0.8929

After retrofit:

Component	IP Units R(above)	IP Units R(below)	SI Units R(above)	SI Units R(below)
Inside air film	0.68	0.68	0.12	0.12
Paneling	0.35	0.35	0.06	0.06
Drywall	0.45	0.45	0.08	0.08
Foam/furring	3.75/0.93	3.75/0.93	0.66/0.16	0.66/0.16
Poured concrete	0.64	0.64	0.11	0.11
Extruded polystyrene	5.41	5.41	0.95	0.95
Earth	0	0.85	0	0.14
Outside air film	0.17	0.17	0.03	0.03
R	11.45/8.63	12.30/9.48	2.01 /1.51	2.15/1.65
1/R = U	0.0873/0.1159	0.0813/0.1055	0.4975/0.6623	0.4651/0.6061
Framing factor	X 0.9 X 0.1	X 0.9 X 0.1	X 0.9 X 0.1	X 0.9 X 0.1
	0.0786+0.0116	0.0732+0.0106	0.4478+0.0662	0.4186+0.0606
System U	0.0902	0.0838	0.5140	0.4792

Therefore:

ΔU-Value

IP Units Above	IP Units Below	SI Units Above	SI Units Below
$\frac{0.0901\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{0.0714\ \text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{0.514\ \text{W}}{\text{m}^2\cdot\text{K}}$	$\frac{0.414\ \text{W}}{\text{m}^2\cdot\text{K}}$

Converting U-values to a lineal ft (m) basis:

	IP Units ΔU	X Height or Depth	= ΔU(lineal)	SI Units ΔU	X Height or Depth	= ΔU(lineal)
Above	0.0901	X (6/12) ft	= 0.0451	0.514	X 0.15 m	= 0.077
Below	0.0714	X 1 ft	= 0.0741	0.414	X 0.30 m	= 0.124

Calculating ΔE when P = 61 ft (18.6 m) of 6 in (0.15 m) height exposure
P = 83 ft (25.3 m) of 1 ft (0.30 m) depth

	IP Units ΔU(lineal)	X P	X N	= ΔE	SI Units ΔU(lineal)	X P	X N	= ΔE
Above	0.0451	X 61	X 1.26	= 3.5	0.077	X 18.6	X 2.39	= 3.4
Below	0.0741	X 83	X 0.681	= 4.2	0.124	X 25.3	X 1.29	= 4.0
Total therms saved per year				= 7.7				= 7.4

House F

Calculating ΔU-value above- and below-grade:

Before retrofit:

Component	IP Units R(above)	IP Units R(below)	SI Units R(above)	SI Units R(below)
Inside air film	0.68	0.68	0.12	0.12
Brick	0.88	0.88	0.16	0.16
Earth	0	0.85	0	0.14
Outside air film	0.17	0.17	0.03	0.03
R	1.73	2.58	0.31	0.45
1/R = U	0.5780	0.3876	3.226	2.222

After retrofit:

Component	IP Units R(above)	IP Units R(below)	SI Units R(above)	SI Units R(below)
Inside air film	0.68	0.68	0.12	0.12
Brick	0.88	0.88	0.16	0.16
Extruded polystyrene	5.41	5.41	0.95	0.95
Earth	0	0.85	0	0.14
Outside air film	0.17	0.17	0.03	0.03
R	7.14	7.99	1.26	1.40
1/R = U	0.1401	0.1252	0.794	0.714

Therefore:

ΔU-Value

IP Units Above	IP Units Below	SI Units Above	SI Units Below
$\frac{0.4379 \text{ Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{0.2624 \text{ Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$	$\frac{2.432 \text{ W}}{\text{m}^2\cdot\text{K}}$	$\frac{1.508 \text{ W}}{\text{m}^2\cdot\text{K}}$

Converting U-values to a lineal ft (m) basis:

	IP Units ΔU	X	Height or Depth	=	ΔU(lineal)	SI Units ΔU	X	Height or Depth	=	ΔU(lineal)
Above	0.4379	X	(8/12) ft	=	0.2919	2.432	X	0.20 m	=	0.486
Above	0.4379	X	(9/12) ft	=	0.3284	2.432	X	0.23 m	=	0.559
Above	0.4379	X	(16/12) ft	=	0.5839	2.432	X	0.41 m	=	0.997
Below	0.2624	X	1 ft	=	0.2624	1.508	X	0.30 m	=	0.452

Calculating ΔE when P = 20 ft (8.8 m) of 8 in (0.20 m) height exposure
P = 10 ft (3.0 m) of 9 in (0.23 m) height exposure
P = 71 ft (21.6 m) of 16 in (0.41 m) height exposure
P = 111 ft (33.8 m) of 1 ft (0.30 m) depth

	IP Units ΔU(lineal)	X	P	X	N	=	ΔE	SI Units ΔU(lineal)	X	P	X	N	=	ΔE
Above	0.2919	X	29	X	1.26	=	10.7	0.486	X	8.8	X	2.39	=	10.2
Above	0.3284	X	10	X	1.26	=	4.1	0.559	X	3.0	X	2.39	=	4.0
Above	0.5839	X	71	X	1.26	=	52.2	0.997	X	21.6	X	2.39	=	51.5
Below	0.2624	X	111	X	0.681	=	19.8	0.452	X	33.8	X	1.29	=	19.7
Total therms saved per year						=	86.8						=	85.4

APPENDIX B
Installed Cost Estimates

Installed cost of 1 in (2.54 cm) extruded polystyrene	=	$ .60 / ft^2	$ 6.45 / m^2
Installed cost of brush-on cementitious coating	=	$1.00 / ft^2	$10.75 / m^2
Installed cost of brush-on cementitious coating with stucco texture finish	=	$1.25 / ft^2	$13.45 / m^2
Installed cost of brush-on cementitious coating with pebble finish	=	$1.75 / ft^2	$18.85 / m^2
Installed cost of J-channel	=	$ .50 / ft	$ 1.65 / m
Labor to dig 1 ft (0.30 m) trench and replace dirt	=	$ .75 / ft	$ 2.54 / m

TABLE 1
The Diminishing Effect of Added Insulation

R-Value	1/R = U-Value	ΔU-Value
10	0.1000	--
20	0.0500	0.0500
30	0.0333	0.0167
40	0.0250	0.0083

TABLE 2
Description of Test Homes

Home	Style	Age When Retrofitted	Percentage of Accessibility to Foundation Perimeter	Typical Height Exposed	Attached Garage?	Heating Equipment	R-Value of Existing Insulation (hr·ft^2·°F/Btu) m^2·K/W Attic	Frame Wall	Foundation
A	Raised ranch	3 yrs	65%	45 in (1.14 m)	Yes	Heat pump	R-19 (R-3.3)	R-16 (R-2.8)	R-4 (R-0.7)
B	One story	50 yrs	92%	26 in (0.66 m)	No	Gas F/A	R-13 (R-2.3)	R-11 (R-1.9)	
C	One story	1 yr	65%	7 in (0.18 m)	Yes	Gas F/A	R-19 (R-3.3)	R-16 (R-2.8)	
D	Two story	2 yrs	53%	8 in (0.20 m)	Yes	Gas F/A	R-24 (R-4.2)	R-11 (R-1.9)	
E	Tri-level	1 yr	63%	6 in (0.15 m)	Yes	Gas F/A	R-30 (R-5.3)	R-19 (R-3.3)	R-4 (R-0.7)
F	Two story	53 yrs	88%	16 in (0.41 m)	No	Gas F/A	R-13 (R-2.3)	R-4 (R-0.7)	

TABLE 3
Effect on Fuel Usage Per Degree-Day

Home	Period	Degree-Days, °F (°C)	Total Gas Usage	Total Gas Usage Per Degree-Day	Item Retrofitted	Period	Degree-Days, °F (°C)	Total Gas Usage	Total Gas Usage Per Degree-Day	Percent Savings Total Gas Usage
Pre-retrofit						Post-retrofit				
B	8/29/80-12/1/80	1213 (674)	279 therms	0.41	Frame wall	9/1/81-12/2/81	1324 (736)	255 therms	0.35	15
	12/1/80-6/3/81	4382 (2434)	1089 therms	0.45	Frame wall and foundation	12/2/81-6/3/82	4732 (2629)	750 therms	0.29	36
				0.45(1 - 0.15)*	Foundation	12/2/81-6/3/82	4732 (2629)	750 therms	0.29	24
C	3/8/81-5/8/81	871 (484)	130 therms	0.27	Foundation	3/8/82-5/10/82	1092 (607)	120 therms	0.20	26
D	12/17/80-5/19/81	3898 (2166)	1060 therms	0.49	Foundation	12/17/81-5/19/82	4220 (2344)	1050 therms	0.45	8
E	1/16/81-5/4/81	2464 (1369)	420 therms	0.31	Foundation	1/5/82-5/4/82	3544 (1969)	520 therms	0.26	16
F	12/12/80-6/16/81	4109 (2283)	868 therms	0.38	Foundation	12/15/82-6/9/82	4310 (2394)	902 therms	0.38	0

*This subtracts the effect of the frame wall insulation

TABLE 4
Annual Therms Saved
(SI units)

Home	Initial Gas Usage Per Degree-Day	-	Retrofit Gas Usage Per Degree-Day		X	Annual Degree-Days, °C Days	=	Annual Therms Saved	Savings Estimate (ASHRAE)	Ratio of Actual to Estimate
B	[0.45(1 - 0.15)	-	0.29	]	X	3111	=	280	149	1.9
C	[0.27	-	0.20	]	X	3111	=	218	44	5.0
D	[0.49	-	0.45	]	X	3111	=	124	35	3.5
E	[0.31	-	0.26	]	X	3111	=	156	8	19.5
F	[0.38	-	0.38	]	X	3111	=	0	86	N/A

TABLE 5
Economic Analysis

Home	Annual Therms Saved	Annual* Dollars Saved	Installed† Cost	Simple†† Payback
B	280	$154	$635	4.1 yrs
C	218	$120	$345	2.9 yrs
D	124	$ 68	$270	4.0 yrs
E	156	$ 86	$305	3.5 yrs
F	0	0	$500	N/A

*Assuming $.55/therm
†See Appendix B
††Installed Cost ÷ Annual $ Savings = Simple Payback

TABLE 6

Comparison of Energy Savings to Test House Characteristics

Home	Age	Percent of Accessibility to Perimeter	Typical Height Exposed	Attached Garage?	R-Value of Existing Insulation ($hr \cdot ft^2 \cdot °F/Btu$) ($m^2 \cdot K/W$) Attic	Frame Wall	Foundation	Percent Savings in Gas Usage per Degree-Day Because of Foundation Insulation	Annual Therms Saved
B	50 yrs	92	26 in (0.66 m)	No	R-13 (R-2.3)	R-11 (R-1.9)	--	24	280
C	1 yr	65	7 in (0.18 m)	Yes	R-19 (R-3.3)	R-16 (R-2.8)	--	26	218
D	2 yrs	53	8 in (0.20 m)	Yes	R-24 (R-4.2)	R-11 (R-1.9)	--	8	124
E	1 yr	63	6 in (0.15 m)	Yes	R-30 (R-5.3)	R-19 (R-3.3)	R-4 (R-0.7)	16	156
F	53 yrs	88	16 in (0.41 m)	No	R-13 (R-2.3)	R-4 (R-0.7)	--	0	0

Typical Distribution of Home Heat Loss

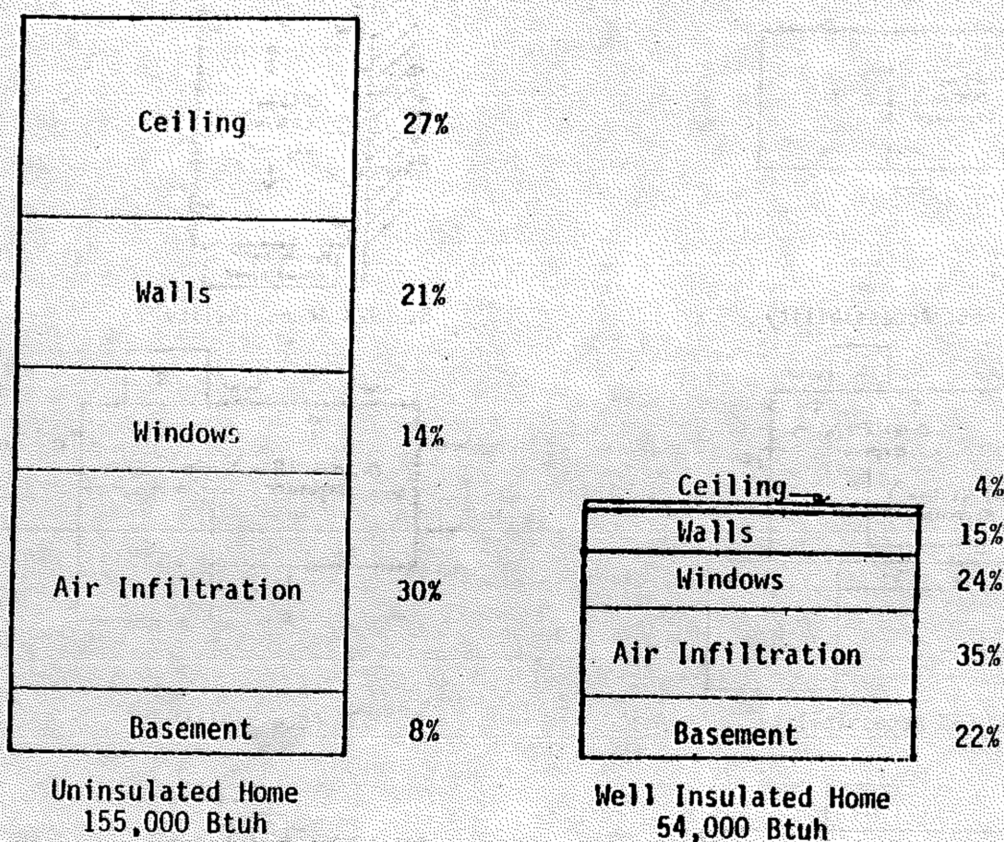

Figure 1. *Heat loss distributions are determined using ASHRAE methodology presented in the 1981 Handbook of Fundamentals. The "typical" home considered is a two story rectangular structure with full basement. The perimeter of the conditioned area measures 40.2 m (132 ft). The 8ninsulated home has no ceiling, wall cavity, or basement insulation. The wall sheathing is 1.3 cm (0.5 in.) wood fiberboard and windows are single glazed. The well insulated home features R-5.3 (R-30) ceiling insulation, R-1.9 (R-11) insulation in the wall cavity, R-1.0 (R-5.4) sheathing on tle frame walls, and dual glazed windows. The sheathing on the frame walls, and dual glazed windows. The basement is uninsulated. An indoor-outdoor temperature difference of approximately 38.9 C^{o}(70 F^{o}) is assumed in both the uninsulated and insulated analyses.*

Plan View of Test Homes

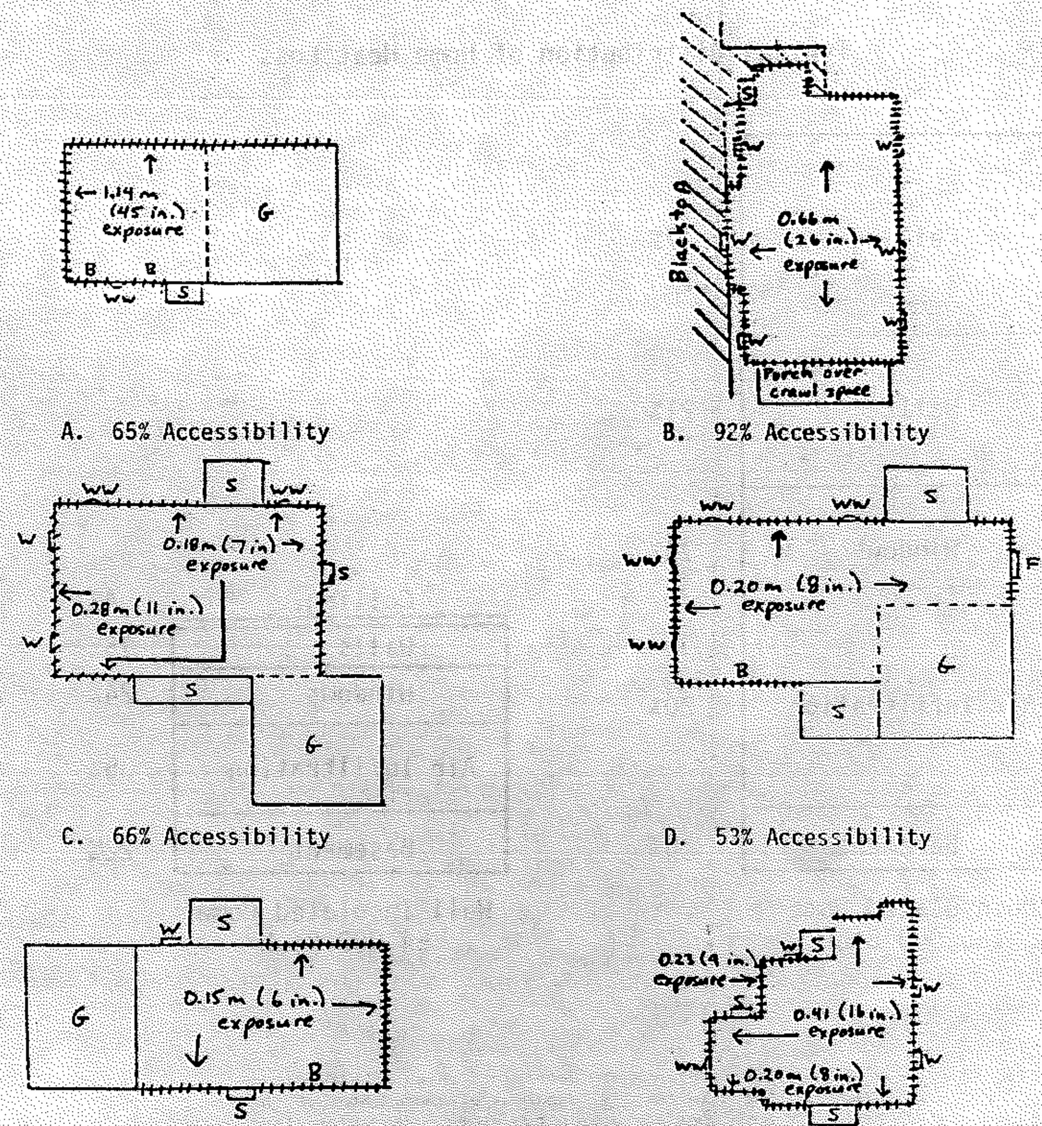

Figure 2. *Key: Brick exterior (B); slab, steps, or porch (S); garage (G); window (W); window and window well (WW); fireplace chimney (F); insulated portion of the perimeter*

Scale: Approximately 1:300; 1 cm = 3 m (3/8 in. = 10 ft)

Determining Percent Accessibility.

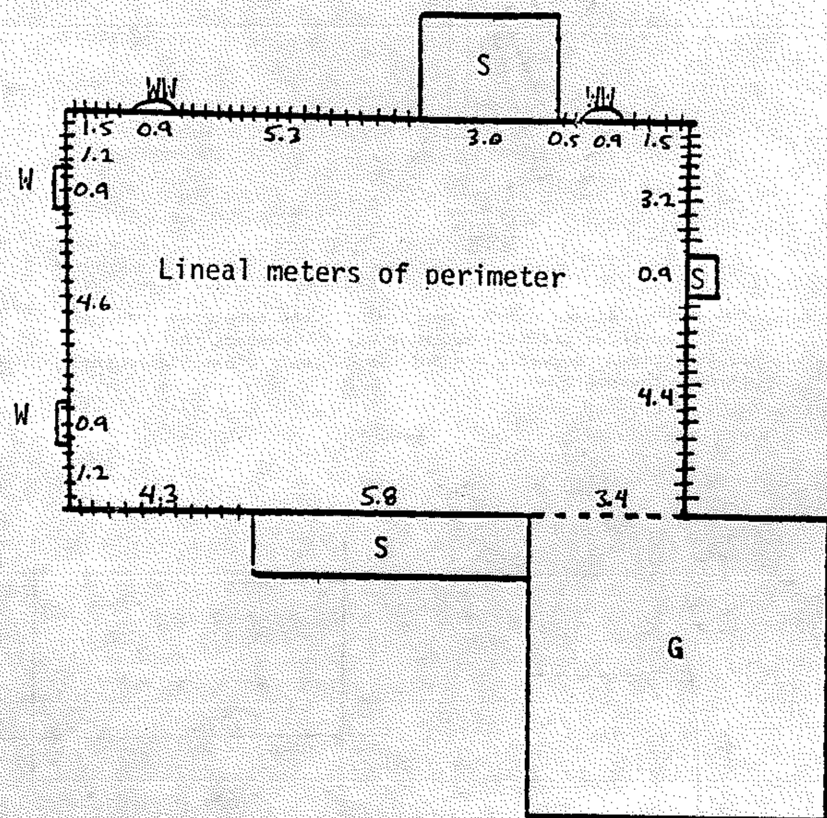

Figure 1. Total Effective Perimeter = (3.4 + 5.8 + 4.3 + 1.2 + 0.9 + 4.6 + 0.9 + 1.2 + 1.5 + 0.9 + 5.3 + 3.0 + 0.5 + 0.9 + 1.5 + 3.2 + 0.9 + 4.4) m

= 44.4 m (146 ft)

Total Insulated Perimeter = (4.3 + 1/2 + 0.9 + 4.6 + 0.9 + 1.2 + 1.5 + 5.3 + 0.5 + 1.5 + 3.2 + 4.4) m

= 29.5 m (97 ft)

$$\text{Percent Accessibility} = \frac{\text{Insulated Perimeter}}{\text{Effective Perimeter}} \times 100\%$$

$$= \frac{29.5\ m}{44.4\ m} \times 100\%$$

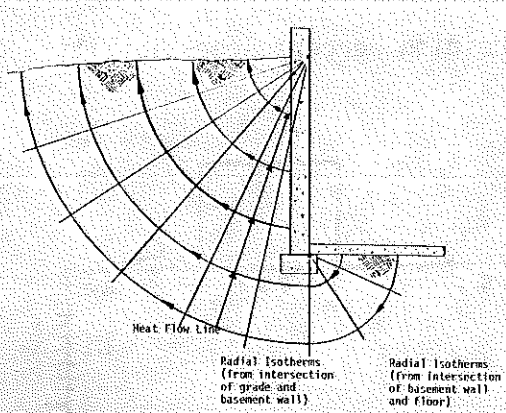

Figure 4. The current ASHRAE model - particularly the tabulated data on heat loss below grade in basement walls - assumes that heat flows through the walls and follows concentric circular paths through the earth.

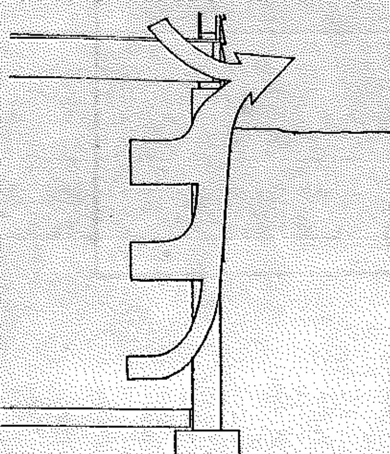

Figure 5. Concrete block is highly conductive to heat transfer. A 0.20 m (8 in.) concrete block has an insulating value of only R-.20 R-1.11). Therefore, it's very likely that a significant portion of basement heat loss follows a vertical path up through the foundation wall, leaving relatively small amounts of heat to escape horizontally intc the surrounding earth.

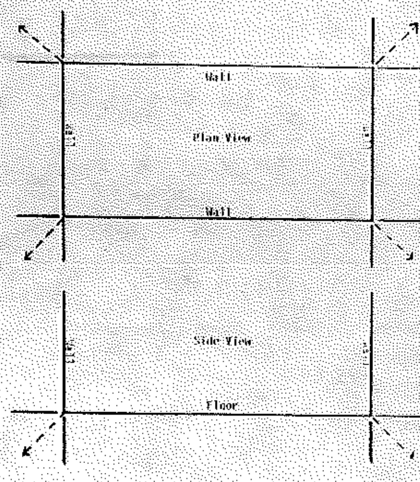

Figure 6. The dashed arrows represent the diagonal path of heat flow which is neglected in current ASHRAE models. Their absence in an analysis leads to understated heat loss and savings estimates.

Discussion

D.M. Onysko, Forintek Canada Corp., Ottawa, Ontario, CANADA: Have you considered the possibility of degradation by insects of externally applied rigid foam insulation (carpenter ants, termites)? We had an ant colony that happily tunneled into polystyrene insulation.

K. Wolfgram: Although polystyrene insulation offers no food value to rodents or insects, some burrowing vermin, such as termites or carpenter ants, may tunnel into it, as they do to other construction materials. If such vermin are abundant, then normal techniques to control the infestation are advisable.

A.W. Johnson, NAHB Research Foundation, Rockville, MD: I would like to encourage your continued research in as wide a variation of U.S. climates as you can fund. Fundamental radials based on Canadian work with extrapolation to Latin America are somewhat suspect.

Wolfgram: Other foundation insulation projects currently underway include another basement retrofit experiment in Canada and slab insulation studies done in cooperation with Clemson University.