Conditions of a Sample of Minnesota Exterior Foundation Wall Insulation Materials

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ABSTRACT

A study was conducted on the condition of exterior residential foundation wall insulation materials buried 6 to 24 in. (15 to 60 cm) below grade. Specimens were obtained from 59 houses between two and seven years old in the Minneapolis-St. Paul metropolitan area. The insulation materials included were: extruded polystyrene, mineral fiber board, molded expanded polystyrene, faced polyisocyanurate, and spray-applied urethane.

At more than half of the sites from which specimens were collected, above-grade insulation protective covering was missing or deteriorating. At a number of sites, the insulation did not extend over the entire exposed foundation wall.

The moisture content of the insulation was not a function of either surrounding soil moisture content or soil type. The specimens with high moisture content were taken from those sites where either the below-grade protective coating was damaged (for those products having below-grade protective coating), the above grade protective coating was deteriorating or absent, or where a gap existed between the bottom of the siding and the insulation, allowing moisture to get between the insulation and wall. High-moisture-content outliers were deleted from averages because they may have been the result of installation practices that could be corrected. Most of the higher moisture-containing specimens were collected from east-facing walls.

The moisture in the insulation specimens was calculated to have a minimal effect on R-values - less than 10% loss for most specimens. When combining the effect of moisture with the measured R-value of the specimens and eliminating outliers, the R-value change from nominal for extruded polystyrene, mineral fiber board, and spray-applied urethane ranged from a slight gain to less than 10% loss. Molded EPS and polyisocyanurate materials had net calculated R-value losses of greater than 10%. Caution should be used when interpreting these results since some of the specimen sample sizes were small.

BACKGROUND

Since January 1984, the Minnesota Energy Code has required foundation wall insulation on all new residential buildings having three stories or less. This requirement calls for R-5 (RSI-0.88) insulation over the entire foundation wall, or R-10 (RSI-1.76) insulation from the top of the foundation wall to the design frost line. The insulation may be placed on either the interior or exterior of the foundation wall.

In 1986, the Minnesota Insulation Standards Program (Minn. Rules Chapter 7640) was initiated. One part of these rules requires that material sold for use as exterior foundation wall insulation be shown to meet certain criteria. A literature search found no survey of exterior foundation wall insulation of actual houses. From a regulatory perspective, the lack of research on this subject served as the primary impetus for this project.

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EXPERIMENTAL APPROACH

The number of specimens of each material type and the code abbreviations used to identify 58 of the specimens collected are shown in Table 1. Specimen SU-1 was a unique composite of a one-half-inch coating of spray-applied urethane on one inch of extruded polystyrene, and thus was not used in this study.

TABLE 1
Number of Specimens and Specimen Codes

Material	Number of specimens collected	Specimen codes
Extruded polystyrene	14	EP-1 to EP-14
Mineral fiber board	3	MB-1 to MB-3
Molded EPS	2	ME-1 to ME-2
Faced polyisocyanurate	4	PI-1 to PI-4
Spray applied urethane	35	SU-2 to SU-36

Cities in the Minneapolis-St. Paul metropolitan area with the largest growth in the past 10 years were targeted. Building officials of these cities were asked to provide neighborhoods or specific sites between 2 and 10 years old and with exterior foundation wall insulation. In all, 233 potential sites were identified.

A mailing was sent to the owner of each potential site. The mailing included a general letter from the Department of Public Service, a letter addressed to the homeowner signed by the specimen collection contractor, and a homeowner agreement form. The incentives were designed to appeal to a desire for information, community spirit, and the pocketbook ($10 remuneration for participating in the project). Nevertheless, many follow-up phone calls were necessary to solicit participation. Following collection of insulation specimens, all of the participating homeowners were sent thank-you letters signed by the governor of the State of Minnesota.

All specimens were collected between April 7, 1988 and June 15, 1988. The beginning date of collection was determined by when the ground thawed sufficiently to enable excavation. One piece of exterior foundation wall insulation approximately 15 by 15 in. (38 by 38 cm) was collected from each site. Care was taken to remove the insulation as close to in situ condition as possible. No water was observed to be draining from any of the specimens as they were being collected. The spray-applied urethane material generally adhered to the foundation and had to be scraped and peeled off; consequently, some specimens were in two or three pieces. The insulation specimens were immediately weighed. The wind sometimes interfered with the accuracy of this reading. Insulation specimens were immediately sealed in heavy-duty polyethylene bags for shipment to the test laboratory.

Specimens of the soil adjacent to the foundation wall were collected in glass canning jars with tightly sealed lids. Information about the site and a qualitative description of the above-grade and below-grade foundation wall were recorded.

The insulation specimens were weighed upon arrival at the laboratory and then allowed to come to equilibrium with the laboratory environment. Laboratory conditions were $70^0\pm5^0$F ($21^0\pm3^0$C) and 40% $\pm$ 10% relative humidity. Specimen weights were recorded daily until equilibrium was attained. No standard method exists to calculate the percent by volume of insulation materials. To quantify the amount of water within the insulation specimens, it was recognized that water is absorbed within the cells or between the fibers of the insulation. Therefore, the percent of water by volume of each specimen was calculated as the volume of water divided by the volume of the insulation specimen as received (Equation 1).

percent water by volume = water volume / insulation volume x 100%

$$= \frac{((W_r - W_e)/D_w)}{W_e/D_i} \times 100\% \qquad (1)$$

where

W_r = specimen weight as received (kg)

W_e = specimen weight at equilibrium (kg) = weight of insulation

D_w = density of water (1000 kg/m^3)

D_i = density of insulation (kg/m^3) for each specimen

Most of the urethane specimens were coated with bitumen on one side. The percent water by volume for the urethane specimens was calculated after removal of the bitumen. The moisture content of the soil specimens (in percent weight) was done in accordance with ASTM D 2116 and visual classification was performed in accordance with ASTM D 2488.

Thermal resistance of wet insulation was calculated. Dechow and Epstein (1981) is a recognized source for the effect of moisture on the thermal performance of insulation. The equations to calculate the effect of low moisture content on thermal resistance for each type of insulation from this reference are shown in Equations 2 through 7.

Extruded polystyrene (%W < 30%) $$R_w = 1 / (1/R_o + 0.008 * \%W) \quad (2)$$

Mineral fiber board (%W < 2%) $$R_w = 1 / (1/R_o + 0.082 * \%W) \quad (3)$$

Molded EPS (%W < 10%) $$R_w = 1 / (1/R_o + 0.012 * \%W) \quad (4)$$

Polyisocyanurate (%W < 10%) $$R_w = 1 / (1/R_o + 0.008 * \%W) \quad (5)$$

Spray urethane (%W < 10%) $$R_w = 1 / (1/R_o + 0.008 * \%W) \quad (6)$$

Spray urethane (%W ≥ 10%) $$R_w = 1/(1/R_o + 0.055*\%W + 0.0028*\%W^2) \quad (7)$$

<u>where</u>

R_w = the thermal resistance of wet insulation

R_o = the thermal resistance of dry insulation

%W = the percent water by volume of the insulation specimen (i.e., 5.0% = 5.0, not 0.050)

For comparison, nominal dry insulation R-values are assumed. The assumed values and their sources appear in Table 2.

TABLE 2
Assumed Nominal Dry Insulation R-Values

Material	Nominal thermal resistance R-Value per inch	RSI	Source
Extruded polystyrene	5.0	0.88	ASTM C 578 - Type IV
Mineral fiber board	4.2	0.74	Manufacturer's data
Molded EPS (Type VII)	3.8	0.67	ASTM C 578
Molded EPS (Type II)	4.0	0.70	ASTM C 578
Faced polyisocyanurate	7.2	1.27	Manufacturer's data
Spray-applied urethane	6.2	1.09	ASTM C 1029

The values for extruded polystyrene, polyisocyanurate, and spray urethane represent conditioned or "aged" R-values. These assumptions are made with reasonable certainty, with the possible exception of molded EPS, because of the wide range of densities manufactured. The "types" of polystyrene in ASTM C 578 commonly manufactured as molded EPS have R-values per inch varying from 3.6 @ 0.9 pcf (Type I) to 4.2 @ 1.8 pcf (Type IX). The densities of the molded EPS specimens collected indicate that they may be one each of Type VII (nominal 1.15 pcf) and Type II (nominal 1.35 pcf).

Thermal resistance of the insulation specimens was measured in accordance with ASTM C 518. The apparent thermal conductivities were obtained (after drying to equilibrium with laboratory conditions) at a mean specimen temperature of 75^o F (23.89^{o}C) and with temperature differences of 50^{o}F (27.8^{o}C).

For this report, the data are presented by treating the outliers separately and explaining why they should be separate. This choice implies that perhaps there was some problem -- either common or unique to the outliers -- that might be corrected in future installations. This survey could not characterize the condition of the materials as installed when the house was built (either the precise thickness or the density). Thus, no results for these conditions are reported here.

ENVIRONMENTAL CONDITIONS

The suburban Minneapolis-St. Paul area normally has approximately 2200 annual freezing

°F days (1200°C FDD). The design frost depth is 42 in. (107 cm). The precipitation received at the Minneapolis-St. Paul airport during the months prior to and during specimen collection was below normal.

In addition, the specimen collection contractor noted considerable lawn watering at one site (SU-15).

RESULTS

Of the 233 homeowners contacted, only 70 (30%) agreed to participate. Of these sites, 11 did not have exterior foundation wall insulation. Of the 59 sites from which specimens were collected, 52 of the homeowners accepted the $10 financial incentive offered for their participation in the project.

At more than half of the sites there was a gap between the top of the exterior foundation wall insulation and the siding. In some cases, none of the exterior foundation wall was insulated above grade. For example, at site EP-14, the gap between the siding and the start of the foundation wall insulation ranged from 1 to 16 in. (2.5 to 40 cm) (Figure 1). Since no information about the home's interior was obtained for any site, it is not known whether the interior wall was insulated. None of the sites had flashing installed over the exterior foundation wall insulation.

At the sites where the insulation covered most of the above-grade wall, 62% had damaged protective coating with the exposed insulation deteriorating. Nineteen sites had insulation protected only by paint, which had been gouged. Two of the 14 EP sites had a troweled-on cement coating and both were reported to be cracked, exposing the underlying insulation. Two MB sites were protected with fiberglass-reinforced resin panels which were reported in poor condition, breaking off in many places. Of the spray-applied urethane sites, three had unpainted bitumen that neither uniformly nor completely covered the insulation above grade. Of the 12 painted bitumen SU sites, 10 were reported to be dried and cracking, exposing the insulation to deterioration. The protective coating on most of the SU sites was reported as either gouged or flaking off. The above grade gouging of extruded polystyrene and spray urethane ranged from 1/4-in. to more than 1 in. in depth and sometimes spanned the entire length of the wall.

Some of the above-grade protective coating materials were in good to excellent condition. One MB site with troweled-on cement coating was in good condition. At three EP sites, the rigid fiberglass panel used for above grade covering was in excellent condition. One EP site was covered above-grade with 1/4-in. (0.6 cm) unpainted exterior plywood which was only slightly warped. All four PI sites were coated with 1/2-in. (1.27 cm) exterior grade plywood in excellent condition.

Only two insulation types were protected below grade: all of the faced polyisocyanurate (aluminum foil) and all of the spray-applied urethane (bitumen and sometimes polyethylene film), with the exception of sites SU-33 and SU-35. Most of the exterior surface of below-grade insulation or coatings was reported to be in "near original" condition. The below-grade protective coating at site PI-3 had several gouges, apparently made during backfill. The protective coating at site SU-30 was not complete and the below-grade surface of the insulation was crumbly.

The foundation wall insulation at sites EP-6, EP-13, EP-14, and all of the PI sites showed signs of water flow between the insulation and foundation wall. For all of these specimens, the surfaces that had been facing the wall had soil deposits with a pattern indicating that it was deposited by water flow (Figure 2).

Attachment A lists the measured site soil moisture content (percent by weight), which ranged from 4.9% to 41.5%. Attachment A also lists the soil type for each site. Soil type characteristics are explained in Labs et al. (1988).

A calculation of the percent weight loss between the field measurement and measurement upon receipt at the laboratory showed widely disparate results (Attachment A). The average weight loss of the specimens between these two measurements was 2.4% (standard deviation = 2.1%). This average was determined by neglecting three specimens with weight loss of more than 10% (speculating that these were cases in which a piece of the specimen weighed in the field was not weighed in the laboratory). This difference represents a combination of error in the field weight (due to wind and the accuracy of the scale), moisture loss during storage, and soil that may have been loosened from the specimen during transportation. If the average weight loss of 2.4% were accurate, it would introduce a significant error because it represents an approximate 0.70% by volume under calculation of the insulation specimen moisture content. Because of the uncertainties in the weight recorded at the collection site (perhaps resulting in "negative" weight losses) and the unknown variability of the weight loss in transit, the weight as received at the laboratory was used in the following calculations.

The density of each specimen measured after drying to laboratory conditions is listed in Attachment A and summarized for each type of insulation in Table 3.

TABLE 3
Average and Standard Deviation (SD) of Densities of Insulation Specimens

Material	lb/ft3 Average	lb/ft3 SD	kg/m3 Average	kg/m3 SD
Extruded polystyrene	2.01	0.25	32.2	4.0
Mineral fiber board	5.85		93.7	
Molded EPS (ME-1)	1.36		20.3	
Molded EPS (ME-2)	1.17		20.3	
Polyisocyanurate	2.13		34.1	
Spray-applied urethane	2.24	0.28	35.9	4.5

Generally, densities of the insulation materials as originally installed could not be inferred from the data collected; therefore, nominal densities are not listed. The measured densities of the two molded EPS specimens indicate that they may each be one of two ASTM C 578 types: ME-1 at 1.36 pcf appears to be Type II and ME-2 at 1.17 pcf appears to be Type VII. Thus, the data for these specimens are not averaged in the following analysis.

Insulation moisture content (in percent by volume) of all specimens is plotted against soil moisture content (in percent by weight) for each insulation type in Figures 3 through 7. By visual inspection, there appears to be some positive correlation between insulation moisture content and soil moisture in some of these figures. However, statistical analysis of each data set shows no correlation of insulation moisture content with soil moisture for any of the insulation types.

Extruded Polystyrene. Figure 3 is a plot of the insulation and soil moisture data for this type of insulation. The three specimens that had water flow between the insulation and foundation wall (a problem that might be avoided) were omitted from averaging. The average moisture content of the remaining 11 specimens is 0.25% by volume. The average moisture content of the remaining specimens with good above-grade protection was no less than that of the specimens with not-so-good above-grade protection.

Mineral Fiber Board. Figure 4 is a plot of the insulation and soil moisture data for this type of insulation. Even though these specimens have a much lower moisture content than the other types of materials in this sample, the effect of that moisture on R-value is greater (see Equation 3).

Molded EPS. Figure 5 is a plot of the insulation and soil moisture data for this type of insulation. Both sites had gaps between the bottom of the siding and the top of the insulation.

Polyisocyanurate. Figure 6 is a plot of the insulation and soil moisture data for this type of insulation. One specimen (PI-3) had a higher moisture content, which may have been due to gouges in the foil protective coating below grade (a problem that might be avoided with supplemental below-grade protective coating). The average moisture content of the polyisocyanurate specimens (omitting specimen PI-3) is 0.82% by volume.

Spray Urethane. Figure 7 is a plot of the insulation and soil moisture data for this type of insulation. There may be explanations for several of the outliers. Specimen SU-30 had a very thin and inconsistent bitumen coating; specimens SU-2 and SU-19 had unprotected gaps between the top of the insulation and the bottom of the siding. However, it is noteworthy that a number of specimens from sites with gaps between the top of the insulation and the bottom of the siding had <u>low</u> moisture contents. The noted presence of lawn watering may have contributed to the exceptionally high moisture content of specimen SU-15. The average moisture content of the remaining 31 specimens is 0.58% by volume. For these 31 specimens, there was no statistical support for higher or lower moisture content being associated with the condition of the above-grade protective coating or insulation.

The average insulation moisture conditions for each type of insulation (nine specimens omitted) are summarized in Table 5.

TABLE 5
Moisture Content of Insulation Specimens
(nine specimens omitted)

Material	Number of specimens	Average % by volume	Standard deviation
Extruded polystyrene	11	0.25	0.32%
Mineral fiber board	3	0.10	
Molded EPS (ME-1)	1	0.13	
Molded EPS (ME-2)	1	0.85	
Polyisocyanurate	3	0.82	
Spray urethane	31	0.58	0.64%

Neither insulation moisture content nor soil moisture content appeared to correlate with rainfall variables. This was true for both the amount of rainfall received prior to specimen collection and the period of time since rain.

Summarizing the above discussion on insulation moisture vs. soil moisture content shows both interesting and confounding results. The insulation moisture content of these specimens was not a function of surrounding soil moisture content, as would be expected. Specimen SU-20, taken from the highest moisture content and poorest draining soil, had relatively low moisture. Yet SU-15 was exceptionally damp, even though it was surrounded by soil of moderate moisture content and had protective coating in much better condition than many other specimens.

Thermal Resistance of Insulation

The thermal resistance of the specimens based on their moisture content was calculated as discussed in the "Experimental Approach section". Attachment A lists the calculated resistance due to moisture and the percent difference from the nominal R-value (from Table 2) for each specimen. It is noted that most of the specimens show less than a 5% loss in R-value due to moisture content, and only a few exceed 10%. The average R-value per inch and percentage of loss due to moisture content for each material are summarized in Table 6.

Note that although the approximate thickness of most specimens is reported, it may have been compressed; thus, the total R-value loss for the insulation could be different than is shown in Table 6.

TABLE 6
Calculated Thermal Resistance of Specimens at Average Water Content
(nine specimens omitted)

Material	Average water content % by volume	Average R-value per inch	Nominal R-value per inch	Avg. % loss from nom.
Extruded polystyrene	0.25%	4.95	5.0	1.0%
Mineral fiber board	0.10%	4.06	4.2	3.3%
Molded EPS (ME-1)	0.13%	3.98	4.0	0.6%
Molded EPS (ME-2)	0.85%	3.71	3.8	3.8%
Polyisocyanurate	0.82%	6.90	7.2	4.2%
Spray urethane	0.58%	6.03	6.2	2.8%

R-Value Loss Due to Moisture vs. Soil Type

The effect of moisture content on R-value varies among the different types of insulation. Thus, to compare the effect of soil type on the different insulations on the same scale, the average R-value loss is chosen as the dependent variable instead of moisture content. The calculated average R-value loss of each insulation type due to moisture for each soil type is plotted in Figure 8.

Thermal Conductivity of Dry Specimens

Apparent thermal conductivities measured for 30 specimens are summarized in Table 7.

TABLE 7
Summary of Measured Thermal Resistance of Dry Insulation Specimens

Material	Number of specimens	Average R-value per inch	Standard deviation	Nominal R-value per inch	Percent difference from nom.
Extruded polystyrene	11	4.85	0.13	5.0	-3.0%
Mineral fiber board	3	4.41		4.2	+5.0%
Molded EPS (ME-1)	1	3.35		4.0	-16.3%
Molded EPS (ME-2)	1	3.36		3.8	-11.6%
Polyisocyanurate	2	6.46		7.2	-10.3%
Spray urethane	12	5.85	0.32	6.2	-5.7%

Net R-Value Per Inch

Taking the average of the measured laboratory dry R-value per inch for each material type from Table 7 and computing the effect of the average moisture found in that material (outliers omitted) yields a net average R-value per inch for each material. The result of this computation appears in Table 8. The percent difference from the nominal R-value per inch (from Table 2) is also shown.

TABLE 8
Net Calculated Thermal Resistance Per Inch

Material	Average measured R-value per inch	Average insulation moisture content*	Net calculated R-value per inch	Percent difference from nominal
Extruded polystyrene	4.85	0.25%	4.80	-4.0%
Mineral fiber board	4.41	0.10%	4.26	+1.3%
Molded EPS (ME-1)	3.35	0.13%	3.33	-16.8%
Molded EPS (ME-2)	3.36	0.85%	3.25	-14.5%
Polyisocyanurate	6.46	0.82%	6.20	-13.9%
Spray urethane	5.85	0.58%	5.70	-8.1%

*nine specimens omitted

DISCUSSION

The procedure developed to identify potential sampling sites resulted in an unbiased specimen, but also netted fewer sites than desired for some of the insulation types. The specimen collection went smoothly. More information could have been obtained if the average thickness had been precisely determined or if characteristics of the materials at installation had been known. Error introduced by the loss of moisture from the insulation specimens between collection and laboratory weighing may have resulted in a calculation of higher R-values for the specimens than was actually the case.

Exterior foundation wall insulation not extending to the top of the foundation wall was frequently observed. This condition was found to exist in most, though not all, of the higher moisture-containing specimens. Several sites were found either without protective coating or damaged protective coating above grade. The exposed insulation at these sites showed deterioration that could be expected to get worse over the years, degrading the insulating qualities of the material. The condition of the above-grade protective coatings varied widely. These findings are similar to those of a 1986 Wisconsin study (Schlegel et al.1986).

There was no indication that the insulation had degraded due to contact with the soil, or that frost action had damaged the insulation after at least two years in the ground. Some damage was found to below-grade protective coatings for polyisocyanurate and spray urethane, which may have contributed to high moisture in the insulation.

Several extruded polystyrene and polyisocyanurate specimens that showed water flow between the insulation and wall were high in moisture content. The high moisture may have been due to water vapor being driven into the insulation from the warm side.

With the exception of the polyisocyanurate specimens and a number of the spray-applied urethane specimens, all types of materials appeared to absorb little water when installed as exterior foundation wall insulation. The moisture content of the insulation was not a function of soil moisture content or soil type. The specimens with high moisture content associated with their sites usually had one or more of three conditions: either the above-grade protective coating was deteriorating or absent; a gap existed between the bottom of the siding and the insulation, allowing moisture to get between the insulation and wall, or the below-grade protective coating was gouged during backfill. Another similarity of the higher moisture-containing specimens was that they were collected from east-facing foundation walls.

Extruded Polystyrene. All specimens of this type were performing well, but not exceptionally better than most specimens of other types of insulation materials.

Mineral Fiber Board. Of the five materials in this study, this one appeared to have the best retention of insulation value as measured by the net R-value per inch (combining the measured dry R-value with the effect of the average moisture content). However, there were so few specimens that broad generalizations about the performance of this material in all conditions cannot be made from this survey.

Molded EPS. The two specimens in this survey, older than any other specimens, had relatively low moisture content. Both of these specimens had an approximately 15% loss of R-value per inch when the the measured dry R-value was combined with the effect of their measured moisture content. However, with only two specimens collected, generalizations cannot be made from this survey.

Polyisocyanurate. One specimen had a higher moisture content, which may have been due to gouges in the protective coating below grade. Even eliminating the outlier, on the average, these specimens had a relatively high net loss of R-value (13.9%). There were so few specimens that broad generalizations about the performance of this material in all conditions cannot be made from this survey.

Spray-Applied Urethane. The quality of the above-grade protective coating used for spray-applied urethane varied widely and the material frequently performed poorly. The paint and/or bitumen was found to be flaking and gouged in most cases, exposing insulation to deterioration. Several specimens had very high moisture contents, resulting in up to a 34% loss of R-value per inch.

It is apparent that spray-applied urethane and faced polyisocyanurate, when exposed to conditions for which there is yet only partial explanation, absorb much more moisture than other materials in this survey. The loss of R-value due to moisture was more than 10% for five of the 35 spray-urethane specimens and 1 of the 4 polyisocyanurate specimens. The higher measured loss of R-value for two polyisocyanurate specimens may indicate an underestimation of the aging effect of this material in this application.

Because outlying data were not included in averages presented in this study, those averages are limited (in addition to the statistical limitations of very small samples) to representing future installations only if conditions that produced the high moisture in the outlying specimens are avoided. This is expected to be a particular challenge for spray-applied urethane because of the high percentage of outliers. Several specimens of both polyisocyanurate and extruded polystyrene were also outliers. It is speculated that some specimens of the other two materials might also be found to have high moisture levels; the size of the sample for this study was just not large enough to discover any outliers.

Assuming that the outlying data reflect problems that would not be found in future installations, these insulation materials appear to perform with minimal loss of R-value per inch in most cases. Combining the average measured R-values with the average moisture contents of the specimens shows an average percent R-value per inch loss for each of these materials. Although with too few specimens collected to generalize the finding, the mineral fiber board had the best retention of R-value per inch. The net loss in R-value per inch of the extruded polystyrene specimens was less than 5%. While again too few specimens were collected to generalize the finding, the net loss in R-value per inch for the molded EPS sample was highest, at about 15%. The total change in R-value of the specimens could not be determined for certain because there was no characterization of the materials as installed.

It should also be noted that the specimens were collected during a relatively dry spring. Although not shown to be true by this investigation, if the insulation moisture content is a function of rainfall, a more normal precipitation year may result in higher moisture content specimens than were found here.

REFERENCES

Dechow, F.J., and Epstein, K.A. 1981. "Laboratory and field investigations of moisture absorption and its effect on thermal performance of various insulations. In: Special Technical Publication 660, pp. 234-260. Philadelphia: American Society for Testing and Materials.

Labs, K., et al. 1988. Building foundation design handbook, Table 7-4. Prepared for Oak Ridge National Laboratory. Available from Underground Space Center, University of Minnesota, 500 Pillsbury Drive SE, Minneapolis, MN 55455.

Schlegel, J.A.; O'Leary, L.A.; and Post, L.K. 1986. Foundation insulation field survey -- final report. Wisconsin Energy Conservation Corporation, 1045 East Division St. #117, Madison, WI 53703; December, unpublished.

ATTACHMENT A
Characteristics of Sites, Soil and Insulation Specimens

Specimen Code	Age yrs.	Thickness inches	Wall dir.	--- Soil --- type	Moisture % by wt.	--- INSULATION --- % wt. loss collection to lab	Density lb/ft^3	Vol. % moist.	R-Value per inch @ % moisture	R-value % loss @ moisture
EP-1	2	1	E	CL	35.3%	6.7%	2.45	0.90%	4.8	3.5%
EP-2	3	1	W	SM	11.3%	1.2%	1.89	0.03%	5.0	0.1%
EP-3	2	2	NW	SM	10.7%	0.1%	1.68	0.01%	5.0	0.1%
EP-4	2	1	N	CL	21.3%	5.1%	2.36	0.71%	4.9	2.7%
EP-5	2	2	N	SM	8.6%	0.8%	2.12	0.01%	5.0	0.0%
EP-6*	4	1 1/2	SE	CL	18.7%	3.0%	1.92	1.44%	4.7	5.5%
EP-7	2	1	W	SM	5.7%	4.4%	1.79	0.05%	5.0	0.2%
EP-8	4	1	N	SP-SM	8.0%	-1.5%	1.80	0.00%	5.0	0.0%
EP-9	4	1	SW	SM	16.4%	2.3%	1.82	0.00%	5.0	0.0%
EP-10	2	2	S	SP-SM	8.4%	1.8%	2.13	0.05%	5.0	0.2%
EP-11	4	2	E	SP-SM	7.7%		1.91	0.63%	4.9	2.5%
EP-12	4	1	W	SM	14.4%	4.9%	1.73	0.37%	4.9	1.5%
EP-13*	3	2	S	SP-SM	5.9%	3.1%	2.14	1.09%	4.8	4.2%
EP-14*	2	1	SE	CL	16.8%	6.0%	2.44	1.32%	4.7	5.0%
MB-1	2		SE	SM	8.9%	-0.4%	6.02	0.16%	4.0	5.3%
MB-2	2		W	CL	22.0%	2.7%	5.49	0.11%	4.0	3.7%
MB-3	2		S	SC	12.7%	-0.1%	6.06	0.04%	4.1	1.3%
ME-1	7	2	NW	SC	10.0%	5.5%	1.36	0.13%	4.0	0.6%
ME-2	6	2	E	SP	4.9%	3.2%	1.17	0.85%	3.7	3.8%
PI-1	2	3/4	NW	SM	12.8%	5.3%	2.24	0.92%	6.8	5.0%
PI-2	2	1 1/2	NE	SM	10.2%	2.0%	1.87	0.68%	6.9	3.8%
PI-3*	2	3/4	NE	SM	11.7%	2.3%	2.15	3.57%	6.0	17.1%
PI-4	2	3/4	NE	SM	10.0%	4.5%	2.25	0.85%	6.9	4.7%
SU-1*	2	1 1/2	N	CL	24.5%	3.2%	2.07			
SU-2*	2	1	NE	CL	17.4%	1.9%	1.94	8.12%	4.4	28.7%
SU-3	2	1 1/2	E	CL	26.4%	2.2%	2.39	1.42%	5.8	6.6%
SU-4	2	3/4	NE	CL	21.6%	77.8%	2.40	1.19%	5.9	5.6%
SU-5	2	1	W	CL	11.5%	2.3%	2.17	0.17%	6.1	0.8%
SU-6	2	2	S	SP-SM	6.5%	8.5%	2.28	1.17%	5.9	5.5%
SU-7	2	1	E	SM	8.9%	-3.3%	2.05	0.03%	6.2	0.1%
SU-8	2	1	N	SM	9.1%	3.0%	2.93	0.09%	6.2	0.4%
SU-9	2	1	S	SM	8.4%	-0.5%	2.48	0.03%	6.2	0.1%
SU-10	2	1	S	SM	11.6%	0.6%	1.77	0.06%	6.2	0.3%
SU-11	2	2	SE	SM	9.5%	1.5%	1.96	0.24%	6.1	1.2%
SU-12	2	2 3/4	SW	SM	11.5%	0.0%	2.02	0.34%	6.1	1.6%
SU-13	2	2	S	SM	9.2%	1.5%	2.05	0.21%	6.1	1.0%
SU-14	2		E	SP-SM	6.6%	0.9%	2.11	1.76%	5.7	8.0%
SU-15*	2		N	SM	7.3%	2.0%	2.07	15.23%	4.1	34.4%
SU-16	2		S	SM	12.3%	32.0%	2.01	0.13%	6.2	0.6%
SU-17	2	1 1/2	E	SP-SM	8.4%	0.6%	3.10	0.12%	6.2	0.6%
SU-18	2	3/4	S	SM	7.8%	2.4%	2.53	0.12%	6.2	0.6%
SU-19*	2	2	NE	SM	9.7%	2.0%	2.57	6.06%	4.8	23.1%
SU-20	2	1 1/4	S	CL-OL	41.5%	1.6%	2.13	0.24%	6.1	1.2%
SU-21	4	1 1/4	E	SC	6.4%	10.4%	2.43	0.24%	6.1	1.2%
SU-22	2	2	W	SP-SM	8.2%	2.0%	2.26	0.34%	6.1	1.7%
SU-23	2		S	SM	10.2%	1.7%	2.10	0.48%	6.1	2.3%
SU-24	2		W	SC	8.1%	3.2%	2.26	0.18%	6.1	0.9%
SU-25	2		E	CL	17.2%	2.5%	2.45	0.70%	6.0	3.4%
SU-26	2		E	SP-SM	8.3%	1.4%	2.22	1.55%	5.8	7.1%
SU-27	2	1	E	SP-SM	9.6%	-0.3%	2.45	2.49%	5.5	11.0%
SU-28	2	1	E	SM	10.3%	2.6%	2.19	1.88%	5.7	8.5%
SU-29	2	2	E	SP-SM	6.5%	3.1%	2.20	0.54%	6.0	2.6%
SU-30*	2	1 1/4	N	SP-SM	8.7%	2.9%	2.56	11.20%	4.5	27.7%
SU-31	4	1	NW	SC	15.2%	1.3%	2.02	0.63%	6.0	3.0%
SU-32	4	1 3/8	SW	SM	6.1%	1.2%	1.90	0.24%	6.1	1.2%
SU-33	3	7/8	NE	SM	12.8%	5.8%	1.98	0.17%	6.1	0.8%
SU-34	4	1	S	SC	11.2%	2.1%	1.97	0.03%	6.2	0.1%
SU-35	4	1	NE	CL	12.1%	5.8%	2.16	0.91%	5.9	4.3%
SU-36	3	3/4	E	SC	14.9%	4.4%	2.45	0.18%	6.1	0.9%

* indicates specimens omitted from averages as noted in the text

Figure 1. *Gap between the bottom of the siding and top of the foundation wall insulation*

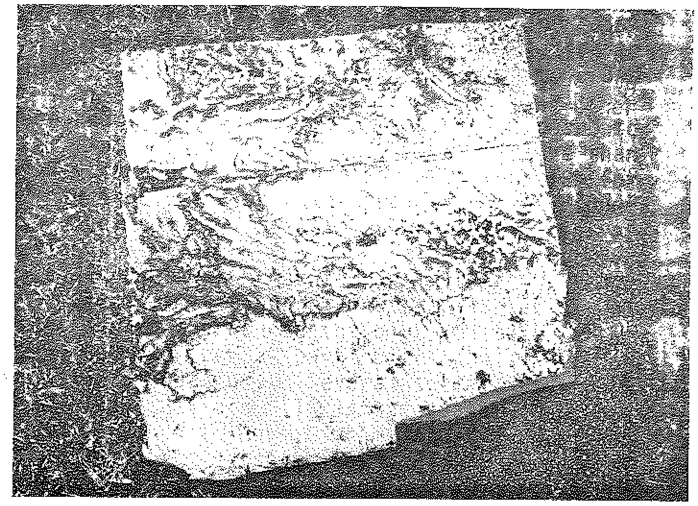

Figure 2. *Evidence of water flow on the side of the insulation sample facing the wall*

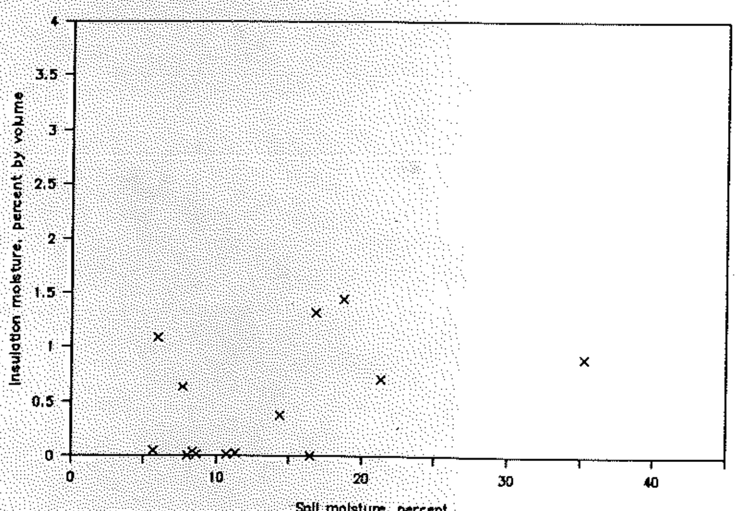

Figure 3. *Insulation moisture content vs. soil moisture content for fourteen extruded polystyrene specimens*

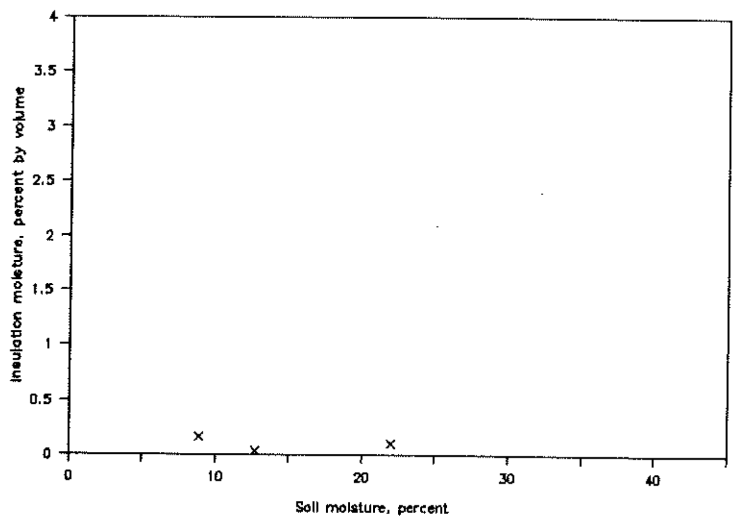

Figure 4. *Insulation moisture content vs. soil moisture for three mineral fiber board specimens*

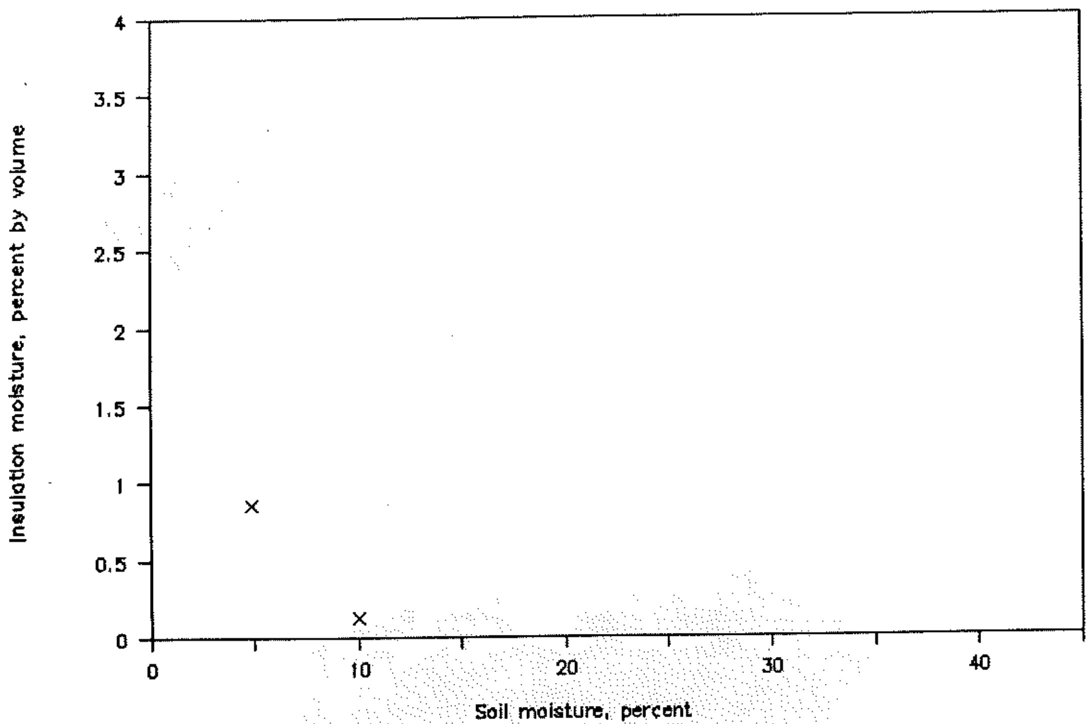

Figure 5. Insulation moisture content vs. soil moisture content for two molded EPS specimens

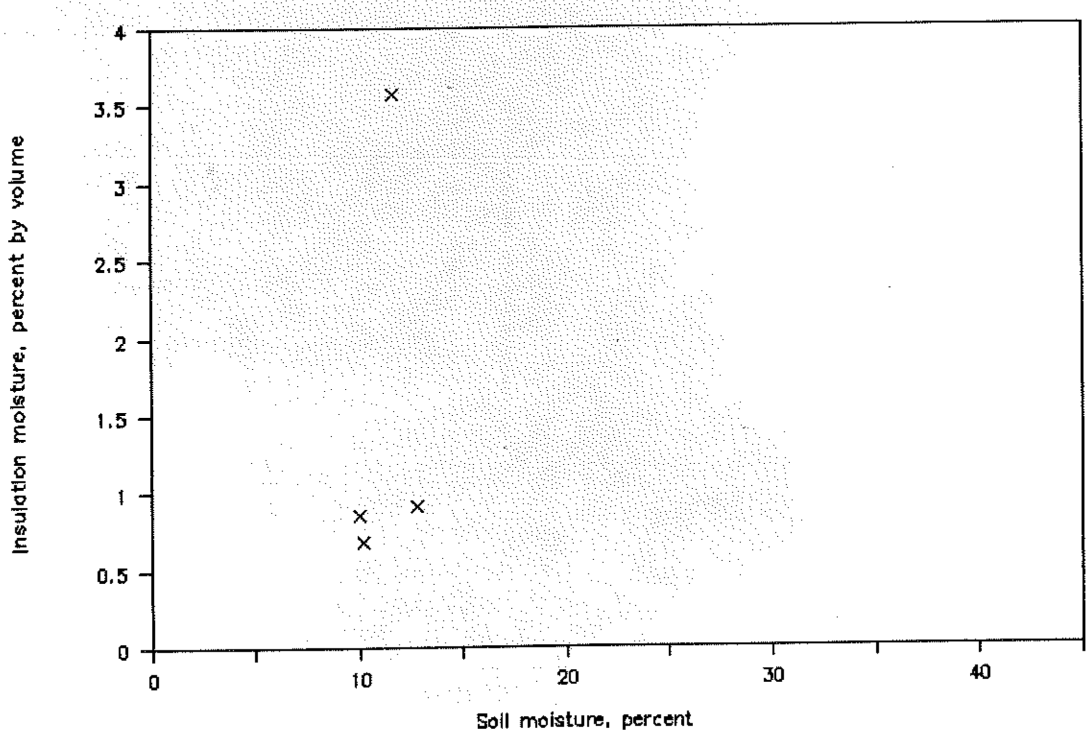

Figure 6. Insulation moisture content vs. soil moisture content for four polyisocyanurate specimens

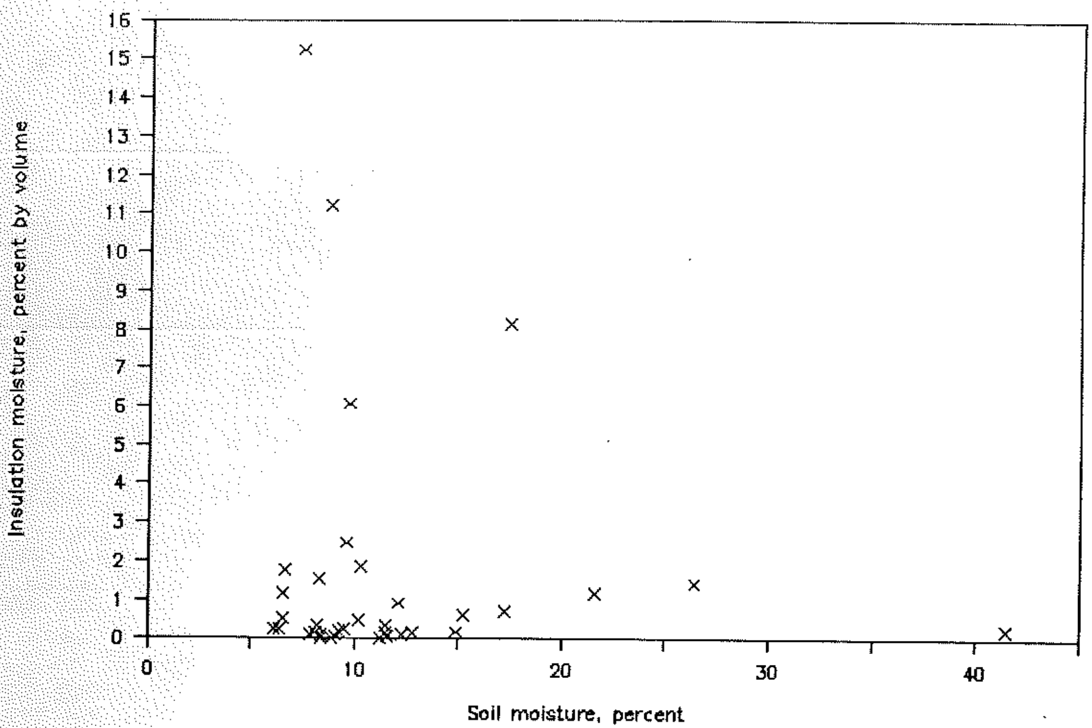

Figure 7. Insulation moisture content vs. soil moisture content for thirty- five spray-applied urethane specimens

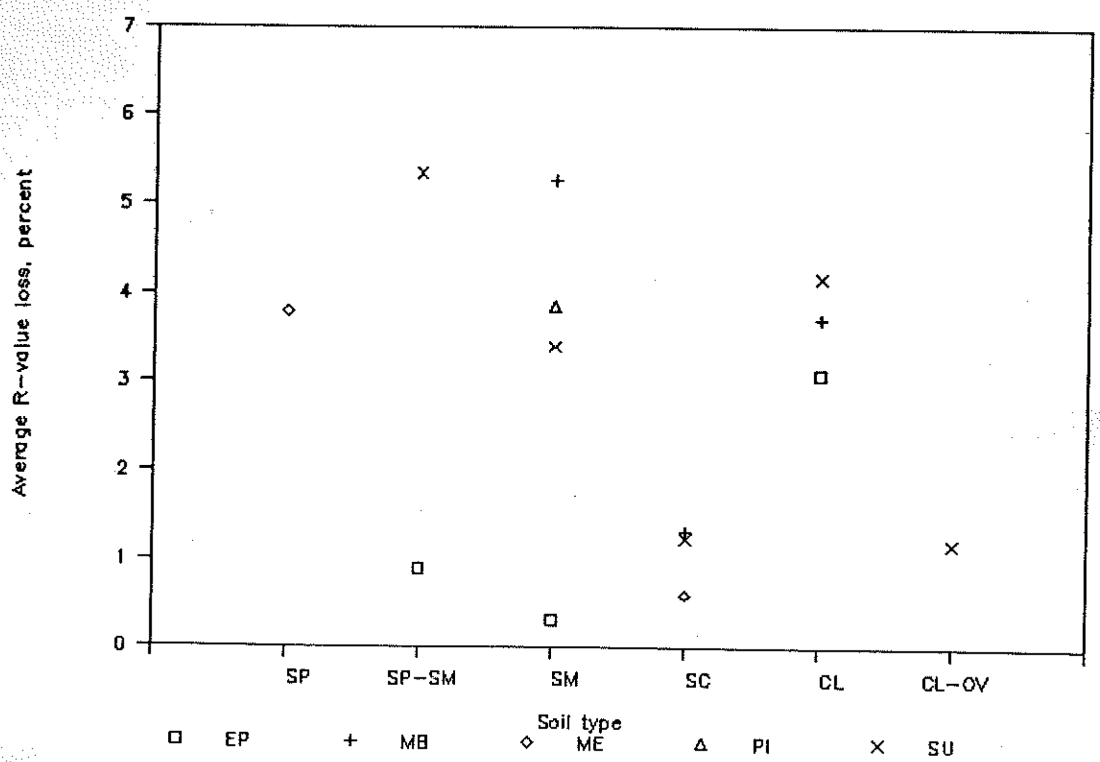

Figure 8. Average R-value loss due to moisture content vs. soil type (nine specimens omitted)