A FIELD STUDY OF MOISTURE DAMAGE IN WALLS INSULATED WITHOUT A VAPOR BARRIER

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ABSTRACT

Considerable uncertainty has existed over whether or not wall insulation installed without a vapor barrier causes an increased risk of moisture damage (wood decay) within walls. This paper describes the results of a study aimed at finding out if such a moisture problem really exists. The exterior walls of a total of 96 homes in Portland, Oregon were opened, of which 71 had retrofitted insulation (three types) and 25 were uninsulated. Field and laboratory test results are presented which show the absence of moisture accumulation, and wood decay fungi, or other indications of moisture damage in the walls of the test homes. Data on shrinkage and settling of insulation are also given, as are results of air leakage measurements by fan depressurization tests. The study concludes that the addition of wall insulation without a vapor barrier does not cause moisture damage in existing homes with wood siding in climates similar to that of Western Oregon. The overall advisability of future retrofitting of wall insulation is discussed.

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1. INTRODUCTION

Weatherization of existing homes is an important part of the current emphasis on energy conservation. The addition of wall insulation is one practice which has been advocated and employed in many cases. The major types of insulation that have been retrofitted include cellulose, mineral wool (rock wool and fiberglass), and urea-formaldehyde foam.

Because insulation is added to existing homes in nearly all cases without a vapor barrier, major questions have increasingly been raised regarding the possible effects of moisture migration through walls on the thermal performance of the insulation and on moisture damage in the wall structure. The theory of moisture condensation in wall cavities has been well documented.[1] In the absence of a vapor barrier, it has been postulated that moisture from the interior of the house tends to migrate through the walls, condense, and accumulate in the wall cavity during cold weather, degrading insulation performance, and creating an environment conducive to fungal decay of wood members when warming occurs in the spring. Because the addition of insulation lowers the temperature of the outer portion of the wall cavity, more condensation is likely to occur in an insulated wall than in an uninsulated one.

Countering this hypothesis, however, are unanswered questions regarding natural drying, quantities of accumulated moisture, and other factors which might tend to mitigate potential moisture problems.

Because of the uncertainty in this area, most utilities in the Pacific Northwest have not been actively promoting retrofitted wall insulation in their weatherization programs. Public energy agencies have also been uncertain in their approach to wall insulation, recognizing its potential conservation benefits but conscious of their responsibility to consider potentially damaging side effects of moisture condensation. The concern extends beyond the Pacific Northwest to other parts of North America as well; the U.S. Department of Energy has considered it a problem of major importance in its assessment of building thermal envelope systems.[2]

It is against this background that the Oregon Department of Energy, with the cooperation of the U.S. D.O.E. and a number of utilities and contractor groups, developed the objectives and specifications for a field study of moisture damage in walls insulated without a vapor barrier. The study was initiated in January 1979, and the walls of 96 homes in the Portland area were opened between February 2 and April 11, 1979, resulting in physical measurements and observations of moisture in wood members and insulation, insulation quality, air leakage rates and other related variables.

2. SELECTION AND DESCRIPTION OF TEST HOMES

2.1 Selection Criteria and Description of Sample Population

The initial study design proposed a total sample group of 96 homes distributed evenly in four groups of 24 test homes representing three commonly-used wall insulation types and a control group of uninsulated houses. Each group of 24 was to be subdivided into 12 homes having "ducted" heating systems, defined as any combustion system or any electric forced air system with ducts outside the heated space, and 12 homes having "non-ducted" heating systems. Other criteria included requirements that all homes with insulated walls were to have been retrofitted without a vapor barrier, that the insulation was to have been in place at least three years, that all homes had a crawl space equipped with a ground cover, and that all homes have less than 121 sq.m. (1300 sq.ft.) of floor space and be occupied by three or four persons.

As the home solicitation and selection process got under way, it quickly became apparent that the initial criteria could not be met if the total sample population of 96 homes was to be attained. The criteria were successively relaxed in order to allow wall openings to continue on schedule and complete the field work by early April. The final sample selected for analysis consisted of 93 homes, after data from 3 homes was discarded for various quality control reasons. Characteristics of the 93 homes are summarized as follows:

a) Distribution among insulation types:

Uninsulated	25
Urea-formaldehyde foam	43
Cellulose	10
Mineral wool	15
	93

b) Of the entire sample population only eleven homes were non-ducted, while 82 had ducted systems. The test home solicitation process demonstrated one intuitively assumed characteristic of Portland's housing stock - that the vast majority of uninsulated and retrofit-insulated homes are older homes heated with gas (27) and oil (52); 53% of the homes were between 20 and 40 years old, while 40% were over 40 years old. The majority of electrically heated (unducted systems) homes are newer units built originally with wall insulation.

c) All insulated homes were retrofitted at least 3 years prior to the study. The average age of the insulation is shown below.

Age(yrs)	U-F	Cellulose	Mineral Wool
3-5	79%	90%	53%
6-9	16%	-	20%
GT10	5%	10%	27%

d) All homes had no vapor barrier on the inside wall surface, such as plastic sheet, aluminum foil, or any kind of wallpaper. All except one home had wood (or wood and brick) exterior siding. Most all had a 15# felt moisture barrier just inside the siding. The majority had lapboard sheathing, but 12 homes had plywood sheathing.

e) 75 homes had full or partial basements and 29 homes had heated basements. Among the 37 homes with a full or partial crawl space were 11 homes without ground covers in the crawl spaces; they were included as a means of testing for overt moisture effects of not having a ground cover.

f) No limitations were placed on the number of occupants. The average sample home was occupied by 3 persons, with 93% housing 4 or fewer persons.

g) No limitations were placed on size of home; however, 88% had 204 sq.m. (2200 sq.ft.) of living area or less, while 57% of the test homes had less than 135 sq.m. (1500 sq.ft.)

An additional group of factors with direct bearing on energy consumption and moisture accumulation were identified in the course of the study.[3] Taken together, they provide a profile of the typical Portland study test home as one which:

- had ceiling insulation and storm windows but no underfloor insulation
- had weather stripping around doors but not around windows
- did not have air conditioning
- had a fireplace or wood stove in use

2.2 Solicitation and Qualification of Test Homes

A total of over 40,000 introductory letters and questionnaires were sent out. Of these, a total of 1766 responses were received, from which the quotas were satisfied.

Initial contact with potential participants was made in a letter describing the project and its purpose and soliciting participation. Accompanying the letter was a questionnaire aimed at providing initial information about the house.

As questionnaires were returned, the project coordinator screened them for conformance with study criteria. The owners of homes appearing to qualify were interviewed by telephone to obtain more information and, for those homes continuing to meet criteria, to make an appointment for a personal interview and initial house inspection.

The preliminary survey was conducted by an interviewer and an engineer. The interviewer noted physical characteristics of the house and lifestyle patterns of the occupants that related to energy use and potential moisture accumulation. The engineer thoroughly inspected the house to confirm questionnaire responses and note signs of moisture damage. The results of the visual inspection and/or homeowner interviews thus identified exterior signs of possible moisture or rot (e.g., blistered paint, warped siding, and termite or dry rot damage).

In addition, the relative moisture content of the walls was assessed to determine wall opening locations in regions of the highest moisture content. The moisture content was checked from the inside of all outer perimeter walls using RF (radio frequency) surface-type moisture meters. The objective in selecting locations for openings was to find the highest moisture levels that were not affected by physical leakage of water. Oftentimes while checking for high moisture content, high readings were found to be caused by leaks. No openings were made in those areas. When no regions of relatively high moisture content were discerned with the instruments, an effort was made to make openings in walls with exterior signs of moisture, or in high moisture production rooms such as bathrooms and kitchens, or on north walls where moisture might most likely accumulate.[4] However, other factors such as accessibility, visibility, ease, or homeowner desires often became important when relatively high moisture content or damage were not found. Two main sites with different orientations were selected for the opening crew. Two homes, and sometimes three, were scheduled for opening each day.

3. METHODOLOGY

3.1 Field Test

The walls of each test home were opened from the outside in the two locations selected during the initial house inspection. At each main location two openings were made - one near the first story ceiling height just below the upper plate and one near the floor just above the lower plate. Each opening was about 0.4 m (16 in) wide (one stud space) and about 0.3 m (12 in) high. The carpenter carefully removed the exterior siding and then cut through the exterior moisture barrier (typically 15# felt) and the wood sheathing (typically 1x8 lapboard or plywood).

The data collection and recording was actually begun while the carpenter opened the wall. Indoor and outdoor dry and wet bulb temperatures were measured, and the corresponding indoor and outdoor relative humidities were found from a psychometric chart.

Immediately upon opening each hole, a sample of insulation was removed and sealed full in a 100 ml glass jar. The sample was removed quickly to avoid any change in its moisture content and treated carefully to avoid contamination with skin or other moisture. The samples were later gravimetrically analyzed in a laboratory for moisture content. The next step was the measurement of the surface and interior temperature of the plate, one stud, and the inside of the sheathing. A digital thermometer was used to determine the wood temperatures, which were required to correct the moisture content readings obtained directly from a moisture meter. The wood moisture content of the plate, stud, and sheathing was then measured using a penetrating resistivity-type moisture probe with insulated pins. Measurements at both the surface and the interior of the wood were made. To check the moisture meter readings, wood samples were chiseled from the edge of the plate, stud and sheathing, then wrapped tightly in plastic film and sealed in a glass jar; their moisture contents were later gravimetrically analyzed. Finally, wood core samples were taken from the plate, stud, and sheathing with a simple leather punch. The samples, about 5 mm (3/16 in) in diameter and 6 mm (1/4 in) long, were sealed and stored in plastic straws and refrigerated until they were cultured in a laboratory to determine if decay fungi were present.

During the time the walls were opened and closed at many of the test houses, a fan depressurization unit was installed in a doorway and the house slightly depressurized. By varying the pressure drop across the fan at known fan speeds, a measure of the air leakage characteristics of a house was ascertained.

3.2 Laboratory Analysis

One sample of insulation and three wood samples for each wall opening were analyzed gravimetrically for moisture content by placing in an oven at 100°C (212°F) and drying to a constant weight. Three wood core samples from each hole were also bioassayed to determine if decay fungi were present.

3.3 Statistical Analysis

Data files were created using all physical and lifestyle data from the preliminary interview and inspection, wall openings, and laboratory tests. Frequency distributions of each variable were produced as a means of profiling test homes. Bi-variate tests of correlation and significance were made to identify significant relationships among variables. Factor analysis and multiple regression analysis were employed as a means of explaining relationships between moisture and other variables.

4. RESULTS

4.1 Wood and Insulation Moisture Contents

4.1.1 Field Results. Valid data was obtained from 93 of the 96 test homes. In each wall opening the wood moisture content of the plate, sheathing and stud both on the surface and in the interior was measured using a moisture meter. The moisture readings were corrected for temperature and for use of the meter with two insulated electrode pins rather than four. No correction was made for type of wood, since most of the wood tested was Douglas fir.

The results for the corrected wood moisture content are presented in Table 4.1. The mean values for all stud, plate, and sheathing measurements were 11.6%, 11.9% and 12.1%, respectively. The average upper hole moisture content of 11.4% was slightly lower than the

12.2% average of the lower holes. Holes with a north orientation averaged 12.1%, those with south exposure averaged 11.4%, while those with east-west facings averaged about 11.9%; these differences are in agreement with Duff's results.[4] In addition, the interior values were consistently about one percent higher than the surface values. This appears consistent with the fact that wood generally has a higher interior moisture content. The overall wood moisture content mean was 11.8%. For reference purposes, air-dry wood typically has 12 to 15% moisture content,[5] and framing members in the Northwest typically fall in the range of 10 to 12%.[6,7]

Of major importance in this study is the fact that there were very few readings of high moisture content. Moisture content of about 20% or higher is generally required before decay will occur (as well as temperatures greater than about 24°C (75°F).[5] Yet no readings greater than 20% were found out of 1559 readings. The highest instrument measured moisture content was 20%, and that occurred in only one case.

It is important to note that the data from 22 holes (12 houses) out of 372 holes was voided and not presented in Table 4.1. In each of those cases, some type of water leak, such as a roof leak or gutter leak or bathroom leak, was found that might have biased the data. Those leaks were discovered after making the wall openings; they had not been noted during the initial home inspection when opening sites were determined. In some, but not all, of these leak cases, high moisture content and/or moisture damage was found. Moisture contents in those situations ranged as high as 30% in one case where the sheathing was soaking wet; however, in all other cases the highest reading was 23%. Leaks were found in homes with all insulation types as well as uninsulated homes. It should also be reiterated that numerous other leaks were found when the RF surface type moisture meter was used to select opening sites. No openings were made in those leaky locations.

4.1.2 Laboratory Results. Wood and insulation samples were taken during the wall openings for laboratory analysis of their moisture content. The wood samples were analyzed as a check of the moisture meter used in the field tests. The wood moisture content results are noted in parentheses in Table 4.1. The two sets of results are in good agreement, with the laboratory results consistently slightly lower than the field results. There are two likely explanations for that behavior. First, the moisture content readings were always made in the field as soon as the wall was opened and exposed to the cool day outside air. The wood samples were taken some 5 to 10 minutes later, and some drying due to vapor loss to the air might have occurred prior to removing the sample. Moreover, the moisture meter tends to read the highest moisture content in the area between the probe pins.

It should be noted that the maximum moisture content values determined from the wood samples exhibited more scatter than the corresponding meter readings. However, only six samples out of the total of 896 had a moisture content equal to or greater than 20%. It is believed that the two large values of 30% and 31%, and perhaps others, must be in error because wood with that high a moisture content would be notably wet, and such was not the case. The samples might somehow have been contaminated or incorrectly measured. The meter readings are generally more consistent and would appear to be more valid.

The results of insulation moisture analyses are presented in Table 4.2. No results are presented for those holes invalidated because of leaks. Only two samples out of the 242 total had a moisture content of 20% or higher; those values were 20% and 22% and occurred in U-F foam. There were no significant differences among insulation moistures as far as orientation and topness or bottomness of holes is concerned.

One of the more interesting results is the extremely low average moisture content of the mineral wool insulation. Each house had consistent results in all four holes, and in no case was moisture content above 2%. These results are in excellent agreement with those obtained by Weidt,[8] who removed four samples of mineral fiber insulation from wall openings and found them to have less than 1% moisture content. Probably the result is attributable to the fact that mineral wool is not hygroscopic, whereas the cellulose and U-F foam both tend to retain moisture. Weidt[8] also found the moisture contents of six samples of cellulose and twelve U-F foam samples taken from homes in Minnesota. The results from a re-evaluation of his data indicate very close agreement with the results of this study.

4.2 Moisture Damage

4.2.1 Types. Prior to opening any walls, a number of possible types of moisture damage were anticipated, including actual wood decay inside and outside the wall cavity, warped siding and/or dry wall, blistering and peeling paint, wood staining or discoloration, evidence of mold or mildew, termite or ant activity, corroding and rusting of nails and wire, and leaks around water, sewer and electrical connections. Later, the complete house and the opened walls were inspected for signs of the above.

4.2.2 Visual Observations. During the initial home inspection and interview, a relatively large number of possible moisture damage indicators were found in a number of homes. The frequencies of occurrence are presented in Table 4.3. As noted earlier, during the wall openings a number of wall cavities were found to be adversely affected by a variety of leaks rather than by the addition of insulation. In many of those cases a number of the above-noted types of exterior moisture damage were observed. Even in those cases, however, there was relatively little actual wood decay. For those wall openings where leaks had not occurred, there was essentially no evidence of high moisture or moisture damage within the wall cavities, although there were numerous suggestions of moisture damage outside the wall cavities. Thus, there was no correlation between external signs of damage and the existence of moisture damage within the cavities. There was no visual evidence that the addition of wall insulation in existing homes leads to moisture damage inside or outside the wall cavity. In fact, just the opposite may be true. Comparison between insulated homes and uninsulated homes of the occurrence of pre-opening signs of moisture problems indicates that evidence of moisture in the attic, blistering paint, and previous moisture problems were found less frequently in the homes with insulation than in those without. There was no significant difference in the frequency of occurrence of the other signs noted in Table 4.3.

4.2.3 Presence of Decay Fungi. Since decay fungi must be present in order for wood decay to occur, three wood core samples from each hole were taken for a laboratory bioassay (culturing) to determine if decay fungi were present or absent. Of the 1071 wood core samples, only two had decay fungi present. One was found in the upper hole sheathing of a U-F foam home, while the other was in the stud of an upper uninsulated hole. In neither case were there any signs of high moisture or moisture damage. However, other non-decay fungi and bacteria were commonly present in the samples.

4.4 U-F Foam Shrinkage and Voids

U-F foam shrinkage in thickness (nominal 0.09 m (3-5/8 in)), width (nominal 0.37 m (14-1/2 in) cavity spacing between the studs), and height (nominal 2.44 m (8 ft)) was measured. The results for thickness and width are given in Table 4.4. The mean thickness shrinkage from 32 homes was 10.5%, while the mean width shrinkage from 41 homes was 8.1%. The width shrinkage is in very close agreement with the average value measured in a National Bureau of Standards test house after a period of 26 months.[9] However, Weidt[8] measured shrinkage in twelve samples (average age of 1.85 years) and found an average value of 4.5% with a range of 2.5 to 9%. Eighty percent of the Portland U-F foam samples were 3 to 5 years old, with the remainder older.

An attempt was made to measure shrinkage in the vertical direction as well as in width and thickness. However, it was difficult to distinguish between actual shrinkage and a possible void at the top of the wall cavity due to incomplete filling. Sometimes it was clear that only shrinkage had occurred; in those roughly two dozen cases the vertical shrinkage was about 8%. However, because the full height of the wall cavity was not opened, it was impossible to tell if the foam had any horizontal cracks in it in between the upper and lower holes. Such cracks would mean even larger shrinkage than that measured. Since such cracks were sometimes seen in the opened holes, it was decided not to tabulate the vertical shrinkage results because of the uncertainty in their interpretation. Moreover, it should be noted that in a number of cases no insulation was visible upon opening the upper hole. That was due both to shrinkage and filling voids (because of shrinkage the insulation usually dropped to the bottom of the wall cavity).

Shrinkage and cracking can have a considerable effect on the performance of U-F foam wall insulation. Because shrinkage is known to occur, the U.S. Department of Housing and Urban Development has derated the nominal R-value of U-F foam by 28%,[10] and the Canadian government has derated it by 40%.[11] Vinieratos[12] has reported that a 10% linear shrinkage corresponds to a roughly 70% increase in heat loss with nominal 0.09 m (3-1/2 in) thick insulation. Such an increase is considerably greater than would be expected based only on the reduced insulation area, and is in part due to the development of convection loops within the wall cavity.

4.5 Observations of Installation Quality and Settling

Generally speaking, the quality of insulation installation was poorer than expected, independent of type of insulation. Numerous empty cavities between studs were observed in many insulated homes. Improved quality control on the part of installers would appear to be needed. The fact that cavities are not all filled reduces the expected insulated wall performance considerably,[12] and yet that reduction is seldom accounted for.

Some settling or incomplete filling of cellulose or mineral wool was also observed. Of the twenty upper holes of the ten cellulose houses, eight had upper plates that were clearly visible. Of those, one cavity was totally void, and another in the same house was void in the top 0.46 m (18 in). This appeared to be a case of incomplete filling. Of the other full cavities, the cellulose was tight up against the top plate.

Of the thirty holes in the fifteen mineral wool homes, twelve had the top of the insulation and the upper plate clearly visible. Of the twelve, three cavities were partially void in the top or had settled by 0.05, 0.08, and 0.5 m (2, 8 and 2 in), respectively. In the last case, an adjacent cavity was full, suggesting that the partially void cavity might not have been filled completely. Once again, the others were filled right to the top, suggesting that the other cavities with voids or settling might have been incompletely filled. Numerous cases were also observed where U-F foam was clearly incompletely filled in wall cavities.

4.7 Fan Depressurization Air Leakage Tests

In an effort to determine if the relative air tightness or leakiness of a home was an important moisture parameter, air leakage measurements were made using a door-type fan depressurization unit.[13] Each of the homes was depressurized by adjusting the fan speed (and hence the flow rate) to produce preselected values of pressure drop across the door. Using a calibration curve, the volumetric flow rate in cubic meters per hour (cu.m/hr) at a standardized pressure drop of 50 Pa (0.2 in H_2O) was determined for each house. Then knowing the volume of each house, the number of air changes per hour was determined for each of the 71 houses tested. While many houses were not tested because the owner could not be home during the daytime, a few others were not tested because one or more large leaks were present, such as a fireplace flue without a damper. The cu.m/hr values ranged from 3,161 to 17,114, with a mean value of 5485 cu.m./hr. The number of air changes per hour at 50 Pa ranged from 5.4 to 37.5 with a mean value of 16.2/hr. The mean value for these relatively old houses is slightly higher than the average value of 13.3/hr found for four detached houses in Twin Rivers, New Jersey.[13] However, similar tests on Swedish tract housing built in the seventies and employing plastic vapor barriers produced exchange rates of 1-6/hr with an average value of 4.5/hr.[14] Moreover, the current Swedish standard for detached houses built after July 1978 is 3.0/hr maximum, thus requiring continuous plastic vapor barriers as an effective energy conservation measure.

While no statistically significant correlation was observed between the measured air leakage rates and the moisture content of either wood or insulation, there was a considerable difference between the air leakage rates associated with insulated and uninsulated homes as well as between insulation types (see Table 4.5). The addition of wall insulation appears to substantially reduce air leakage and its associated energy loss. However, these results may be due to differences in the characteristics of the selected homes. Unfortunately, tests of air leakage before and after retrofitting wall insulation were not possible. If the interpretation is correct that adding wall insulation reduces infiltration losses, then the results indicate that a substantial portion of the infiltration loss in a home is through the walls. Moreover, it would appear that cellulose reduces air leakage the most and mineral wool the least, although mineral wool appears to provide a substantial reduction relative to air leakage in uninsulated homes. That result seems reasonable in light of the porosity and shrinkage of those materials.

5. APPLICABILITY OF RESULTS

A number of questions have been addressed[3] regarding the applicability of the results from tests of homes in Portland, Oregon, during the 1978-1979 winter. Results of an analysis[3] suggested that condensation could have occurred in the insulated walls of the test homes well over 50% of the hours during the winter. Moreover, the 1978-79 winter was found to be more or less typical. In addition, it was determined that because of similarities in climate and housing characteristics, the test results of this study should be applicable throughout the western section of the Pacific Northwest. They should also apply to other areas of the country with similar weather conditions (ASHRAE Condensation Zone III[1]) and housing characteristics. Portland has about 4700 heating degree-days and an average winter temperature of 8°C (46°F).

6. CONCLUSIONS

6.1 Moisture Damage Conclusions

The purpose of this study was to determine scientifically and objectively if the addition of wall insulation without a vapor barrier caused moisture damage (wood decay) in existing homes in the western portion of the Pacific Northwest. The fact that virtually no incidence of high moisture content, moisture damage or decay fungi was found inside the walls of homes with wood siding opened during this field study strongly suggests that there is no such problem. While moisture damage was found in both insulated and uninsulated walls, it was always caused by a leak of one sort or another. There were a fair number of indicators of moisture damage on the exterior of the walls, but there was no corresponding damage inside the wall cavities.

An analysis of the opportunities for condensation to occur in the insulated walls of the Portland test homes during the test winter and in previous winters was conducted, and condensation could have occurred during over 50% of the winter season hours. Moreover, the field test results and conclusions should apply throughout the western portion of the Pacific Northwest as well as in other parts of the country with similar weather conditions (Condensation Zone III). It is not obvious that the results of this study can be extended to colder climates.

These field test results suggest that it is not necessary to add a vapor barrier when insulating the walls of existing homes in the Pacific Northwest. However, it should be emphasized that continuous plastic vapor barriers are beneficial in newly constructed homes to keep insulation dry so it can provide its maximum thermal benefit and to substantially reduce infiltration losses and save energy - especially since in well-insulated homes infiltration losses can be the major source of energy loss.

6.2 Retrofit Insulation Characteristics

U-F foam shrinkage was measured in thickness, width and height and found to be considerable - averaging about 9-10% linear shrinkage. Such shrinkage may have a significant deleterious effect on the thermal performance of walls insulated with foam; 10% shrinkage has been cited to correspond to about a 70% increase in heat loss from a conventional 2 x 4 wall.

In addition to shrinkage, the quality of installation of all types of insulation was found to be poorer than expected, with numerous partially or completely empty cavities between studs observed. Such insulation voids, like shrinkage, also cause a notable reduction in thermal performance relative to a fully insulated wall. Thus, the effect should be more thoroughly investigated. In addition, a few instances of what appeared to be incomplete filling, rather than settling, or shrinking, were also observed in the installation of cellulose and mineral wool.

6.3 Air Leakage Tests

Air leakage tests were run on 71 of the test houses using a door-type fan depressurization unit. The number of air changes per hour determined at the standard pressure differential of 50 Pascals ranged from 5.4 to 37.5 with a mean value of 16.2/hr. That mean value generally agrees with values measured elsewhere in similar homes using essentially the same test equipment, but it is considerable larger than the current Swedish standard of 3.0/hr maximum that requires continuous plastic vapor barriers as an effective energy conservation measure.

A possibly important finding of the study is that, based on a comparison of air leakage rates of 18 uninsulated homes and 53 insulated homes, the addition of wall insulation appears to significantly reduce air leakage. Thus, the energy loss associated with infiltration would be reduced. That would appear worthy of further study to determine how it affects the cost effectiveness of wall insulation.

6.4 Overall Desirability of Retrofitting Wall Insulation

The findings and conclusions of this field study appear to resolve the question of possible moisture damage associated with the addition of wall insulation in existing homes without a vapor barrier, at least for most homes in the western region of the Pacific Northwest. However, the advisability of retrofitting wall insulation is still not completely settled since numerous other problems exist, and many questions are yet unresolved. Of major importance is the fact that the effect of moisture migration on the thermal performance of wall insulation is still not well understood. While settling appears minimal, incomplete filling of all types of insulation in wall cavities is a critical problem that strongly influences the overall performance of insulated walls. The performance of U-F foam is further degraded to a considerable extent because of the existence of voids due to shrinkage.

In the face of these and other problems, the present study can offer no firm guidance on the ultimate question of whether retrofitting wall insulation is worthwhile. That moisture damage is no problem (at least in the western region of the Pacific Northwest) seems clear; that some insulation types are preferable to others is also evident. Pending further studies of the questions outlined above, however, the effectiveness of retrofitted wall insulation can appropriately be considered an open question.

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8. ACKNOWLEDGEMENTS

This project is indebted to a number of state and federal agencies, public and private utilities, and contractor organizations for financial support. Special thanks must go to the Oregon and U.S. Departments of Energy. The families in the test homes must especially be thanked for making this study possible.

TABLE 4.1 WOOD MOISTURE CONTENT IN WALL OPENINGS

			Moisture Content (%)			
Hole No.	Wood Member	Valid Readings	Ave.	Max.	Min.	Number of Readings MC 20%
-1	Stud Surface	89(87)	11.5(11.0)	16(18)	6(4)	0(0)
	Stud Interior	88	12.1	16	7	0
	Plate Surface	88(86)	11.6(11.2)	17(20)	8(8)	0(1)
	Plate Interior	88	12.6	17	7	0
	Sheathing Surf.	70(71)	11.9(11.3)	18(16)	7(7)	0(0)
	Sheathing Int.	2	14.5	16	13	0
-2	Stud Surface	89(89)	10.7(10.2)	17(19)	6(8)	0(0)
	Stud Interior	88	11.6	16	8	0
	Plate Surface	59(54)	10.8(10.0)	15(14)	8(7)	0(0)
	Plate Interior	57	11.7	16	8	0
	Sheathing Surf.	72(72)	12.0(11.1)	18(30)	8(7)	0(1)
	Sheathing Int.	2	14.5	15	14	0
-3	Stud Surface	87(85)	11.9(11.1)	19(23)	7(8)	0(2)
	Stud Interior	87	12.7	19	9	0
	Plate Surface	85(82)	11.8(10.9)	20(15)	8(8)	1(0)
	Plate Interior	85	12.6	20	9	1
	Sheathing Surf.	70(68)	12.4(11.3)	18(20)	6(7)	0(1)
	Sheathing Int.	3	12.3	15	11	0
-4	Stud Surface	89(87)	11.0(10.4)	16(31)	8(7)	0(1)
	Stud Interior	88	11.6	17	7	0
	Plate Surface	51(44)	11.1(9.9)	15(13)	7(7)	0(0)
	Plate Interior	47	11.8	16	9	0
	Sheathing Surf.	72(71)	11.9(10.7)	18(19)	6(6)	0(0)
	Sheathing Int.	3	13.0	15	11	0

Note: The values shown without parentheses were obtained from the moisture meter, whereas the values in parentheses were obtained from laboratory analysis of wood samples taken from corresponding locations.
-1 and -3 are at bottom of wall cavity.
-2 and -4 are at top of cavity.

TABLE 4.2 INSULATION MOISTURE CONTENT

Insulation Type	Number of Samples	Moisture Content (%) Avg	Max	Min
Mineral Wool	50	0.1	2	0
Cellulose	30	13.4	18	6
U-F Foam	159	11.7	22	6

TABLE 4.3 PRE-OPENING SIGNS OF POSSIBLE MOISTURE PROBLEMS

Category	Frequency of Occurrence in Homes (%)
Evidence of discoloration and/or staining in attic	15
Warping of siding and/or dry wall	27
Stained interior and/or exterior surfaces	34
Blistering and peeling of paint	39
Evidence of mold or mildew	33
Evidence of ant or termite activity	10
Evidence of dry rot - wood decay	17
Corroding & rusting of nails, wire, etc.	1
Foundation cracks	31
Leaks around water, sewer and electrical	11
Previous moisture problems	46

TABLE 4.4 U-F FOAM SHRINKAGE

Shrinkage Direction	Hole Number[1]	Cases	Shrinkage (%) Avg.	Max.	Min.
Thickness	-1	25	10.0	21	3
	-2	18	10.6	17	3
	-3	20	11.0	25	3
	-4	15	10.9	25	3
	All	78	10.5	25	3
Width	-1	35	8.0	19	3
	-2	21	8.3	12	3
	-3	32	7.6	16	4
	-4	21	8.9	14	3
	All	109	8.1	19	3

[1]Hole designations: -1, -3 holes at bottom of cavity
-2, -4 holes at top of cavity

TABLE 4.5 DEPRESSURIZATION FAN TEST AIR LEAKAGE RESULTS

	Air Leakage @ 50 Pa	
	cu m/hr	air changes/hr
All Homes (71/93)[1]	5485	16.2
Uninsulated Homes (18/25)	7163	18.7
All Insulated Homes (53/68)	4916	15.2
Mineral Wool Homes (10/15)	6065	16.4
U-F Foam Homes (35/43)	4730	15.2
Cellulose Homes (8/10)	4292	13.6

1 The first number in parentheses is the number of homes tested; the second is the total number of homes in the given category. For example, 18 out of 25 uninsulated homes were tested for air leakage.