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Measurement of Water Vapor Migration and Storage in Composite Building Construction

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ABSTRACT

The moisture and thermal performance of a typical insulated wood-framed residential wall structure was investigated in the laboratory. The study included the effects of three types of vapor retarder systems and the effects of zero, positive, and negative total pressure differences across the wall. Exposure conditions were representative of a northern winter climate.

Three types of vapor retarder systems were included in the study: polyethylene film ("excellent"), flat latex paint ("poor"), and polyethylene film plus an electrical receptacle ("point-source defect"). The effects of air infiltration and exfiltration were investigated by imposing various negative and positive pressure differences on the wall structure.

Overall time rates of moisture gain (or loss) were measured by weighing the test wall structure daily. Periodically the test wall was disassembled and the amount and location of the accumulated moisture determined. Thermal performance changes were measured by observing changes in the temperature gradient through the insulation layers.

INTRODUCTION

The problem of moisture behavior in building envelope components is one that has been universally recognized as having serious consequences in terms of both performance and durability. Many investigations have been made concerning various aspects of the performance of building materials under moist conditions. Chapter 21 of the ASHRAE Handbook - 1981 Fundamentals, "Moisture in Building Construction" (ASHRAE 1981), contains many references and a comprehensive bibliography. In spite of this, the BTESIM advisory committee reviewing the NPP felt in Comment 13 that "the NPP is deficient in its planned research on the effect of moisture on envelope components and HVAC systems", and that even more detailed investigations were required (Stamper 1980).

Many previous studies of the thermal and moisture performance of wall structures have been oriented toward the role of the vapor retarder (formerly called vapor barrier). Another factor affecting the overall moisture and the thermal performance of a wall structure is the total pressure difference across the wall. Previously, this factor seems to have received insufficient attention.

When the total pressure difference across a wall structure is zero, moisture enters by the mechanism of gas diffusion under the influence of a water vapor partial pressure difference. However, when the wall structure experiences a positive total pressure differential, as might be caused by wind or temperature, there can be concurrent mass movement of moist interior air into the wall structure (exfiltration), in addition to the diffusion of water vapor. Conversely, when the wall has a negative total pressure

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differential, the mass movement of the air (infiltration) is countercurrent to the direction of the diffusion. Practical experience, especially in Canada (Latta 1976), has shown that the moisture effects of total pressure differentials can be much more significant than those resulting strictly from diffusion.

The objective of this investigation was to study the migration and accumulation of water vapor and its effect on the thermal performance of a typical insulated wood-framed residential wall structure under various conditions of vapor retarder (barrier) and total pressure differential. It was expected that total pressure differentials, causing air exfiltration or infiltration, might have a marked effect on the moisture accumulation rate and related thermal performance within an insulated wall structure.

The three constructions of water vapor retarder system investigated were:

1. "Excellent" vapor retarder (such as polyethylene film).

2. "Poor" vapor retarder (such as painted gypsum board).

3. "Point-source defect" in the vapor retarder (such as an electrical outlet).

Three total pressure differentials across the wall structure were investigated for each vapor retarder system:

1. Zero.

2. Positive (causing air exfiltration).

3. Negative (causing air infiltration).

INVESTIGATION

Test Wall

The same basic wall structure was utilized for all three test series. It was 5 by 10 feet (1.5 by 3.0 m) and constructed of nominal 2 by 4 wood stud members (1.5 by 3.5 in, 38 by 89 mm actual), 16 in (406 mm) on center. It was insulated with a series of seven layers of mineral fiber insulation batts, each 0.5 in (13 mm) thick, of about 0.9 lb/ft^3 (14 kg/m^3) density, to make up the required 3.5 in (89 mm) total thickness. Multiple layers of insulation were chosen to allow a careful examination of the material for uniformity and to permit the insertion of thermocouples between layers to measure the temperature gradient. The individual pieces of insulation were carefully selected after "light-box" examination to insure uniformity of density.

Thermocouple temperature sensors were placed between each of the insulation layers in the center portion of the test wall structure. This permitted measurement of changes in the temperature gradient through the wall structure, during the progress of a test. The insulation layers at the warm side of the wall structure (which were expected to remain free of condensed moisture during the test) were utilized as heat flow transducers for monitoring overall heat flow through the structure. By careful selection of the insulation pieces, this method can be utilized to provide a useful estimate of the heat flux.

The warm or interior surface of the wall structure consisted of 0.5 in (13 mm) gypsum board, with joints taped. The cold or exterior surface of the wall structure consisted of 0.5 in (13 mm) asphalt-saturated wood fiberboard sheathing, nailed to the framing. The siding was prefinished noninsulated aluminum siding, installed with no intentional airspace between the sheathing and the siding. However, joints in the siding would be expected to make it somewhat permeable, as is typically the case with field construction.

For Test Series I, an "excellent" vapor retarder system was achieved by installing 4 mil (0.004 in ; 0.1 mm) polyethylene film under the gypsum board interior surface, stapled to the studs. The gypsum board joint was sealed; however, the surface was left unpainted for this series.

In the Test Series II, with a "poor" vapor retarder system, the polyethylene film was omitted. The water vapor transmission (WVT) rate of a number of latex paint systems was measured using the desiccant method of ASTM E 96 at 90 F (32°C) (ASTM 1981). The system selected for Test Series II was two brush-applied coats of a flat latex paint with a measured WVT of 13.2 perms (grains/h·ft²·in·Hg) (760 E-9 g/s·m²·Pa). The estimated thickness of the two-coat paint film was 1.8 mils (0.0018 in; 0.046 mm).

The test wall for Series III had a "point-source defect" in an otherwise "excellent" vapor retarder system. Four mil (0.004 in; 0.1 mm) polyethylene film was stapled to the studs as was done for Test Series I. The "defect" consisted of the installation of a conventional metal electrical box, duplex receptacle and plastic cover. The gypsum board interior surface was painted for Series III tests.

The air leakage rate, as a function of total pressure difference, was determined for the Series III test wall. With increasing order of the absolute value of the total pressure, the infiltration rate actually decreased above about 0.16 in H_2O (40 Pa), thus indicating a one-way valve action within the test wall that partially sealed with increasing negative pressure. With decreasing order of total differential pressure, both the infiltration and exfiltration rates followed the expected log-log relationship.

See Figures 1 and 2 for diagrams showing the construction details of the test wall. Figures 3 and 4 show the completed exterior and interior surfaces of the test wall, respectively.

Test Apparatus

Figure 5 is an overall view of the moisture transmission testing apparatus used in this investigation. The device consists of two major elements, (1) the control cabinet seen on the right and (2) the test cell on the left. The cabinet contains instrumentation to control and measure the temperature and humidity in the bottom or warm chamber of the test cell. The make-up water reservoir is located here together with temperature and humidity indicating devices and all control instrumentation. The test apparatus is shown in the horizontal position, for weighing of the test wall specimen. Except during the weighing operation, the test cell was rotated to the vertical orientation (Figure 6).

The test cell is composed of three chambers, five feet wide by ten feet long (1.5 by 3.0 m). The bottom chamber (in the weighing mode) represents the inside, usually warm, atmosphere of a building. The center chamber contains the test specimen. In the weighing mode, this center chamber is supported from a pair of load cells, and thereby weighed to a sensitivity of 0.01 pound (0.005 kg). The top chamber is the cold side.

Test Procedure

Except for the initial tests with Series III, the temperature and humidity conditions were maintained constant with the warm chamber at 70 F (21°C) and 50 % rh and the cold chamber at 20 F (-7°C) and nearly saturated. These conditions provided a mean temperature of 45 F (+7°C), typical of average January winter conditions encountered in a northern climate.

The temperatures of the test panel and pressure difference across the test wall were measured and recorded on a daily basis. For the weighing operation, the test apparatus was rotated to a horizontal orientation. After weighing, the test apparatus was rotated back to a vertical orientation for further exposure.

At the conclusion of a test, when significant moisture accumulation had occurred, the test panel was disassembled starting from the interior face. The gypsum board face was removed and destroyed in the process. Each of the 0.5 in (13 mm) thick mineral fiber insulation specimens in the test area was quickly removed and placed in individual, sealed plastic envelopes for subsequent weighing. After the initial weighing, each of the insulation specimens was removed from the plastic envelopes and placed in a 140 to 150 F (60 to 66°C) oven for drying to constant weight.

Data Analysis Procedure

The same basic data analysis procedures were used for all three series of tests. The test wall panel assembly was weighed daily. When it was considered that the test conditions had stabilized as to temperature, humidity, and pressure differential, useful weight data were tabulated. By means of a linear regression analysis, the rate of moisture accumulation was determined (slope of the weight versus time relation). The coefficient of determination (r^2) was also determined. Except for test conditions where the rate of moisture accumulation was very low, r^2 terms of 0.99 or higher were not uncommon. Average moisture accumulation rates are reported in Table 1 (IP units) and Table 2 (SI units).

Temperature data were taken at least daily, usually just prior to the weighing operation. In order to determine the effect of moisture accumulation on thermal performance, the temperature gradients were compared at the beginning and during a test series. Averages of three sets of temperature readings were calculated. From this, the average temperature difference was calculated by taking temperature differences for the series of components comprising the test wall panel.

The goal was to have a total air-to-air temperature difference of 50 F (27.8°C). This was not achieved exactly for each test. It was necessary to adjust the temperature difference across each of the components proportionately, so that the total air-to-air temperature difference was precisely 50 F (27.8°C), and thus provide a true basis for comparisons. A measure of the thermal performance of each of the test wall components is the ratio of the adjusted temperature difference after exposure to that at the beginning of that test series.

The moisture content of the insulation sections at the conclusion of each test phase is reported in Table 3 as both the weight and volume percentages.

TEST RESULTS AND ANALYSIS

Test I - "Excellent" Vapor Retarder System

Test Ia had zero total pressure difference across the test wall. Test Ib, with +0.10 in H_2O (+25 Pa) total pressure difference, was equivalent to that produced by a 15 mph (24 km/h, 6.7 m/s) wind on the leeward side of a building. Positive total pressure implies that the total pressure differential was concurrent with the vapor pressure gradient. Test Ic had -0.10 in H_2O (-25 Pa) total pressure difference. Negative pressure implies that the total pressure differential was counter to the vapor pressure gradient. The negative moisture accumulation rate observed means that the test wall panel tended to dry out during the course of Test Ic.

For the moisture accumulation rate for the Test I series, see Table 1 (IP units) or Table 2 (SI units).

With a positive total pressure differential, the rate of moisture gain increased markedly over that with zero total pressure difference, but it was still insignificant from a practical standpoint. When the total pressure was negative, the test wall actually lost previously accumulated moisture. Four mil (0.004 in, 0.1 mm) polyethylene film is normally considered an "excellent" water vapor and air barrier. However, the above tests showed that, as typically installed with staple and drywall screw penetrations, there is at least a small amount of air movement through the wall. This does influence the rate of moisture accumulation. (Subsequent Test II, in which the gypsum board was painted with a low vapor flow resistance paint, indicated that the application of paint was probably successful in sealing around the drywall screws, thereby reducing the air leakage at these points.)

There was no consistent pattern of change in the adjusted temperature difference ratios for the insulation and sheathing components, indicating no degradation of the thermal performance of the wall structure with the amount of moisture accumulated during the Test I series.

At the conclusion of Test Ic, the test wall was dismantled. Visually, each of the insulation pieces appeared completely dry. The amount of moisture that had accumulated in each of the insulation pieces was determined. Except for that nearest the warm side, none of the thin test area insulation specimens had a measurable amount of accumulated moisture (see Table 3).

Test II - "Poor" Vapor Retarder System

Test IIa had zero pressure differential across the test wall panel. Test IIb had +0.10 in H_2O (+25 Pa) total pressure differential. A slight reduction in the rate of accumulation for Test IIb compared with Test IIa was observed, but this difference is not considered significant.

The moisture accumulation rate for Test IIa, with a "poor" vapor retarder system, was about ten times that for Test Ia with an "excellent" vapor retarder system. The moisture accumulation rate for Test IIb was about five times that for Test Ib. The Test I series responded to changes in the differential total pressure, while Tests IIa and IIb did not.

The measured water vapor transmission rate (WVT) of the gypsum board interior surface was 13.2 perms (grains/h$\cdot$ft$^2\cdot$in$\cdot$Hg). This can be converted into the same units as the test wall panel moisture accumulation rate, taking into account the water vapor partial pressure on the warm side of the panel and that on the cold side of the insulation. The painted gypsum board moisture transmission was equivalent to 0.0118 lb/ft$^2\cdot$day (0.058 kg/m$^2\cdot$day). The average rate of moisture gain of the test wall panel in Tests IIa and IIb was 0.0099 lb/ft$^2\cdot$day (0.048 kg/m$^2\cdot$day).

It is believed that the difference between the moisture input rate through the gypsum board and the accumulation rate represents the amount of moisture lost by the mechanism of transmission via the sheathing on the cold side of the test wall panel. Normally, the asphalt-impregnated wood-fiber sheathing board used would be considered a water vapor permeable material. However, at the low temperatures experienced by the sheathing (average 25.2 F, -3.8°C), the differential water vapor partial pressure difference available as a driving force is not sufficient to move much water.

Converting the difference between the transmission rate of the painted gypsum board and the accumulation rate of the test wall panel, and assuming saturation on both sides of the sheathing, the apparent permeance of the sheathing is 15 perms. Admittedly, the precision of the above calculation is not great; however, the result is within the right order of magnitude.

The observation is made that total pressure difference did have an effect on the moisture accumulation rate with Test I, but not with Test II. This is probably due to the sealing effect of the paint film on the air permeability of the gypsum board interior for Test II. (The gypsum board was left unpainted for Tests Ia, Ib, and Ic.) Although the latex paint film was relatively poor as a water vapor retarder, apparently it was quite effective in reducing air permeability.

The adjusted temperature difference across insulation layer No. 1, next to the sheathing on the cold surface of the wall, showed a marked reduction during Test IIa and IIb. On the other hand, the temperature difference across the other insulation layers increased. Analyzing these other specimens, which for the moment can be assumed to have remained dry, the increase in temperature difference was found to be consistent. The average increase in the temperature difference was 5.2 %, indicating the overall heat flux through the test wall panel increased 5.2 % during the accumulation of the moisture.

Immediately upon the conclusion of Test IIb, the test wall panel was disassembled. A heavy accumulation of moisture in the form of frost was observed at the interface between the coldest insulation surface and the sheathing board. In removing the insulation specimens from the test wall panel, much of the moisture at the interface remained on the sheathing board, which quickly turned to the liquid phase.

The moisture accumulation in insulation specimen No. 1, which was adjacent to the sheathing board, had accumulated over 500 % moisture by weight (Table 3). None of the other test insulation specimens had accumulated a significant amount of moisture. The overall average accumulated moisture for all of the insulation specimens was 57 %. Because of the difficulty in separating the moisture accumulated within the insulation from that adhering to the sheathing board, the insulation moisture content measured cannot be considered highly precise. However, the overall average is probably a reasonable figure.

The test wall panel had been disassembled and reassembled for Tests IIc through IIf with several new insulation pieces and a new gypsum board face and paint surface. Every effort was made to reassemble the test wall as it was previously, with the same construction details, paint and paint application techniques.

Test IIc had +0.20 in H_2O (+50 Pa) total pressure difference across the test wall, the same as for Test IId. The cold side temperature regulation for Test IId was much closer than for Test IIc and is therefore considered to have the better test results. However, the two moisture accumulation rates differ by less than 10 %. Test IIe had -0.10 in H_2O (-25 Pa) total pressure difference across the test wall. While the panel still continued to gain moisture during Test IIe, the rate of gain was substantially less with the countercurrent total pressure differential than it was with the total pressure differential concurrent with the vapor partial pressure gradient. This seems to indicate that there was some air leakage through the test wall panel, which would cause some "drying" effect. However, the high water vapor permeability rate of the interior face still dominated, with the net result that the panel continued to gain moisture.

Test IIf, with +0.20 in H_2O (+50 Pa) total pressure difference across the test wall, was added to provide a measure of the test reproducibility and to see if there was any lessening of the accumulation rate with the amount of moisture accumulated. Unfortunately, the refrigerating system failed during the test, allowing the cold side air temperature to rise to 49 F (0°C). The average rate of moisture accumulation during Test IIf of 0.0071 $lb/ft^2 \cdot day$ (0.035 $kg/m^2 \cdot day$) was substantially less than the rate of 0.0121 $lb/ft^2 \cdot day$ (0.059 $kg/m^2 \cdot day$) observed previously during Test IId, with the same test panel under similar exposure conditions. With the unsatisfactory operation of the cooling system, and the relatively low value of the r^2 term for the coefficient of determination, the accumulation rate for Test IIf is not considered too reliable; however, a question remains as to a possible reduction in the rate of accumulation with the amount of moisture accumulated.

During the course of Tests IId through IIf, the adjusted temperature difference decreased substantially for both the sheathing and the insulation layer next to it (No. 1). This indicated moisture accumulation in these components (later confirmed). On the other hand, the temperature difference ratio increased an average of 2.2 % for the other layers of insulation (No. 2 through No. 7). Under the assumption that these insulation layers remained dry (later confirmed), the heat flux through the test wall increased 2.2 % as a result of the accumulated moisture.

At the conclusion of Test IIf, the test wall was dismantled. As observed during the disassembly operation, the amount of moisture in the insulation at the conclusion of Tests IId through IIf was substantially less than at the conclusion of Tests IIa and IIb.

Since the total panel weight gain during the two tests was substantially the same, it is believed that during the cold side refrigeration failure, the moisture that had accumulated as frost in the coldest insulation layer melted and was subsequently absorbed by the asphalt-saturated wood-fiber sheathing board.

The insulation moisture date for Tests IId through IIf are tabulated in Table 3. As indicated on the basis of the temperature differences, insulation specimen No. 1 next to the sheathing had accumulated moisture. The other insulation specimens, No. 2 through No. 7, remained substantially dry. While insulation specimen No. 1 had 51 % moisture by weight at the conclusion of Test IIf, this was only one-tenth the amount of moisture it had accumulated after Test IIb. The moisture content of the sheathing was not determined, as this would have been a destructive test.

Test III - Point Source Defect in Vapor Retarder System

The Test III series was started with less severe warm side exposure conditions than employed previously to avoid a too rapid buildup of moisture within the test wall panel (this concern later proved unfounded). Test IIIa had 0.08 in H_2O (20 Pa) total pressure differential across the test wall panel and warm side conditions of 70 F (21°C) 25 % rh. Under these exposure conditions the panel weight remained approximately constant. The slightly negative rate calculated is not considered significant due to low value of the coefficient of determination (r^2).

For Test IIIb, the relative humidity on the warm side was increased to 40 %, with the other conditions remaining unchanged from Test IIIa. Beginning with Test IIIc, and for the balance of the Series III tests, the relative humidity on the warm side was increased to 50 % rh, the same as for the Test I and Test II series. For Test IIIc, the total pressure difference across the test wall panel was +0.10 in H_2O (+25 Pa). Test IIId had a total pressure differential of -0.10 in H_2O (-25 Pa). The average rate of moisture accumulation during Test IIId was actually a loss of moisture.

After Test IIId, the cold side chiller was shut down for recharging and repairs, as temperature control and the ability to maintain 20 F (-7°C) on the cold side were no longer satisfactory. Test IIIe had a total pressure differential across the test wall panel of +0.12 in H_2O (+30 Pa). The final test, Test IIIf, was conducted with zero total differential pressure across the test wall. The average rate of moisture accumulation during Test IIIf was again actually a loss of moisture.

A comparison was made between the rate of moisture entering the test wall via exfiltration of humid air from the warm side, and the measured rate of weight gain. The assumption was made that the volume/pressure airflow relationships determined previously, with the test wall panel at all room temperature, would also apply when a temperature gradient was imposed. In each case the rate of weight gain of the test wall panel was only a fraction of the rate of moisture entering the test wall: 38 % - Test IIIb, 31 % - Test IIIc, 28 % - Test IIIe. It is interesting to note that as the rate of exfiltration was increased, the fraction of entering moisture that was retained by the test wall decreased.

When the exfiltrating humid air was of low humidity (Test IIIa), test wall panel had no net gain of moisture and possibly lost weight. When cold dry air entered the test wall panel through the mechanism of infiltration (Test IIId), there was a definite drying effect. It should be noted that although Tests IIIc and IIId were both conducted at the same differential total pressure, +0.10 in H_2O (+25 Pa) and -0.10 in H_2O (-25 Pa), respectively, the exfiltration rate was 77 ft^3/h (0.00061 m^3/s) versus a much lower infiltration rate of 29 ft^3/h (0.0023 m^3/s). When the differential total pressure was zero (Test IIIf), the test wall panel lost moisture. All of the above indicates that the natural tendency of the Test III wall panel was to lose moisture, and the effects of exfiltration and infiltration were superimposed on an overall drying tendency.

The adjusted temperature differences across the test wall components during the Test III investigation were compared with that at the beginning of Test IIIa. While a comparison of the temperature gradients provided an excellent relative indicator of the change in the test wall panel thermal performance in the Test I and II series, this was not the case with the Test III series. The exfiltration of warm humid air into the test wall cavity increased the temperature difference across the sheathing and decreased that across the gypsum board interior face. At the conclusion of the test series (Test IIIf), with zero total pressure difference across the test wall, there was decreased temperature difference across the sheathing and coldest insulation layers (which is consistent with the moisture content observed for these elements).

At the conclusion of Test IIIf, the test wall was dismantled. During the disassembly operation no visible moisture was observed in any of the insulation layer pieces. The inside surface of the sheathing was damp at the bottom on both sides of the stud, below the electrical box (no doubt the moisture had been in the form of ice but had melted by the time the test wall panel was disassembled to this point). The outside surface of the sheathing (cold face) and inside surface of the aluminum siding were damp for the lower two-thirds of the test wall. This moisture would have been in the form of ice during the test. The upper one-third had no visible moisture present in this area. The moisture observed on the lower two-thirds of the test wall, on the outside of the sheathing and the inside of the siding, appeared uniformly distributed across the width of the test wall.

The amount of moisture that had accumulated in each of the insulation pieces was determined. The insulation moisture data for the Test III series investigation are tabulated in Table 3. All of the insulation layers had some moisture accumulation, but not the concentration in the coldest insulation layer observed in the Test II series. This is not surprising in view of air movement within the test wall cavity resulting from exfiltration and infiltration.

SUMMARY AND CONCLUSIONS

The moisture/thermal performance of an insulated residential wood-frame wall structure was investigated. The study included the effects of three types of vapor retarder systems and the effects of zero, positive, and negative total pressure differences across the wall. Exposure was representative of a northern winter climate.

The wall section tested was 5 by 10 ft (1.5 by 3.0 m). It was constructed of nominal 2 by 4 wood studs, 16 in (406 mm) on center. The interior face was gypsum board. Asphalt-saturated wood fiberboard sheathing was covered on the outside with aluminum siding. The wall was insulated with mineral fiber insulation. The central insulation area consisted of a series of seven layers, with thermocouples between each to permit monitoring of the temperature gradient as an indication of heat flux. The insulation layers also provided a means of locating moisture accumulation at the conclusion of each test phase.

The following conclusions are drawn as a result of this investigation:

"Excellent" Vapor Retarder System (Polyethylene Film)

1. A measurable but insignificant rate of moisture accumulation was observed.

2. No significant increase in the heat flux was observed.

3. No significant amount of moisture was found in the insulation layers when the test wall was disassembled.

4. A minor response to changes in the direction of the total pressure difference was noted in the rate of moisture accumulation. This indicated a minor degree of air leakage through the panel, possibly around the screw fasteners of the unpainted gypsum board.

"Poor" Vapor Retarder System (Flat Latex Paint)

1. With the initial "poor" test wall panel, the moisture accumulation rate was 0.010 $lb/ft^2 \cdot day$ (0.05 $kg/m^2 \cdot day$), with no increase in the rate when a positive pressure differential was imposed.

2. When the initial test wall was disassembled, the moisture level in the coldest insulation layer was >500 % by weight, with the other insulation layers essentially dry.

3. The moisture accumulated in the initial test wall had increased the heat flux by 5 %.

4. A second "poor" test wall panel, similar to the first, had a moisture accumulation rate of 0.013 $lb/ft^2 \cdot day$ (0.06 $kg/m^2 \cdot day$) with +0.20 in H_2O (+50 Pa) total pressure difference. When the pressure difference was reversed (infiltration), the test wall still gained moisture but at the reduced rate of 0.006 $lb/ft^2 \cdot day$ (0.03 $kg/m^2 \cdot day$).

5. When the second "poor" test wall was disassembled, the moisture accumulation in the coldest insulation layer was 51 % by weight, with the rest of the layers essentially dry. This was much less than with the initial "poor" test. The reduction was probably caused by a refrigerating system failure, which had allowed the cold side to reach 49 F (9 °C) at one point during the test. The accumulated moisture in the coldest insulation layer would have melted and been absorbed by the adjacent sheathing.

6. The moisture accumulated during the exposure of the second test wall increased the heat flux by 2 %.

"Point-Source Defect" in Vapor Retarder System (Electrical Receptacle)

1. With exfiltration of low humidity (25 % rh) air, the moisture accumulation rate was about zero.

2. With 50 % rh air exfiltrating under a total pressure difference of ±0.10 in H_2O (+25 Pa), the moisture accumulation rate was 0.006 $lb/ft^2 \cdot day$ (0.03 $kg/m^2 \cdot day$).

3. With a negative total pressure difference, causing infiltration of dry outside air, the test wall panel lost moisture at the rate of 0.005 $lb/ft^2 \cdot day$ (0.03 $kg/m^2 \cdot day$).

4, With zero total pressure difference, the test wall also lost moisture but at the lesser rate of 0.002 $lb/ft^2 \cdot day$ (0.01 $kg/m^2 \cdot day$).

5. When this test wall was disassembled, considerable moisture accumulation was observed at the bottom inside surface of the sheathing, the lower two-thirds of the outside of the sheathing, and similar locations on the inside of the aluminum siding. All of the insulation layers, including that next to the sheathing, had about 1 % moisture by weight.

6. Changes in the temperature gradients through the insulation layers of this panel could not be used as a guide to changes in the heat flux due to the influence of the exfiltration and infiltration air movements within the insulated wall cavity.

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TABLE 1

Moisture Accumulation Rate (IP Units)

Test I - "Excellent" Vapor Retarder
Test II - "Poor" Vapor Retarder
Test III - "Point-Source Defect" in Vapor Retarder System

Test Number	Total Pressure Difference* - In H_2O	Warm Side Conditions*	Average Rate of Moisture Gain - lb/ft^2·day
Ia	0.00	70 F 50% rh	0.0008
Ib	+0.10	70 F 50% rh	0.0017
Ic	-0.10	70 F 50% rh	-0.0015
IIa	0.00	70 F 50% rh	0.0100
IIb	+0.10	70 F 50% rh	0.0098
IIc**	+0.20	70 F 50% rh	0.0130
IId**	+0.20	70 F 50% rh	0.0121
IIe**	-0.10	70 F 50% rh	0.0063
IIf**	+0.20	70 F 50% rh	0.0071
IIIa	+0.08	70 F 25% rh	-0.0011
IIIb	+0.08	70 F 40% rh	0.0053
IIIc	+0.10	70 F 50% rh	0.0065
IIId	-0.10	70 F 50% rh	-0.0053
IIIe	+0.12	70 F 50% rh	0.0068
IIIf	0.00	70 F 50% rh	-0.0024

* + = air exfiltration
  - = air infiltration
  Cold Side Condition = 20 F

** Test wall panel was disassembled after Test IIb, and reassembled for Tests IIc-f.

TABLE 2

Moisture Accumulation Rate (SI Units)

Test I - "Excellent" Vapor Retarder
Test II - "Poor" Vapor Retarder
Test III - "Point-Source Defect" in Vapor Retarder System

Test Number	Total Pressure Difference* - Pa	Warm Side Conditions*	Average Rate of Moisture Gain - kg/m^2·day
Ia	00	21°C 50% rh	0.004
Ib	+25	21°C 50% rh	0.008
Ic	-25	21°C 50% rh	-0.008
IIa	00	21°C 50% rh	0.049
IIb	+25	21°C 50% rh	0.048
IIc**	+50	21°C 50% rh	0.063
IId**	+50	21°C 50% rh	0.059
IIe**	-25	21°C 50% rh	0.031
IIf**	+50	21°C 50% rh	0.035
IIIa	+20	21°C 25% rh	-0.005
IIIb	+20	21°C 40% rh	0.026
IIIc	+25	21°C 50% rh	0.032
IIId	-25	21°C 50% rh	-0.026
IIIe	+30	21°C 50% rh	0.033
IIIf	00	21°C 50% rh	-0.012

* + = air exfiltration
  - = air infiltration
  Cold Side Condition = -7°C

** Test wall panel was disassembled after Test IIb, and reassembled for Tests IIc-f.

TABLE 3

Accumulated Moisture Location

Insulation Layer (Location)	End of Test Ic % Wt.	Ic % Vol.	End of Test IIb % Wt.	IIb % Vol.	End of Test IIf % Wt.	IIf % Vol.	End of Test IIIf %Wt.	IIIf % Vol.
No. 1 (Coldest)	0.0	0.00	509	7.3	51	0.7	1.4	0.02
No. 2	0.1	0.00	1	0.01	0	0.01	1.1	0.01
No. 3	0.1	0.00	1	0.01	1	0.01	0.9	0.01
No. 4	0.0	0.00	1	0.01	0	0.00	0.7	0.01
No. 5	0.1	0.00	1	0.01	0	0.01	0.7	0.01
No. 6	0.1	0.00	1	0.01	1	0.01	0.8	0.01
No. 7 (Warmest)	0.3	0.00	1	0.01	0	0.01	0.7	0.01

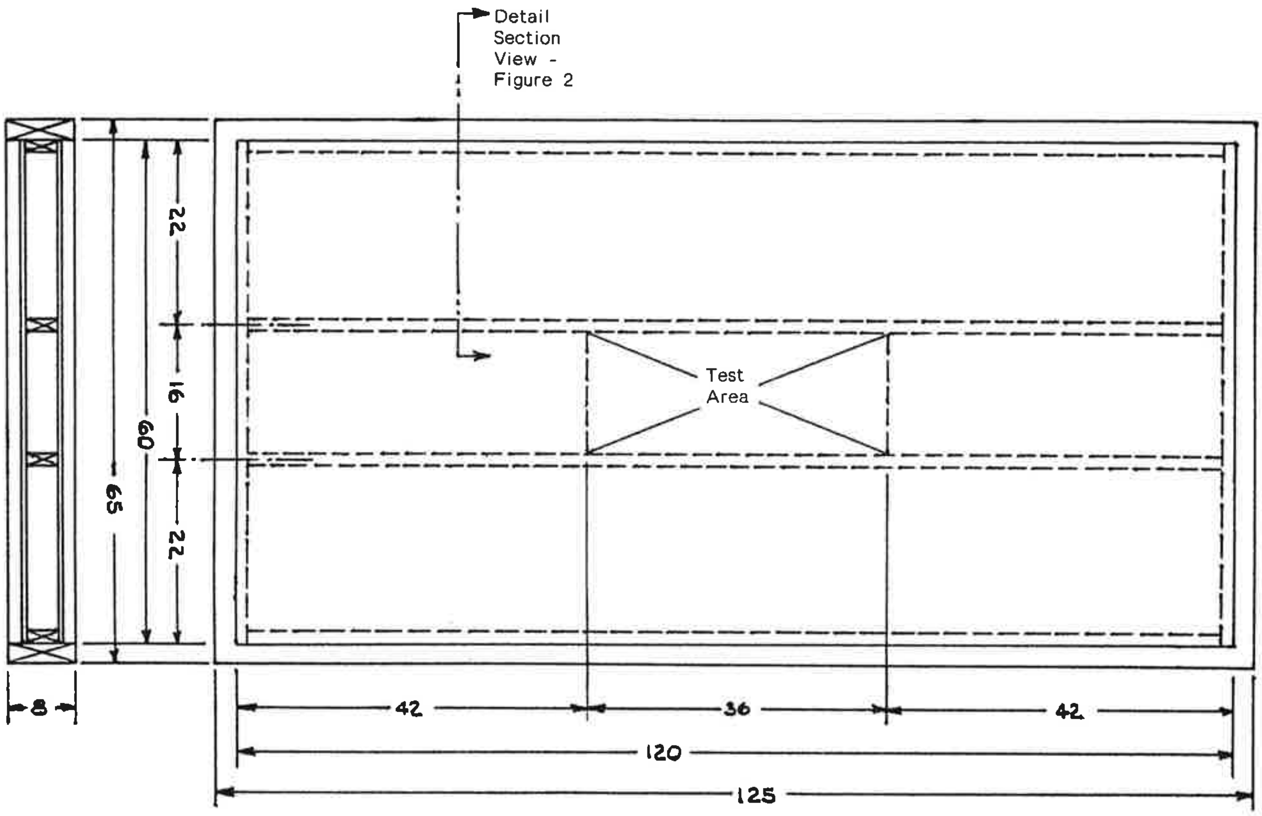

Figure 1. Moisture migration wall test panel (dimensions in inches, in x 25.4 = mm)

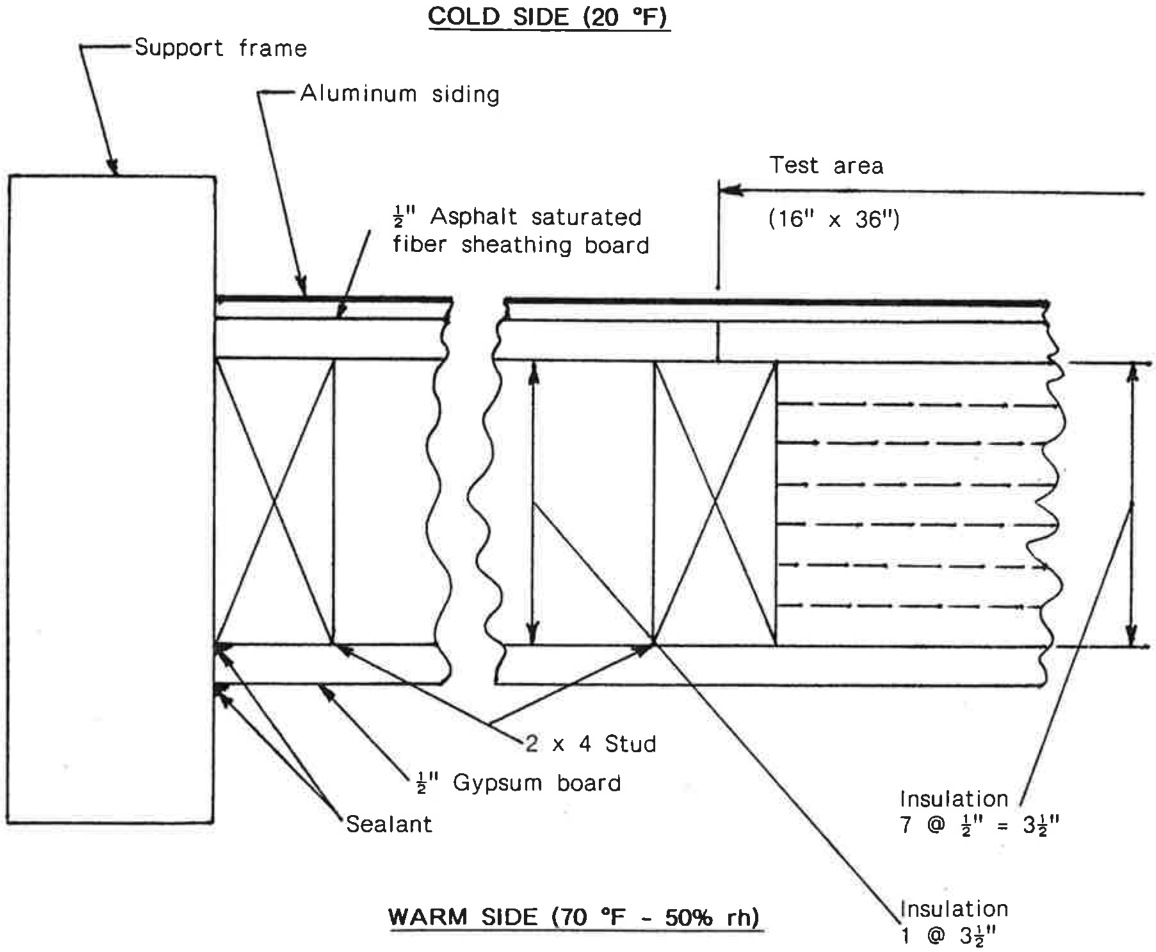

Figure 2. Moisture migration wall test panel - construction details

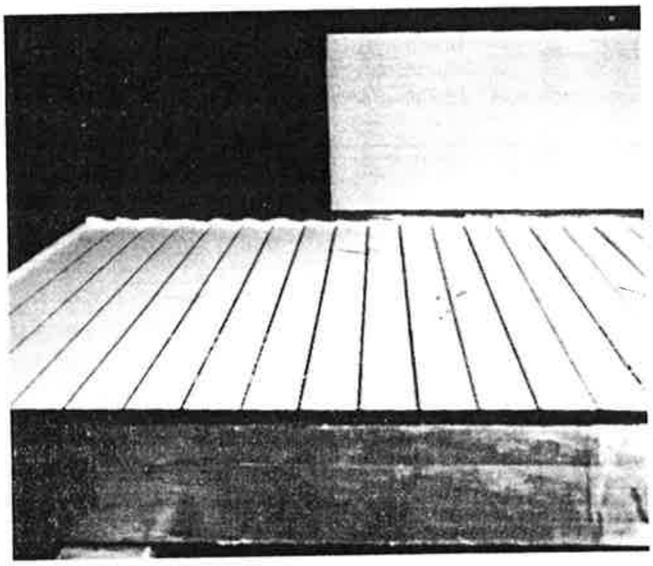

Figure 3. Completed exterior surface of test wall

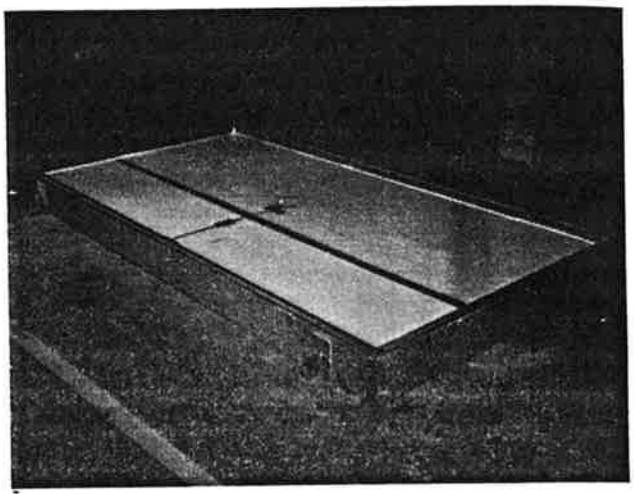

Figure 4. Complete interior surface of test wall

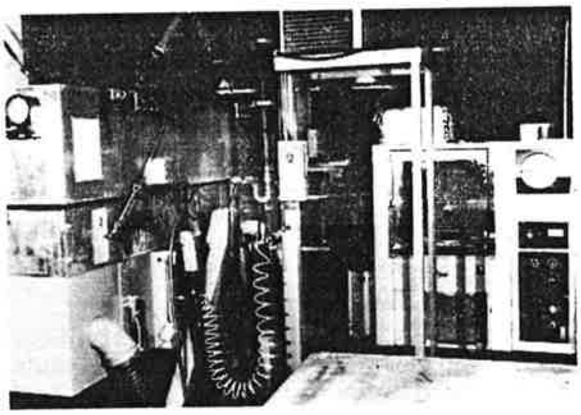

Figure 5. Moisture migration test apparatus

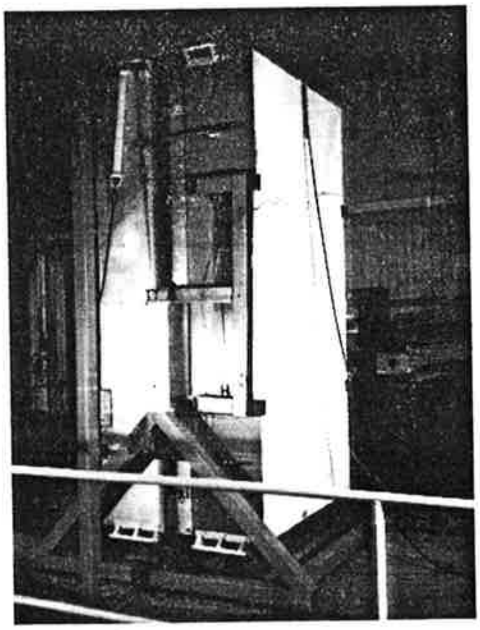

Figure 6. Water vapor migration test apparatus