

# MOISTURE MOVEMENT IN WALLS IN A WARM HUMID CLIMATE

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## ABSTRACT

Most research on condensation of moisture in exterior wood-frame walls has focused on moisture problems in walls in cold winter climates even though air-conditioned buildings in warm, humid climates also have potential for moisture damage. To investigate moisture movement in walls in a warm, humid climate, a test building was erected on the campus of Lamar University, Beaumont, TX. This building holds nine instrumented wall panels of different construction. The panels are all installed on the south side of the building.

All wall cavities were insulated with 3-1/2-in (89-mm) fiberglass batt. Hardboard siding was installed on all wall panels over either wood fiberboard sheathing or aluminum-faced molded expanded polystyrene sheathing. A polyethylene sheet was installed between the fiberboard sheathing and siding in one panel. Another panel contained a ventilated airspace between the fiberboard sheathing and siding. Two panels contained a polyethylene vapor retarder on the room side of the insulated cavity. Temperatures and humidity conditions in the panels were recorded from early spring until late fall in 1984.

In one panel with fiberboard sheathing, moisture condensed on the polyethylene vapor retarder located on the room side during the afternoon but reevaporated during the following night. Other wall panels showed no evidence of condensation. Walls without the aluminum or polyethylene between siding and sheathing showed slightly higher humidity in the cavity, but the siding of those panels was generally drier and experienced less fluctuation in moisture conditions than the siding installed over the aluminum-faced polystyrene or the polyethylene sheet. The ventilated airspace had little effect on moisture conditions in the siding or the rest of the wall but should be further evaluated with sheathing materials other than fiberboard. Taping of the joints between sheathing panels had no discernible effect. Testing of several panels of different dimensions, but with the same design and materials, showed only minor differences in moisture levels.

## INTRODUCTION

Recent changes in wood-frame construction practices and the use of new building materials have renewed interest in the condensation of moisture in walls. Although evidence of condensation damage in walls is scarce, the possibility of extensive concealed structural damage has caused widespread concern.

Most research on moisture movement and condensation in walls has focused on winter conditions. Burch et al. (1978) detected moisture accumulation in walls subjected to a constant temperature and humidity gradient in the laboratory. In field exposure tests, Sherwood (1983) found that moisture condensed during periods of cold weather but evaporated rapidly when the outdoor temperature rose. Surveys of walls during winter and early spring in the Pacific Northwest (Tsongas et al. 1980) showed fewer moisture problems from condensation than

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initially expected. Although the literature indicates that winter condensation in walls is closely related to indoor humidity levels and the presence and integrity of an air-vapor retarder, many questions remain unanswered.

In comparison, even less is known about moisture in the walls of air-conditioned buildings in warm, humid climates. In theory, potential for moisture damage is greater in such a climate, but the evidence of damage from condensation in walls is inconclusive. Verrall (1962) reported some cases of paint failure and mold but no cases of decay. Duff (1972) did not detect significant moisture accumulation in wood-frame walls of an air-conditioned building in Athens, GA. Sherwood (1985) did find evidence of periods of condensation in several walls in an air-conditioned test building in Gulfport, MS, but those walls dried out in the fall and no damage was visible. He also noted that walls with permeable hygroscopic sheathing materials facing south had higher moisture levels than the same type of walls facing north. It appeared that direct sun striking the wall drove moisture out of the sheathing and into the wall cavity.

Condensation problems in warm, humid climates are distinctly different from those in cold-winter climates. During warm, humid days, water vapor moves into the wall from outside to inside and may condense on colder surfaces. Moisture condenses at temperatures that favor growth of decay organisms. Whereas indoor humidity control by ventilation often offers an effective way to prevent condensation in walls during the winter, especially in cold-winter climates, outdoor humidity during the summer cannot be controlled. Design solutions, such as placement of an effective vapor retarder, remain the only options. Mei and Woolrich (1963) investigated the proper placement of vapor retarders in a humid climate, but their study was limited in scope and did not lead to practical installation guidelines.

## OBJECTIVES

To address some of the many remaining questions, Lamar University, Beaumont, TX, and the Forest Products Laboratory, Madison, WI, conducted a cooperative field-exposure study in a warm, humid climate. An air-conditioned test building was erected on the Lamar University campus and wood-frame walls of different designs were monitored during spring, summer, and early fall of 1984.

Specific objectives of the study were:

1. Establish what combination of wall design and weather conditions leads to condensation and moisture accumulation. Specifically, the influence of sheathing type and of the presence and placement of vapor retarders was investigated.
2. Determine whether currently available moisture analysis methods for walls, such as the Kieper and MOISTWALL procedures (TenWolde 1983, 1985), adequately predict condensation.
3. Determine whether the size of wall panels for field tests can be reduced so that more panels can be tested simultaneously.
4. Determine whether sealing the joints between sheathing panels has a significant effect on moisture conditions in the wall.
5. Determine whether a ventilated airspace between siding and sheathing affects moisture conditions in the wall.
6. Determine what can be done to prevent moisture problems in walls in warm, humid climates.

Although it is impossible to answer these complex questions conclusively with one field study over one summer season, we believed that carefully selected designs could yield qualitative answers.

## EXPERIMENTAL DESIGN AND PROCEDURES

### Test Building

The test building (Figure 1) is located on the campus of Lamar University, Beaumont, TX. Beaumont has a Gulf Coast climate with summer temperatures ranging from 68 to 95 F (20 to 35°C) combined with extremely high relative humidity (RH). Winter temperatures average around 54 F (12°C).

The building is about 25 ft long by 8 ft wide (7.6 by 2.4 m) and contains nine instrumented wall panels of varying size and construction, all facing south. The north wall also contains several panels, but these were not instrumented or monitored. South and north walls are framed with nominal 2 by 6 studs. The 1-ft- (305-mm) wide wall sections between test panels are sheathed with 7/8-in- (22-mm) thick molded expanded polystyrene boards with aluminum facing on one side and have a total approximate R-value of 22. East- and west-facing walls have nominal 2 by 4 framing with the same sheathing (total R-14). The ceiling is insulated to R-19 and the floor to R-11. A detailed description of the test building can be found in a previous paper (Mei and Yang 1985).

### Test Wall Panels

The wood-frame test wall panels were all framed with nominal 2 by 4 studs and insulated with 3-1/2 in of fiberglass batt insulation. A 3/8-in hardboard siding covered all panels. Wood fiberboard (1/2 in, 13 mm) and 7/8-in molded expanded polystyrene foamboard were the two sheathing materials used. (Mei and Yang [1985] erroneously reported 1 in fiberboard and 1 in polystyrene.) The foamboard had an aluminum facing that was installed towards the siding. On the inside, 1/2-in (13-mm) unpainted gypsumboard was installed. One panel (S4) contained an airspace between the siding and sheathing. In some panels, the kraft paper backing was removed from the insulation before installation. The inside surfaces of the nominal 2 by 4 framing for the panels were painted with two coats of water seal and paint to prevent lateral movement of water vapor. The panels were installed with a gasket between the edge of the panel and the edge of the opening to prevent air leakage. Construction and design of the panels is summarized in Table 1. The wall panels were of three different sizes: 3 by 7 ft (0.92 by 2.13 m), 1.5 by 7 ft (0.46 by 2.13 m), and 1.5 by 3.5 ft (0.46 by 1.07 m). The sheathing in the two 3- by 7-ft wall panels (S1 and S2) consisted of two 1.5- by 7-ft (0.46- by 2.13-m) polystyrene boards with a joint over an extra nominal 2 by 4 stud in the center of the panel. In wall panel S2 this joint was taped with aluminum tape.

On August 6, 1984, partway through the experiment, changes were made to three panels. We added a polyethylene vapor retarder to S1 and S9 between the insulation and the gypsumboard, and we drilled six 1/4-in- (6-mm) diameter vent holes through the siding of panel S4--three at 1 in (25 mm) from the top and three at 1 in (25 mm) from the bottom.

### Environmental Conditions

Outdoor and indoor temperature and RH were measured and recorded. The indoor temperature was maintained between 68 F (20°C) and 73 F (23°C) with RH between 50% and 60%. It was necessary to install a dehumidifier at the beginning of May to maintain this range in humidity.

### Instrumentation

Outdoor and indoor air temperatures and humidities were measured separately. Humidity was measured with a capacitance-type meter.

Temperatures and humidities in the panels were measured with thermocouples and humidity sensors. The humidity sensors were wood electric resistance sensors, similar to those described by Duff (1966). Mei and Yang (1985) describe this modified sensor in their paper in Appendix A. Two thermocouple/humidity sensor pairs were located on each surface of each material, one pair about 2 ft (0.6 m) from the top and the other pair 2 ft (0.6 m) from the bottom (Figure 2). Additional pairs of thermocouples and humidity sensors were placed in the

insulation 1.5 and 2.5 in (38 and 64 mm) from the gypsumboard both near top and bottom of the panel. The smaller panels S5 and S6 contained only one series of sensors placed at midheight. The total of 120 humidity sensors provided input to four amplifiers via four rotary switches.

On August 6, 1984, partway through the experiment, polyethylene vapor retarders were added to panels S1 and S9. Additional pairs of sensors were placed on the vapor retarders at the top and bottom.

The electronic equipment was calibrated on site by substituting known electric resistances for the sensors. The relationship between electric resistance of the sensor and RH was determined for a sample of ten sensors. This calibration showed that the effective range of the humidity measuring equipment was approximately from 60% to 100% RH. The sensors were calibrated at 70 and 90 F (21 and 32°C). In this temperature range there was no systematic effect of temperature, and RH readings were therefore not corrected for temperature during data analysis.

Uncertainty for individual readings is in the range of  $\pm 10\%$  RH, based on doubling the standard deviation in the calibration data. Individually calibrating each of the 120 sensors before insertion in the panels would be more accurate but impractical.

### Data Collection

Data were collected from April 1 through November 30, 1984, usually twice a day, during mid-morning and mid-afternoon. On many days extra readings were taken late in the evening. For the two days (August 7 and 8) immediately following the modifications of panels S1, S4, and S9, data were recorded hourly. Collection cycles of six to eight readings per day were repeated between August 19 and 25 and throughout September.

### Data Analysis

With the assumption that the humidity sensors were always in moisture equilibrium with the surrounding air, we converted millivolt output to RH, using the results from the calibration tests. RH indicates how close to moisture saturation the various materials were. An RH of 100% indicates condensation. We defined sustained condensation as 100% RH over a period of 24 hours or longer. If condensation occurred for shorter periods and the RH returned to previous levels we labeled it cyclical or transient.

To compare measured results with analytical predictions we used the MOISTWALL analysis method (TenWolde 1983, 1985). MOISTWALL is a computerized moisture analysis method for walls, based on steady-state one-dimensional vapor diffusion theory. As input parameters we used published data for thermal resistance and permeance of the various materials. Temperatures and humidities were chosen close to the measured values in August.

## RESULTS

The measured outdoor conditions are displayed in Figure 3. The temperature varied between 68 to 95 F (20 to 35°C) in the summer months with RH averaging between 60% and 80%. In late October and November temperatures dropped and ranged from 55 to 77 F (13 to 25°C). Measured indoor conditions are shown in Figure 4.

### Condensation

Only panel S9 experienced some cyclical condensation on the vapor retarder immediately after it was installed. The newly installed sensor on the polyethylene immediately began to register cyclical high RH conditions (Figure 5). The sensor in the adjacent insulation, located 1.5 in (38 mm) from the vapor retarder, also shows an increase in RH in the insulation immediately following the change. The condensation on the polyethylene was purely cyclical and there was no long-term moisture accumulation during the period of September 15 through November 30 (Figure 6).

Cyclical condensation was detected only in panel S9, the only wall panel with a permeable, hygroscopic sheathing (fiberboard) and a polyethylene vapor retarder on the room side of the wall cavity. All other panels had either a foil-faced sheathing, an outside polyethylene vapor retarder, or no effective inside vapor retarder and did not experience any condensation.

The condensation cycle in panel S9 was entirely caused by solar radiation warming the siding and sheathing and driving part of the moisture stored in the siding and sheathing into the wall cavity. This moisture eventually condensed on the polyethylene when the humidity in the cavity had risen sufficiently. At night, this relatively small quantity of condensed moisture evaporated and was mostly reabsorbed in the sheathing and siding, while the exterior surface of the siding absorbed moisture from the outside air. The next morning, the cycle repeated.

The events during a condensation cycle in panel S9 are illustrated in Figure 7. On August 7 at 9:20 a.m. the outside surface of the siding showed a high RH but all other sensors indicated an RH of less than 65%. The sun had already raised the surface temperature of the siding to 83 F (28°C), 3 F (2°C) above the air temperature. By late afternoon (4:55 p.m.), the situation had drastically changed. The sun had dried out the siding, which was at 95 to 98 F (35 to 37°C) or 15 to 18 F (8 to 10°C) above air temperature, but the sensor on the lower side of the polyethylene vapor retarder showed condensation. The temperature of the sheathing had reached 93 to 98 F. At midnight the vapor retarder was beginning to dry off and the siding had begun to reabsorb moisture as demonstrated by elevated humidities between 70 and 85%. Both siding and sheathing had cooled to about 80 F (27°C). These trends continued during the night. At 4:10 a.m., sheathing and siding had cooled approximately to outside air temperature and the vapor retarder was almost dry. By 6:20 a.m., the polyethylene was dry (62% RH) and much of the rest of the wall was below 60% RH. The siding was just beginning to dry out as well. At 9:20 a.m., the condensation cycle was about to start again; the siding continued to warm up, driving moisture into sheathing and wall cavity. The humidity at the vapor retarder once again started to rise.

#### Vapor Retarders

The fiberglass batts in panels S1 (before August 6), S2, S4, and S8 all had kraft paper backing. This resulted in somewhat higher humidities in the cavities of those panels and slightly drier gypsumboard, compared to panels without the kraft paper. Apparently the kraft paper is a moderately effective vapor retarder. Unfortunately we were unable to detect if condensation occurred on the kraft paper because there were no humidity sensors in that location. For the remainder of this discussion the term "vapor retarder" will refer to more effective vapor retarders such as aluminum and polyethylene foil, unless specifically stated otherwise.

The results do not clearly show a need for a vapor retarder on the outside of the wall. The cavities of all the panels with such a vapor retarder (panels S1, S2, S3, S5, S6, and S7) were somewhat drier than the other panels, but the difference was very small. However, when a polyethylene inside vapor retarder was present (S1 and S9), the outside vapor retarder (S1) effectively prevented condensation (Figures 6 and 8). Figure 8 shows that, although occasional peaks of 85% to 90% RH were reached at the vapor retarder in S1, the wall stayed essentially dry. This confirms recent data published by Sherwood (1985) who also did not find any moisture accumulation in walls with double (inside and outside) vapor retarders exposed to a hot, humid summer climate.

#### Comparison With Analytical Model Results

Analysis of all panels with the MOISTWALL method predicted no condensation in any of the panels. MOISTWALL is limited to steady-state vapor diffusion and does not consider hygroscopicity or transient phenomena. It was, therefore, unable to predict the condensation cycles in panel S9, but it correctly indicated that no long-term moisture accumulation would take place. Predictions of RH at various locations in the walls were generally inaccurate because of the influence of hygroscopic materials, thermal storage, and transient moisture and heat flows, none of which are considered in the MOISTWALL analysis.

## Taping of Joints in Sheathing

Taping of the joints between sheathing panels had no measurable effect. Relative humidity in the wall with a taped joint (S2) was approximately the same as in panel S1, which was not taped. After August 6, when the polyethylene vapor retarder was installed in S1, RH in the cavity of S1 gradually increased to levels slightly higher than those in S2.

## Ventilation between Sheathing and Siding

The test panel with the 3/4-in (19 mm) airspace between the fiberboard sheathing and the siding (S4) showed little difference in RH from the comparable panel without the airspace (S8). Drilling the ventilation holes through the siding made no difference. Both walls were essentially dry, including the siding. However, ventilating the back of the siding may well have more beneficial effects with different sheathing types or different climates, as we will discuss later.

## Panel Size

The behavior of the smaller panels (S5 and S6) was very similar to that of the larger panel with the same construction (S7). However, all three walls were very dry, and many of the sensors did not register a signal because of their limited range (60 to 100% RH). It may be expedient to reduce the size of test panels for field tests, which would enable simultaneous testing of more different panels, but more evidence is needed before this can be concluded with certainty.

## Insulation

The results show that the fiberglass insulation stayed dry in all panels. This was true even in panel S9 during condensation cycles. Even while water vapor was condensing on the polyethylene, the sensors in the insulation 1.5 in (38 mm) away registered less than 70% RH (Figure 7). The highest RH measured at that location during the entire test period was 76%. The humidity in the insulation of all other panels was well below that. This confirms previous similar findings, as well as demonstrates the accuracy of theoretical calculations, showing that permeable nonhygroscopic insulation in wall cavities tends to remain dry (TenWolde 1983, 1985).

## Siding

Although we did not intend to study moisture conditions in the siding specifically, the results showed an interesting trend: RH at the back of siding applied over an outside vapor retarder (i.e., polyethylene or aluminum foil) was generally 5 to 10% higher than that of siding applied over fiberboard. Figure 9 shows this difference between siding over foil-faced polystyrene (panel S7) and siding over fiberboard (panel S8). Siding over a polyethylene vapor retarder (panel S3) behaved identically to siding over foil-faced polystyrene (panels S1, S2, S5, S6, and S7).

Comparison of Figures 7 and 10 illustrates the difference between panel S9, which has fiberboard sheathing, and panel S1, which has foil-faced polystyrene. The situation in both panels was approximately the same at 9:20 a.m. on August 7. At 4:55 p.m., moisture near the outside surface of the siding had been driven inwards, but in panel S1 this moisture had been trapped by the aluminum foil on the polystyrene, while in panel S9 (Figure 7) it migrated into and through the fiberboard. This resulted in much lower humidity at the back of the siding of panel S9. At midnight the siding had begun to readsorb moisture and continued to do so through the rest of the night. At 9:20 a.m. the next morning, the sun has started to drive moisture to the back of the siding. Throughout the entire 24-hour period, the humidity at the back of the siding of panel S1 was higher than in panel S9.

This effect of an outside vapor retarder on the siding is by no means surprising or even alarming. The moisture content of the siding of all panels remained well within acceptable limits throughout the study period. However, under more severe conditions of humidity or moisture or with other types of siding, ability of the siding to dry out towards the inside may well make the difference between acceptable and problematic performance of the siding.

## DISCUSSION

Although this study has provided some answers, many questions remain partially or completely unanswered. The results showed good performance of walls with exterior vapor retarders during the summer and fall, but we did not gather sufficient data to guarantee good performance during the winter.

The merits of ventilating the back of the siding also remain unclear. Although the results show no effect, this may be caused by the capacity of the fiberboard sheathing to absorb and transmit moisture. With other types of sheathing, especially foil-faced foam sheathing, the results might well have been different. This issue needs more research.

The influence of panel size is also not yet resolved. The results show little difference in behavior of larger and smaller panels. However, the limitations of the instrumentation and the lack of data from similar experiments by others prevent us from drawing a more general conclusion about the influence of panel size.

Although the building and instrumentation were finished by February 1984 and data collection was started, no useful data could be collected until April because it took the wall panels considerable time to equilibrate with their environment. Those involved in similar tests in the future should allow for a one- to two-month adjustment period, especially if moisture and temperature gradients across the wall are relatively small.

We have not discussed the influence of indoor temperature. Of course, lower indoor temperatures during the summer increase the potential for condensation and could well have led to moisture accumulation in panel S9. However, indoor temperatures were already maintained below the more typical setting of 78 F. The cyclical condensation that occurred in panel S9 is most likely also influenced by factors other than indoor temperature and the sun. Outdoor temperature and humidity during the night should have an effect on the amount of moisture absorbed in the siding, which in turn affects the amount of moisture driven into the wall cavity the next day.

Walls with an outside vapor retarder as well as walls without any vapor retarders remained dry throughout the study period. However, the walls without any vapor retarder transferred more moisture, providing greater latent load for the air-conditioning equipment. We are unable to estimate the energy savings resulting from a vapor retarder, although we suspect that it is small compared to the latent load from ventilation air.

## CONCLUSION

For outdoor and indoor temperature and RH conditions similar to those described earlier in this paper (Figures 3 and 4), we can draw the following conclusions:

1. Walls with outside polyethylene or aluminum foil vapor retarders or without any vapor retarders either inside or outside remain dry.
2. An interior polyethylene vapor retarder and fiberboard sheathing can result in cyclical condensation on the vapor retarder. Although it may not produce long-term moisture accumulation, this indicates that in a warm, humid climate, an interior vapor retarder is undesirable unless an exterior vapor retarder is installed as well.
3. A steady-state diffusion analysis method can correctly predict seasonal behavior but is unable to quantitatively predict specific conditions in the panels. Models incorporating hygroscopicity and transient behavior are needed for more accurate predictions.
4. Direct and indirect radiation from the sun has a major influence on humidity conditions in south-facing walls with hygroscopic sheathing.
5. Sealing joints between sheathing panels probably has little effect on humidity conditions in the wall.
6. Although a ventilated airspace between siding and sheathing had no effect on performance, more information is needed to investigate the effect with different siding/sheathing combinations.

7. Nonhygroscopic cavity insulation tends to remain dry.

8. Siding over exterior vapor retarders experiences higher humidities at the backside than siding installed over fiberboard. Although the moisture content of the siding of all panels remained well within acceptable limits, more severe conditions or other types of siding may lead to problematic performance of siding over a vapor retarder.

9. Although panel size had little discernible effect, additional tests are needed to verify this results.

#### REFERENCES

- Burch, D. M.; Contreras, A. G.; and Treado, S. J. 1979. "The use of low-moisture-permeability insulation as an exterior retrofit system--a condensation study. ASHRAE Transactions, Vol. 85, No. 2, pp. 547-562.
- Duff, J. F. 1966. "A probe for accurate determination of moisture content of wood products in use." FPL-0142. Madison, WI: USDA Forest Service, Forest Products Laboratory.
- Mei, H. T.; and Woolrich, W. R. 1963. "Condensation problems and solutions in the insulation of buildings in hot climates." In: Wexler, A., ed. "Humidity and moisture: Measurement and control in science and industry." In: Amdur, E. J., ed. Applications, Vol. 2. New York: Reinhold Publishing Corp., pp. 334-339.
- Mei, H. T.; and Yang, K. H. 1985. "A study of condensation in walls in warm humid climates." Proceedings of the International Symposium on Moisture and Humidity, April 14-19, 1985, Washington, DC. Research Triangle Park, NC: Instrument Soc. of America, pp. 325-332.
- Sherwood, G. E. 1983. "Condensation potential in high thermal performance walls--cold winter climate." Res. Pap. FPL 433. Madison, WI: USDA Forest Service, Forest Products Laboratory.
- Sherwood, G. E. 1985. "Condensation potential in high thermal performance walls--hot, humid summer climate." Res. Pap. FPL 455. Madison, WI: USDA Forest Service, Forest Products Laboratory.
- TenWolde, A. 1983. "The Kieper and MOISTWALL moisture analysis methods for walls." In: Proceedings, ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelopes of Buildings II, December 6-9, 1982, Las Vegas, NV. ASHRAE SP 38. Atlanta, GA: ASHRAE, pp. 1033-1051.
- TenWolde, A. 1985. "Steady-state one-dimensional water vapor movement by diffusion and convection in a multilayered wall." ASHRAE Transactions, Vol. 91, No. 1, pp. 322-342.
- Tsongas, G. A., et al. 1980. "A field study of moisture damage in walls insulated without a vapor barrier." ORNL/Sub-78/97726/1. Oak Ridge, TN: Oak Ridge National Laboratory.
- Verrall, A. F. 1962. "Condensation in air-cooled buildings." Forest Products Journal, Vol. 12, pp. 531-536.

#### ACKNOWLEDGMENT

The authors thank Professor K. H. Yang for his contribution to this study while he was a graduate student at Lamar University.

TABLE 1  
Construction and Design of Test Panels

Panel number	Size	Siding	Exterior vapor retarder	Air space	Sheathing	Insulation	Interior vapor retarder	Interior
	ft (m)			in (mm)				
S1a(before 8/6)	3 x 7 (0.92 x 2.13)	Hardboard	Aluminum foil, untaped joint	--	Polystyrene	Fiberglass	Kraft paper	Gypsum board
S1b(after 8/6)	3 x 7 (.92 x 2.13)	Hardboard	Aluminum foil, untaped joint	--	Polystyrene	Fiberglass	Kraft paper and polyethylene	Gypsum board
S2	3 x 7 (.92 x 2.13)	Hardboard	Aluminum foil, taped joint	--	Polystyrene	Fiberglass	Kraft paper	Gypsum board
S3	1.5 x 7 (.46 x 2.13)	Hardboard	Polyethylene	--	Fiberboard	Fiberglass	--	Gypsum board
S4	1.5 x 7 (.46 x 2.13)	Hardboard	--	3/4 (19) Ventilated after 8/6	Fiberboard	Fiberglass	Kraft paper	Gypsum board
S5,6	1.5 x 3.5 (.46 x 1.07)	Hardboard	Aluminum foil	--	Polystyrene	Fiberglass	--	Gypsum board
S7	1.5 x 7 (.46 x 2.13)	Hardboard	Aluminum foil	--	Polystyrene	Fiberglass	--	Gypsum board
S8	1.5 x 7 (.46 x 2.13)	Hardboard	--	--	Fiberboard	Fiberglass	Kraft paper	Gypsum board
S9a(before 8/6)	1.5 x 7 (.46 x 2.13)	Hardboard	--	--	Fiberboard	Fiberglass	--	Gypsum board
S9b(after 8/6)	1.5 x 7 (.46 x 2.13)	Hardboard	--	--	Fiberboard	Fiberglass	Polyethylene	Gypsum board

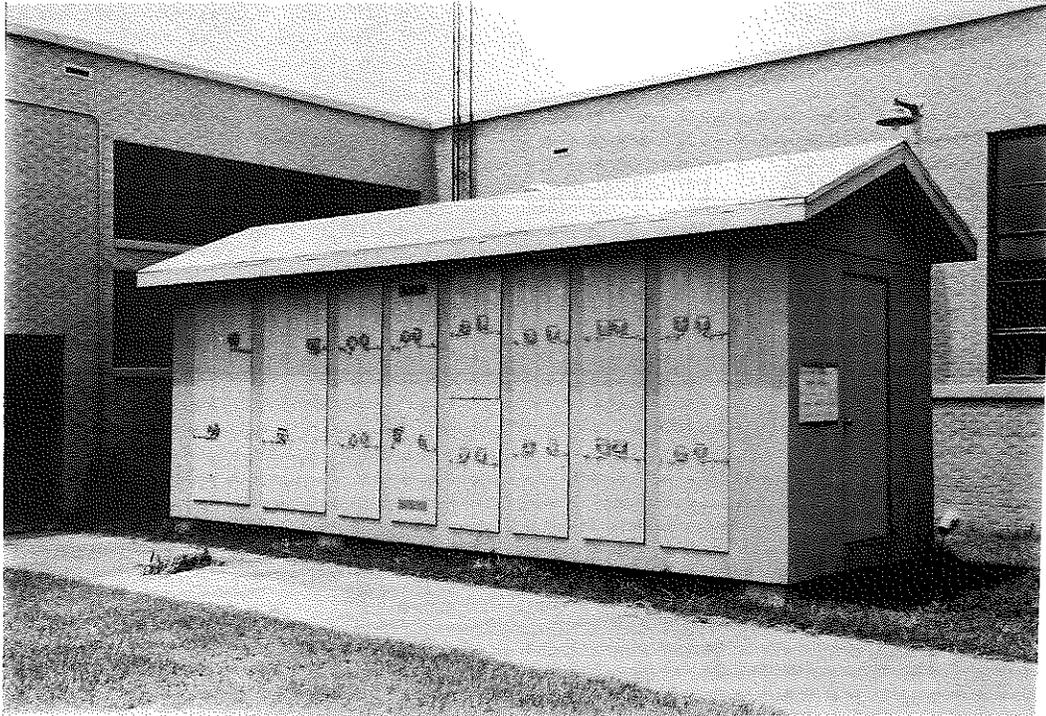


Figure 1. Test building with panels facing south

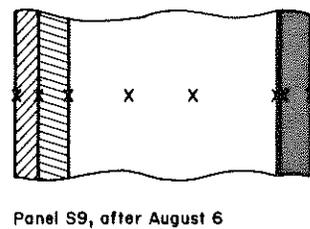
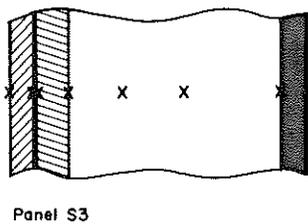
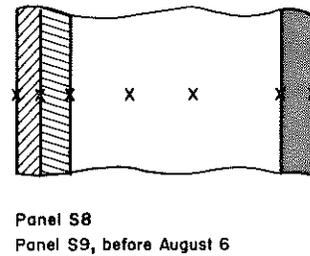
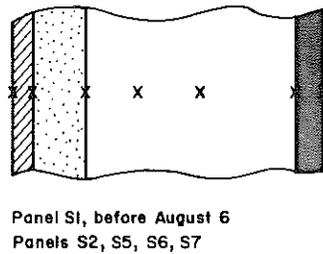
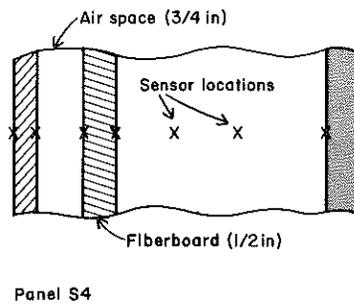
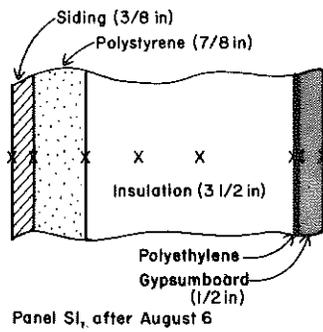


Figure 2. Location of thermocouples and humidity sensors in wall panels

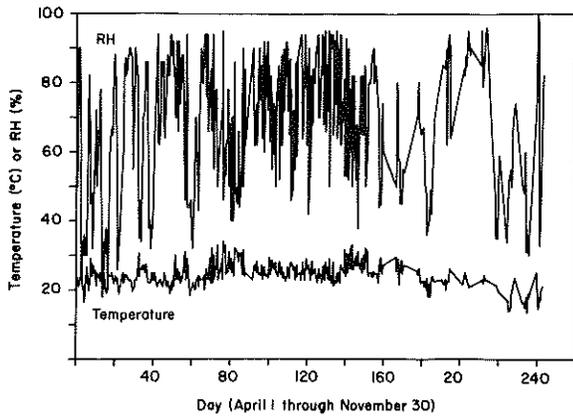


Figure 3. Measured outdoor temperature and relative humidity (RH) at test site, April 1 - November 30, 1984

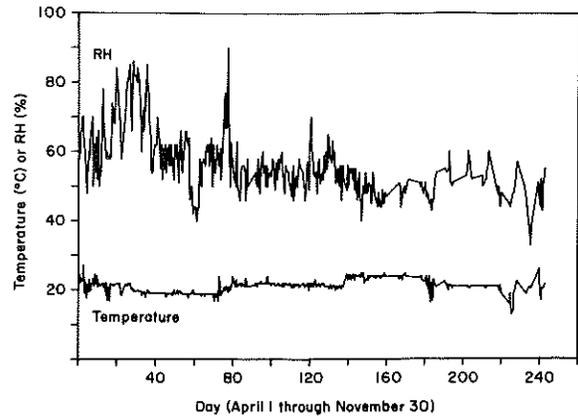


Figure 4. Measured indoor temperature and relative humidity (RH) in air-conditioned test building, April 1 - November 30, 1984

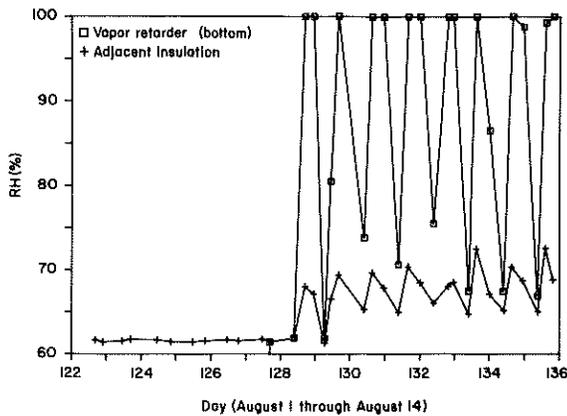


Figure 5. Relative humidity (RH) in panel S9 at insulation-vapor retarder interface and in adjacent insulation, August 1-14, 1984. Vapor retarder was installed on August 6 (day 128)

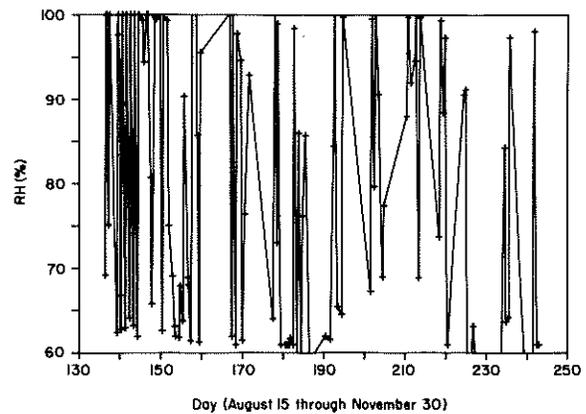


Figure 6. Relative humidity (RH) in panel S9 at insulation-vapor retarder interface, August 15 - November 30, 1984

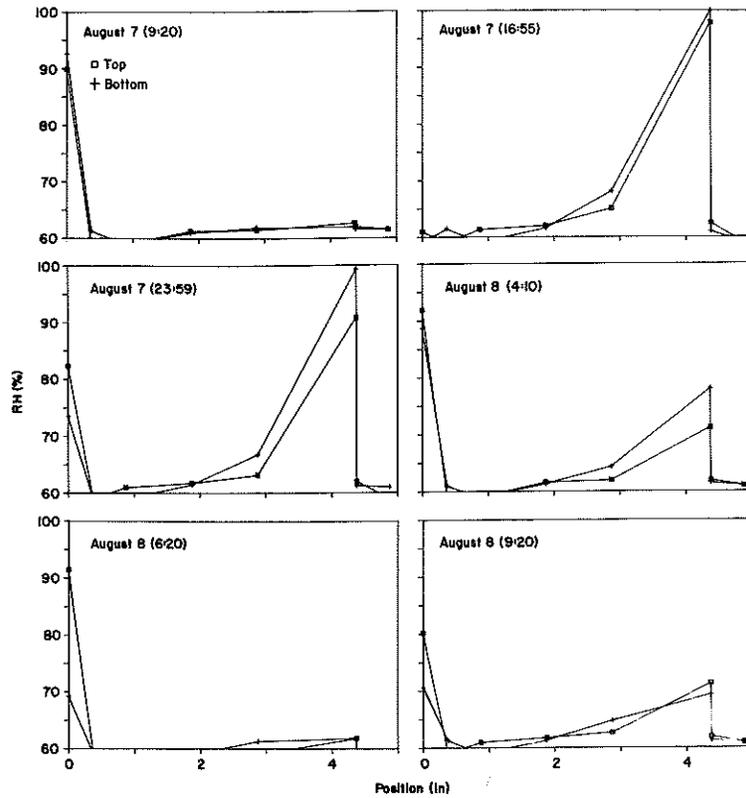


Figure 7. Relative humidity (RH) in panel S9 at different times on August 7 and 8, 1984, measured by sensors positioned as indicated (inches) from the exterior surface of the siding.

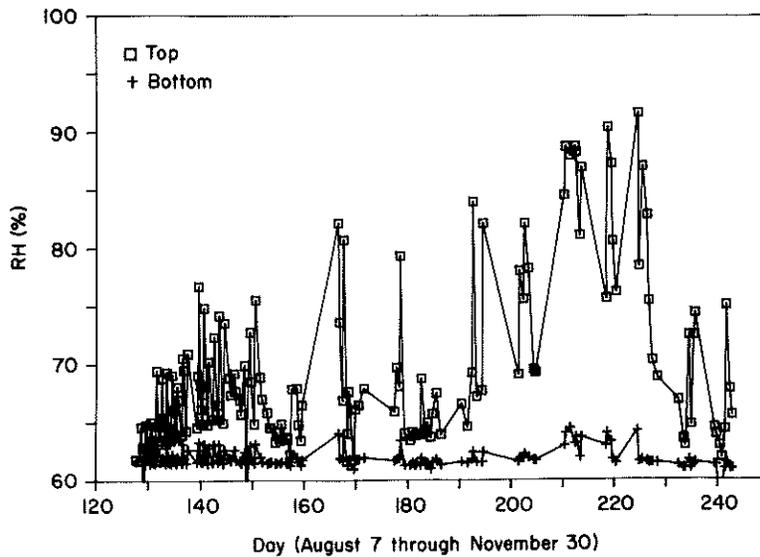


Figure 8. Relative humidity (RH) in panel S1 at the insulation-vapor retarder interface, August 7 - November 30, 1984

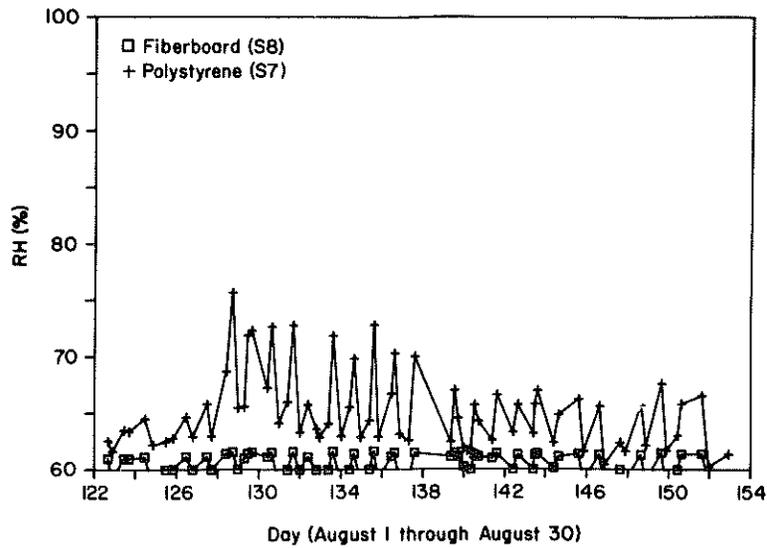


Figure 9. Relative humidity (RH) at back of siding applied over aluminum-faced polystyrene (S7) and over fiberboard (S8), August 1-30, 1984

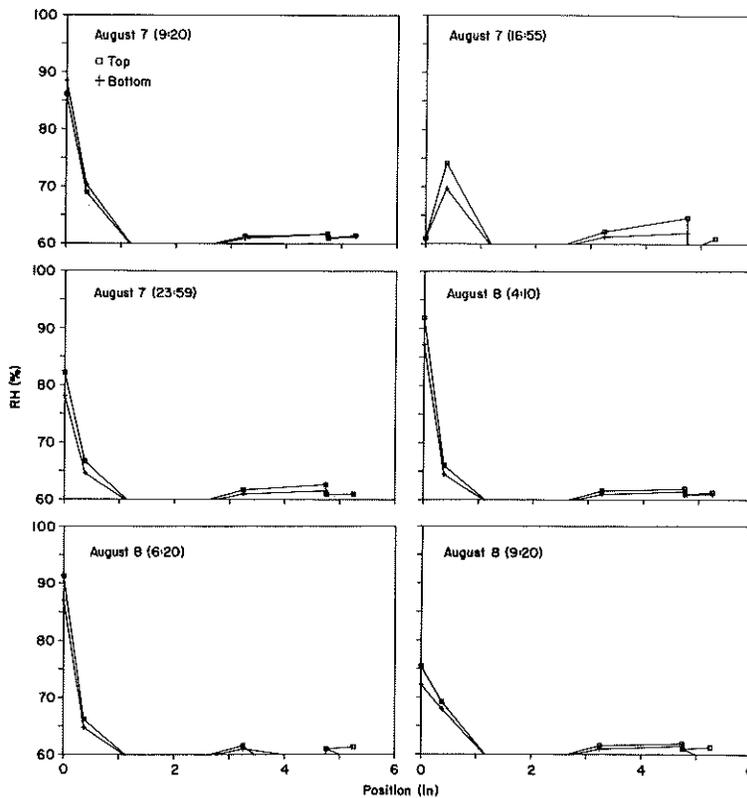


Figure 10. Relative humidity (RH) in panel S1 at different times on August 7 and 8, 1984, measured by sensors positioned as indicated (inches) from the exterior surface of the siding