#5580

Moisture Movement in Walls in a Humid Climate

H.T. Mei, P.E.
ASHRAE Member

ABSTRACT

Condensation problems in warm, humid climates are distinctly different from those in cold climates. To investigate moisture movement in walls in a humid climate, a test building was erected on the campus of a university in Texas. This building holds nine instrumented wall panels of different construction. The panels are all installed on the south side of the building. The results showed one occurrence of condensation—the panel with fiberboard sheathing on the polyethylene vapor retarder located on the room side (interior). The other wall panels showed no evidence of condensation.

INTRODUCTION

In the past, home dwellers were not concerned with the problem of excessive humidity. Houses were bigger and more loosely constructed. The interchange of outside and inside air through defects in the building envelope was sufficient to prevent excessive humidities within the structure. However, in recent years, the tendency has been to construct tight, well-insulated dwellings of modest size. Homes today are caulked, weather stripped, and equipped with storm sashes and doors to make them energy efficient and comfortable. Excessive moisture or structural condensation requires methods of control in today's homes. During construction, preventive measures are inexpensive and should be taken as a matter of simple insurance.

Condensation problems in warm, humid climates are distinctly different from those in cold climates. Moisture is constantly transferred from the warm, moist side of building components to the colder, drier side, and may condense on colder surfaces, usually at temperatures that favor the growth of decay organisms. Outdoor humidity during the summer cannot be controlled. Therefore, placement of effective vapor retarder remains the only option. Generally, the greatest concern in the northern part of the United States is winter condensation, as indoor moisture moves toward the cold outdoors. Various maps of the United States are available that describe the need for moisture control as they relate to potential winter or prolonged condensation problems. The shaded area in Figure 1 (NRCA 1985) shows where vapor retarders are needed on the basis of an average January temperature below 40°F (4.4°C), where the relative humidity in the building is 45% or higher.

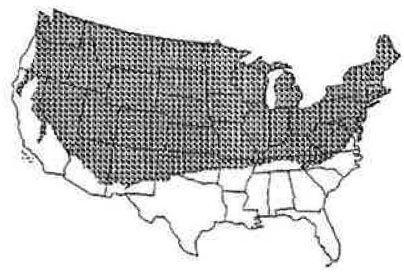

Figure 1 *Mean average January temperature below 40°F (4.4°C)*

Under winter conditions, the source of moisture is usually within the house itself, but in the summer, the reverse flow may occur in hot/warm humid climates where air conditioning is used extensively, unless some preventive measures are taken. While the principles of moisture flow remain the same, climatic differences present different problems. It is important to consider the potential problems under these conditions and to operate the buildings accordingly.

To investigate moisture movement in walls in a warm, humid climate, a test building was erected on the campus of a university in Texas, as a cooperative research project. Beaumont, Texas has a Gulf Coast climate with summer temperatures ranging from 68 to 95°F (20 to 35°C) combined with extremely high (80 to 90%) relative humidity. Winter temperatures average around 54°F (12°C). The indoor temperature of the test building was maintained between 68°F (20°C) and 73°F (23°C), with relative humidity between 50 and 60%.

The definition of "humid climate" has been given in the 1989 *ASHRAE Handbook—Fundamentals* (page 21.13). However, as far as moisture control is concerned, Figure 2 serves as a valuable guide to the warm humid zone in the continental United States. This zone consists of the area south of the 40°F line (Figure 1) and east of Highway 75

H.T. Mei, Professor of Mechanical Engineering, Lamar University, Beaumont, Texas.

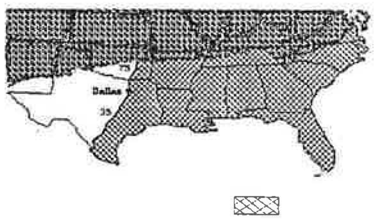

Figure 2 Warm humid region

in Oklahoma and Texas, and Interstate 35 in Texas (from McAlester, OK; Dallas, Austin, San Antonio to Laredo, TX). The warm humid region, therefore, includes South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, east Virginia, east North Carolina, south Tennessee, south Arkansas, the southeast corner of Oklahoma, and east Texas.

TEST BUILDING

The test building (Figure 3) is about 25 ft long by 8 ft wide (7.6 by 2.4 m) and contains nine south-facing instrumented wall panels, each wall of a different structure design combination. The north wall also contains several panels, but these panels were only partly instrumented. Both of the 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 Mei and Yang (1985).

Test Wall Panels

Each wall panel is constructed in a different permutation of design and materials. The panels are designed to permit the measurement of the effects of the following variables on moisture migration and insulation effectiveness:

1. 3/4-in. (19-mm) airspace
2. 1-in. (25.4-mm) foam expanded polystyrene sheathing with aluminum foil facing outdoors
3. 1-in. (25.4-mm) fiberboard sheathing w/wo a polyethylene sheet
4. 3-1/2 in. (89-mm) of fiberglass insulation w/wo kraft paper
5. 1/2-in. (12.7-mm) gypsum board
6. Single-wall versus double-wall construction
7. Wall thickness [4- and 6-in. (102- and 152-mm), single and/or double]
8. Wood siding
9. Brick veneer siding
10. Location of vapor barrier

As can be seen in Table 1, all the panels for Phase I (1983-85) were constructed with hardboard siding for the exterior sheathing. Due to the prolific use of brick in residential construction, it was decided in 1988 that a brick veneer would be added to selected test panels (S2, S5, S6, and S8) in Phase II (1989-91).

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) also described this modified sensor. 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 2 ft (0.6 m) from the bottom (Figures 3 and 4). Additional pairs of thermocouples and humidity sensors were placed in the insulation 1.5 and 2.5 in. (38 and 64 mm) from the gypsum board, both near the top and bottom of the panel. The smaller panels, S5 and S6, contained only one series of sensors placed at midheight. The total of 130+ humidity sensors provided input to four amplifiers via four rotary switches.

The electronic equipment was calibrated on site by substituting known electric resistances for the sensors. The relationship between the electric resistance of the sensor and relative humidity was determined for a sample of ten sensors. This calibration showed that the effective range of the humidity measuring equipment was approximately 60 to 100% rh. The sensors were calibrated at 70 and 90°F (21 to 32°C).

In addition to the bricked panels, other modifications were made in Phase II as follows:

1. Panels S3 and S7 were replaced by double-wall construction, with a vapor retarder (aluminum foil) installed between the walls, to test the effectiveness of a vapor retarder in such an arrangement.
2. Panel S4, which was built with essentially dead airspace just behind the exterior sheathing, was provided with a 1 in. by 12 in. screened ventilation slot in the bottom of the airspace and ducted into the attic at the top. This modification allowed for positive ventilation through the airspace.
3. The polyethylene vapor retarder in the back of Panel S1 was removed.
4. The kraft paper backing on the insulation of Panel S8 (brick siding) was replaced with a polyethylene vapor retarder.
5. On Panel S9, the exterior hardboard siding was replaced with an unfinished 3/8 in. T-111 plywood siding.
6. Finally, the soffit was sealed around the entire unit to ensure that the attic fan would provide positive ventilation on the panels designed for such positive ventilation.

These changes are summarized in Table 2.

RESULTS

The measured (1989-90) outdoor conditions are shown in Figure 5. The temperature varied between 68 to 95°F (20 to 35°C) in the summer months, with relative humidity averaging between 60 and 90%. In the winter season, temperatures dropped and ranged from 37 to 77°F (10 to 25°C). Measured indoor conditions are shown in Figure 6.

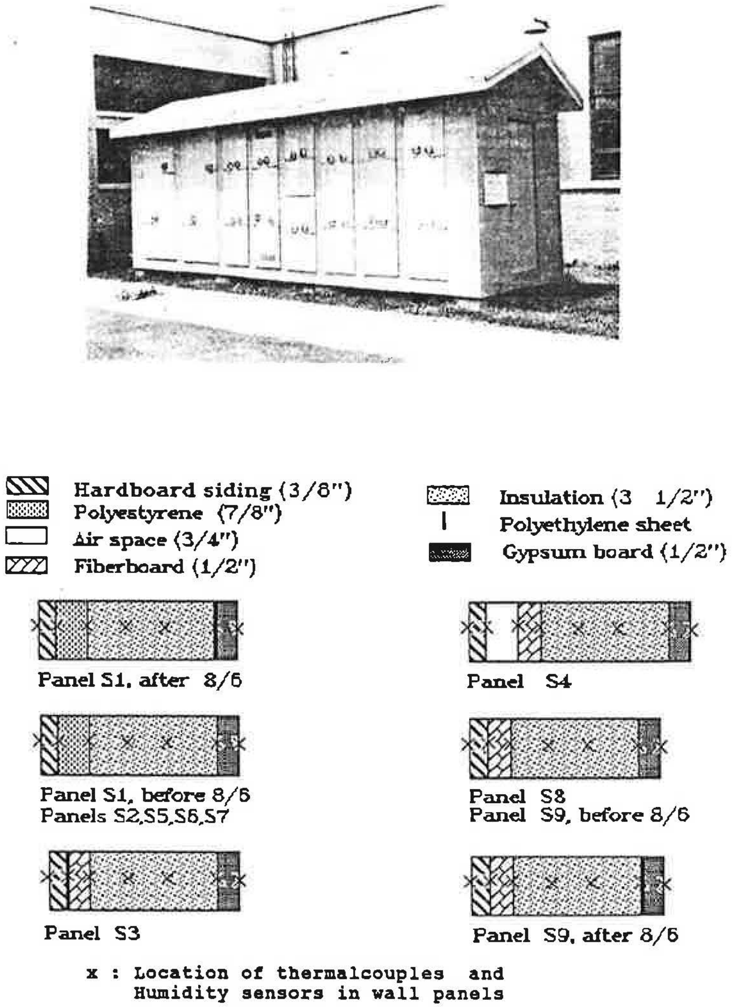

Figure 3 *Test building (Phase I)*

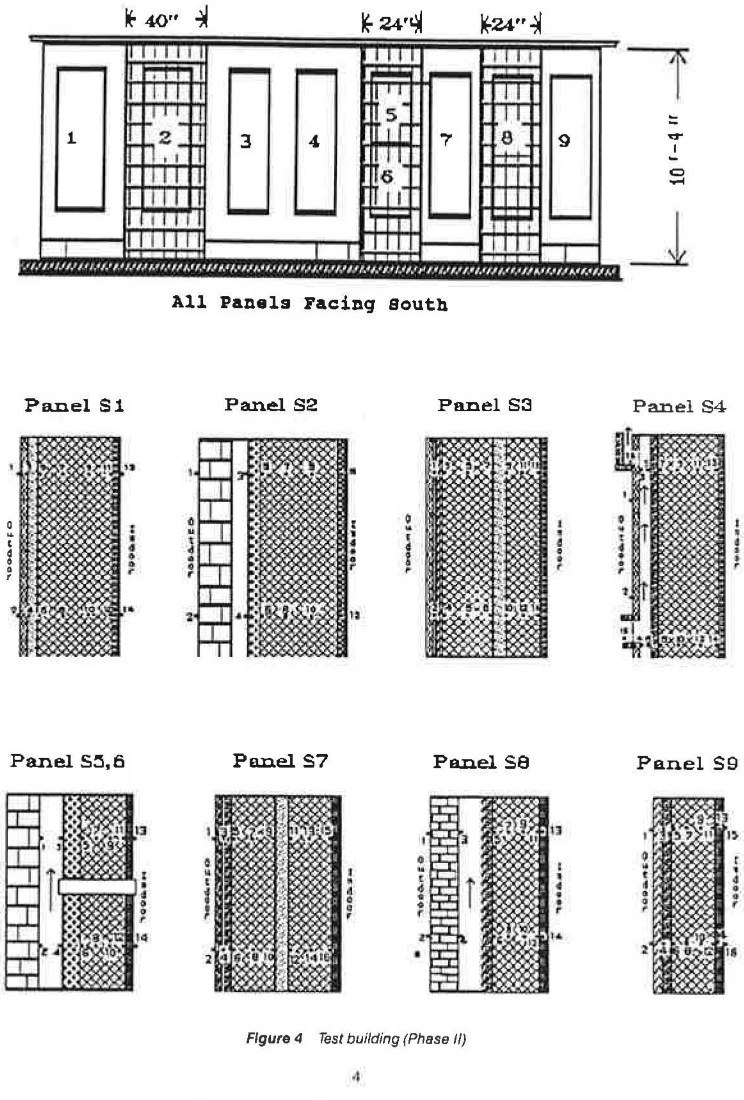

Figure 4 Test building (Phase II)

TABLE 1
PHASE I—Construction and Design of Test Panels

Panel Number	Size ft(m)	Siding	Exterior vapor retarder	Air space in (mm)	Sheathing	Insulation	Interior vapor retarder	interior
S1 before 8/6	3 x 7 (.92x2.13)	Hardboard	Aluminum foil, untaped joint	---	Polystyrene	Fiberglass	Kraft paper	Gypsum board
S1 afetr 8/6	3 x 7 (.92x2.13)	Hardboard	Aluminum foil, untaped joint	---	Polystyrene	Fiberglass	Kraft paper and Polyethylene	Gypsum board
S2	3 x 7 (.92x2.13)	Hardboard	Aluminum foil, taped joint	---	Polystyrene	Fiberglass	Kraft paper	Gypsum board
S3	1.5 x 7 (.46x2.13)	Hardboard	Polyethylene	---	Fiberboard	Fiberglass	------	Gypsum board
S4	1.5 x 7 (.46x2.13)	Hardboard	------	3/4(19) Ventilated after 8/6	Fiberboard	Fiberglass	Kraft paper	Gypsum board
S5,6	1.5 x 3.5 (.46x1.07)	Hardboard	Aluminum foil	---	Polystyrene	Fiberglass	-------	Gypsum board
S7	1.5 x 7 (.46x2.13)	Hardboard	Aluminum foil	---	Polystyrene	Fiberglass	-------	Gypsum board
S8	1.5 x 7 (.46x2.13)	Hardboard	------	---	Fiberboard	Fiberglass	Kraft paper	Gypsum board
S9 before 8/6	1.5 x 7 (.46x2.13)	Hardboard	------	---	Fiberboard	Fiberglass	-------	Gypsum board
S9 after 8/6	1.5 x 7 (.46x2.13)	Hardboard	------	---	Fiberboard	Fiberglass	Polyethylene	Gypsum board

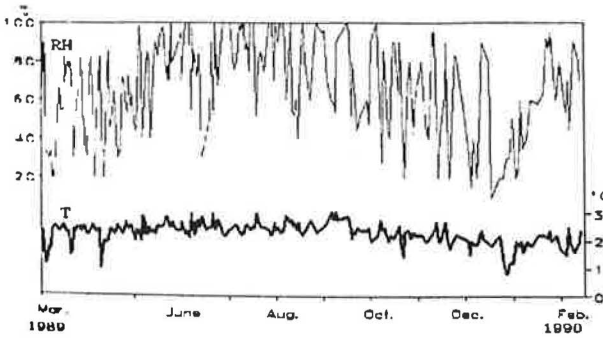

Figure 5 Outdoor temperature and relative humidity

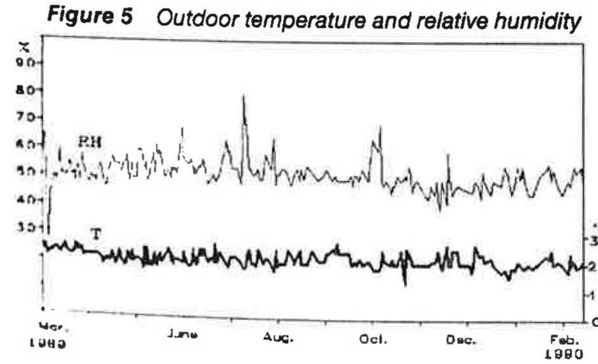

Figure 6 Indoor temperature and relative humidity

Moisture Profile

The instrumentation performed well. The moisture migration profile developed in the test wall panels had a general pattern as shown in Figures 9, 10, 11, and 12.

Condensation Cycle

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

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 relative humidity conditions (TenWolde 1985). The sensor in the adjacent insulation, located 1.5 in. (38 mm) from the vapor retarder, also showed an increase in relative humidity in the insulation immediately following the change. The condensation on the polyethylene was cyclical, and there was no long-term moisture accumulation.

Cyclical condensation was detected 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 a foil faced sheathing, an outside polyethylene vapor retarder, or no effective inside vapor retarder; these structures did not experience any condensation.

TABLE 2
PHASE II—Construction and Design of Test Panels

Panel Number	Size ft(m)	Siding	Air space	Exterior Vapor retarder	Sheathing	Insulation	Interior vapor retarder	interior
S1	3 x 7 (.92x2.13)	Hardboard	---	Aluminum foil, untaped joint	Polystyrene	Fiberglass	-------	Gypsum board
S2	3 x 7 (.92x2.13)	4" Brick	Positive ventilation	Aluminum foil, taped joint	Polystyrene	Fiberglass	Kraft paper	Gypsum board
S3	1.5 x 7 (.46x2.13)	Hardboard	(2 x 6 - 2 x 4 double wall structure)**					Gypsum board
S4	1.5 x 7 (.46x2.13)	Hardboard	Positive ventilation	-------	Fiberboard	Fiberglass	Kraft paper	Gypsum board
S5,6	1.5 x 3.5 (.46x1.07)	4" Brick	Positive ventilation	Aluminum foil	Polystyrene	Fiberglass	-------	Gypsum board
S7	1.5 x 7 (.46x2.13)	Hardboard	(2 x 4 - 2 x 4 double wall structure)**					Gypsum board
S8	1.5 x 7 (.46x2.13)	4" Brick	Positive ventilation	------	Fiberboard	Fiberglass	Polyethylene	Gypsum board
S9	1.5 x 7 (.46x2.13)	Plywood	------	---	Fiberboard	Fiberglass	Polyethylene	Gypsum board

** Between the double walls, there is a layer of 3/4" Polystyrene board with aluminum foil facing outside (see figure 4)

The condensation cycle in panel S9 was caused by solar radiation (Figure 7) warming the siding and sheathing and driving part of the moisture (Figure 8) 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 was repeated.

Ventilation

The purpose of Panel S4 is to investigate the effectiveness of the airspace between the siding and the sheathing. The panel was initially built with a dead airspace, and later, ventilation holes were drilled through the siding at the bottom and top of the panel. These modifications did not show the merit of natural ventilation. In the summer of 1988, it was opened with a 1 in. by 12 in. screened slot in the bottom of the airspace and ducted into the attic at the top. This arrangement allowed for positive ventilation through the airspace. Figure 12 shows the results taken in August 1990.

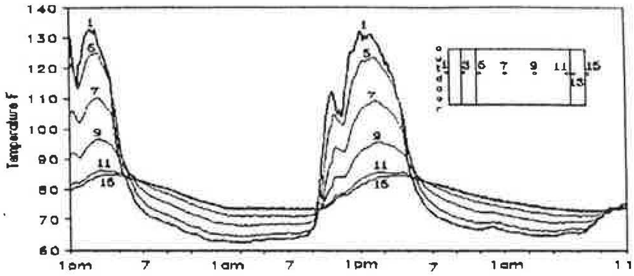

Figure 7 *Temperature measurement on 2/11-12/91 Temperature History (Panel S9)*

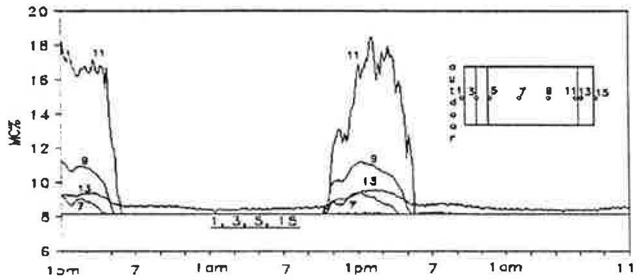

Figure 8 *Moisture measurement on 2/11-12/91 Moisture History (Panel S9)*

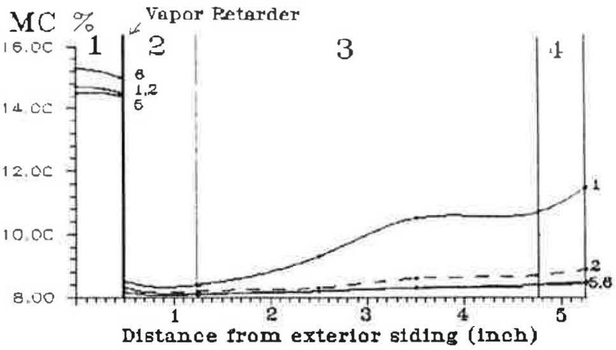

Figure 9 *Moisture distribution of Panels 1, 2, 5, and 6 in August 1990*

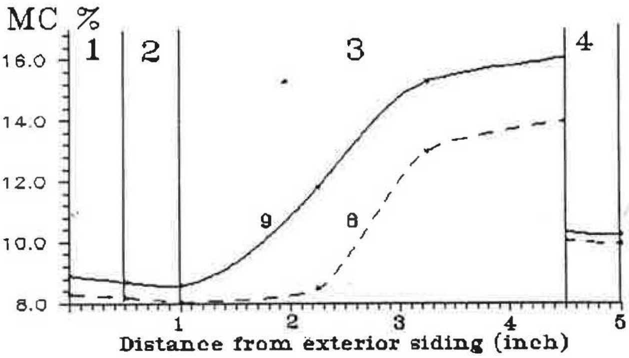

Figure 10 *Moisture distribution of Panels 8 and 9 in August 1990*

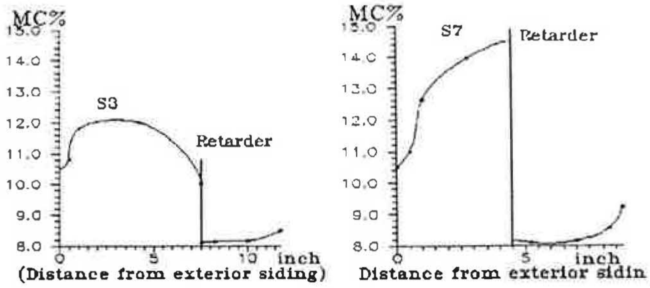

Figure 11 *Moisture distribution of Panels 3 and 7 in August 1990*

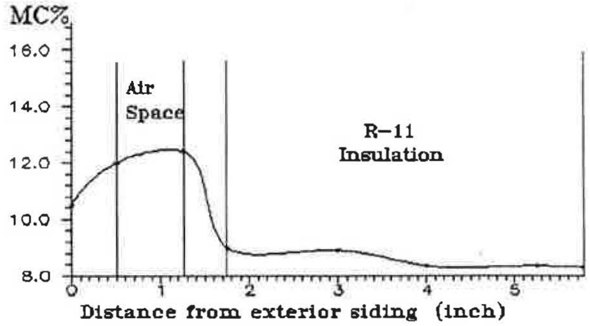

Figure 12 *Moisture distribution of Panel 4 in August 1990*

Panel S8 (with the positive ventilation) experienced no cyclical condensation and accumulated less moisture than Panel S9 (Figure 10). From the results shown in Figure 11, positive ventilation in Panels S2, S5, and S6, made some difference in moisture content in the wall cavities from the comparable panel (S1) without the airspace. This finding demonstrates that positive ventilation can reduce moisture migration into the wall cavity.

Aluminum Foil Foam Sheathing

The builders in the Gulf Coast area prefer to use foam sheathing with aluminum foil as a sheathing material in new houses. It increases the R-value of the wall, saves labor cost, and reduces moisture migration. Figure 9 shows that foam sheathing with aluminum foil facing outdoors has a successful vapor retarding effect during the summer in a warm, humid area.

If only one layer of vapor retarder is used in a double-wall construction, it seems that the ideal location for this material would be the joint section of two walls. Because of the strength of the foam sheathing and its ease of installation, this construction was used for testing the effectiveness of a vapor retarder on Panels S3 and S7. The results are shown in Figure 11.

CONCLUSIONS AND RECOMMENDATIONS

1. An interior vapor retarder and fiberboard sheathing can result in cyclical condensation on the vapor retarder. This finding indicates that in a warm, humid climate, an interior (room side) vapor retarder is undesirable. However, in these tests, no damage on long-term moisture accumulation occurred.

2. Direct and indirect radiation from the sun has a major influence on humidity conditions in south-facing wall cavities, especially those with hygroscopic sheathing.

3. The test results for Panels S1, S2, S5, and S6 (Figure 9) indicate that the foam sheathing with aluminum foil facing outdoors has a successful vapor retarding effect during the summer in a warm, humid area. The polyethylene sheet, when properly installed, also performs satisfactorily. However, a polyethylene sheet can easily rupture due to the stress of wind and mechanical loads, unless it is properly supported.

4. The positive ventilated airspace between the siding (wood or brick) and sheathing can reduce moisture flow into the wall cavity.

5. For a double-wall construction, a vapor retarder located between the walls is feasible. Test data regarding Panels S3 and S7 (Figure 11) showed no condensation, no high concentration of moisture in the walls, and dry insulation.

6. The location of the vapor retarder is extremely important in air conditioned buildings. Installing a vapor retarder on the warm side of the wall requires a thorough local climatic investigation. There is importance in regional tailoring to establish effective solutions regarding moisture migration.

REFERENCES

ASHRAE. 1989. *ASHRAE handbook—1989 fundamentals*. Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

Duff, J.K. 1966. "A probe for accurate determination of moisture content of wood products in use." FPL-0142, Madison, WI.

Luikov, A.V. 1966. "Heat and mass transfer in capillary-porous bodies." New York: Pergamon Press, Ltd.

Mei, H.T. 1989. "Moisture migration in buildings in hot/warm humid climates." Symposium on Improving Building Systems in Hot and Humid Climates, October, Dallas, TX.
Mei, H.T. 1987. "Moisture transfer in a warm humid climate." ASHRAE/DOE/BTECC Conference, December, 1986, Fort Worth, TX, pp. 151-164.
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, Washington, D.C., pp. 325-332.
NRCA. 1985. NRCA roofing and water proofing manual. Chicago: National Roofing Contractors Association.
TenWolde, A., and Mei, H.T. 1985. "Moisture movement in walls in a warm, humid climate." ASHRAE/DOE/BTECC Conference, December, Clearwater Beach, FL, pp. 570-577.

ACKNOWLEDGMENT

The writer is grateful for the support given by the Governor's Energy Management Center; State of Texas Energy Research in Applications Program under Contract No. 5127; Lamar University, Beaumont, Texas; and the Forest Product Laboratory in Madison, Wisconsin.