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MOISTURE TRANSFER IN WALLS IN A WARM HUMID CLIMATE

by

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ABSTRACT

Most research on condensation has been focused on winter climates. However, air-conditioned buildings in a warm humid climate generally have a greater potential for moisture damage in the walls. Too little research has been done to make solid recommendations for prevention, especially with new building materials and construction practices. An outdoor exposure test unit has been constructed on the campus of Lamar University. The first phase results, containing nine instrumented hardboard siding wall panels of different design, have been reported in two previous papers (Mei and Yang 1985, TenWolde and Mei 1985).

In March-May of 1986, we revised all panels as indicated on the attached table and figures. Data were taken in the summer season (June-Oct.) of 1986. This second phase study should yield practical information about proper wall designs and building practices in a warm humid climate to builders, architects, and building researchers.

INTRODUCTION

Excessive moisture in the walls of a building is not a new condition, but its prevalence has increased as modern homes are built smaller and tighter. Under winter conditions, the source of moisture is usually within the house itself. But in the summer, the reverse flow of heat and moisture is a very real problem in air-conditioned buildings in warm humid climates unless some preventive measures are taken.

Moisture is constantly transferred from the warm, moist side of building components to the colder, drier side. Generally, the greatest concern in the northern part of this country is for winter condensation as indoor moisture moves toward the cold outdoors. The reverse flow may occur in warm humid climates where air-conditioning is used extensively. This process can be demonstrated by Figure 1, a Psychrometric Chart.

During winter, the indoor conditions are normally maintained at 70F (21C), 50% RH (point A), while outdoor conditions are 30F (-1C), 45% RH (point B). The moisture content and vapor pressure of point A is much higher than at point B, so moisture is transferred from the inside toward the outside. In the summer, however, indoor conditions shown at point C are 78F (25.6C), 55% RH, outdoor point D could possibly be 90F (32C) and 70 RH in a warm, humid region. As can be seen, moisture will thus move from the outside inward, i.e., from point D to point C. It also can be seen on the Psychrometric Chart that delta W(DC) is much greater than delta W(AB), i.e., the air-conditioned buildings in a warm humid climate generally have a greater potential for moisture damage in the walls.

Condensation problems in warm humid climates are distinctly different from those in cold, dry climates. In cold climates, the indoor humidity control by ventilation often offers an effective way to prevent condensation in walls during the winter, but outdoor humidity during the summer cannot be controlled.

As indicated in earlier papers (1,2), very little research has been done regarding the migration and condensation of moisture in the walls of residential structures located in warm humid environments. In an effort to fill this "void", the full-scale experimentation, which has been carefully documented to date, is on-going at the campus of Lamar University in Beaumont, Texas.

OBJECTIVES

The wood-frame walls of different designs for phase I were monitored during 1984-85. Second phase designs were monitored during the summer and fall of 1986, and will be monitored into the summer of 1987.

Specific objectives of the study were:

1. Establish what combination of wall design and weather conditions leads to condensation and moisture accumulation.

2. Compare the currently available moisture analysis methods for walls, namely the ASHRAE, the Glaser and the Kieper methods.

3. Determine whether a ventilated airspace between siding and sheathing affects moisture conditions in the wall.

4. Determine what can be done to prevent moisture problems in walls in warm, humid climates.

EXPERIMENTAL DESIGN

Test Building

The test building (Figure 2) is located on the campus of Lamar University, Beaumont, Texas. Beaumont has a Gulf Coast climate with summer temperatures ranging from 68 to 95 F (20 to 35 degrees Celsius) combined with extremely high relative humidity (RH). Winter temperatures average around 54 F (12 degrees Celsius).

The building is about 25 feet long by 8 feet 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. 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 foil 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

As can be seen in Table 1, all of the panels for phase I were constructed with hardboard siding for the exterior sheathing. Due to the prolific use of brick in residential construction, it was decided that a brick veneer would be added to selected test panels (S2, S5, S6, and S8). It should be noted for the ensuing discussion, that looking north, the south wall panels are numbered left to right, S1 through S9.

The original design for the brick modifications can be seen in Figure 3 and the construction was followed closely. Layers from outdoor to indoor are:

1. 4" brick veneer.
2. 1-1/2" airspace (the positive ventilation is provided through the weeping holes to the air space, and then, ducted into attic).
3. 3/4" fiberboard sheathing or 3/4" foam expanded polystyrene sheathing with aluminum foil facing outdoor.
4. 3-1/2" fiberglass insulation with either kraft paper or polyethylene vapor retarder (facing indoors).
5. 1/2" gypsum board interior sheathing.

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

1. Panels S3 and S7 were replaced by double-wall construction with a vapor retarder (aluminum foil) installed in between the walls (See Figure 4), to test the effectiveness of a vapor retarder in such arrangement.
2. Panel S4, which was built with an essentially dead airspace just behind the exterior sheathing, was provided with a 1" x 12" screened ventilation slot in the bottom of the airspace and "ducted" into the attic at the top. This modification allows for positive ventilation through the airspace (See Figure 8).
3. The polyethylene vapor retarder in the back of the 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" T1-11 plywood siding.
6. Finally the soffit was sealed around the entire unit to insure that the attic fan will provide a positive ventilation on the panels designed for such.

These changes have been summarized in Table 2.

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. 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 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. The sensor locations are shown on Figure 5.

TEST RESULTS

The experimental results are satisfactory and can be categorized into four groups, namely, the temperature profile, moisture profile, ventilation, and the condensation cycle.

Temperature Profile

Data obtained indicate that the temperature distribution across each wall layer is very close to a straight line. This validates the assumption in setting up the mathematical model.

Moisture Profile

The moisture profile developed in the wall panels has a general pattern shown as Figure 6.

Ventilation

The panel S4 with the 3/4-in (19 mm) airspace (has ventilated holes) tested in phase I showed little difference in RH from the comparable panel without the air space.

The data taken during the test in phase II, with the positive ventilated airspace between siding and sheathing (S4) and between brick and sheathing (S2, S5, S6, and S8), indicates a reduction of 5% moisture flow into wall cavity. However, the computer simulation showed a 8% moisture reduction.

Condensation Cycle

The condensation cycle (especially in the cooling season) is of prime interest to this study. During the first phase of the study, from February through July 1984, all panels indicated no condensation. On August 6, 1984, polyethylene sheets had been added to panel S1 and panel S9 on the room side of the wall between the insulation and gypsumboard. No condensation was indicated in panel S1. However, condensation did occur in panel S9 on the polyethylene sheet. The measurement indicated that evaporation was taking place after midnight, and then condensation was repeated again the following afternoon.

In the second phase study, the exterior hardboard siding of panel S9 was replaced with an unfinished 3/8" T1-11 playwood siding. The condensation disappeared after the changing. It seems that the plywood performed as an external vapor retarder. However, the panel S8 with brick siding experienced daily cyclical high concentration of moisture at daily peak time around 7 p.m. (see Figure 7), after the kraft paper backing on the insulation of panel 8 was replaced with a polyethylene vapor retarder. This finding is a direct result of placing a vapor retarder at an improper position.

MOISTURE MIGRATION ANALYSIS

The mathematical model for formulating one-dimensional heat and mass transfer through the wall is simplified from Luikov's system of equations while still keeping its transient features. It is composed of a straight-line temperature distribution and a Fick's type moisture diffusion distribution.

One of the major concerns in this study is the moisture migration rate through the wall layers. The closed form analytical solution is obtained for the moisture flux. Following a polynomial expansion of the LaPlace domain solution, LaPlace inversion is carried out by the Partial Fraction method.

The mass effect, a significant transient phenomenon of the wall, is calculated for both thermal and moisture fields. The results show that the moisture mass is much higher than the thermal mass.

In the condensation study, the diffusion model is unduly complicated; therefore, the steady-state model is used instead.

Only a few available methods can analyze water vapor migration in walls and determine where and how much moisture is accumulated if condensation is occurring. The most widely accepted is the Dew-point of Moisture Profile Method, described in the ASHRAE Handbook of Fundamentals. It is based on the steady-state linear diffusion theory and ignores the effect of air convection and condensation-drying cycles. In spite of its obvious limitations, the Dew-point Method may serve to give the user an indication of whether or not moisture accumulation is likely. However, this method can be very time consuming and is often used incorrectly. It may not always identify the region in the wall where condensation is occurring and how much moisture is accumulating.

An alternative to tne Moisture Profile Method was introduced by Prof. H. Glaser. It was not until 1956 that the equation known as the "community equation" was evolved, and the development of pressure-diffusion resistance diagram in 1959. Glaser's Method depicts the values of resistance to moisture conductance, which enables calculations to be executed within an acceptable time on building designs.

Another alternative to the Moisture Profile Method was introduced by Kieper in 1976. Kieper's Method is a graphical method based on one dimensional steady-state heat conduction and diffusion equations, but allows for rapid evaluation of different wall designs under the same environmental conditions. Unfortunately, this method has not yet found widespread acceptance, partly because it has not been clearly described and partly because blank Kieper diagrams are not readily availble.

Evaluations on these three methods, namely the ASHRAE, the Glaser, and the Kieper methods, indicate (Mei and Yang 1983) that the Kieper method is the most efficient for engineering application. Although a more comprehensive analytical tool which includes convection and transient effects is needed, such a method has yet to be developed. Until it is available, the Kieper Method may serve as the optional alternative.

CONCLUSION AND RECOMMENDATION

1. The 'reverse flow' (from outdoor towards inside) of heat and moisture is a very real problem in an air-conditioned building in warm humid climates unless some precautions are taken.

2. Three methods, namely, the ASHRAE, the Glaser, and the Kieper methods, based on the steady-state model, are currently available in condensation study. It has been demonstrated that the Kieper method is the most efficient for engineering application. For greater accessibility, the Kieper Method has been compiled into a micro-computer package (Mei 1985).

3. The temperature profile is very close to a straight line, which strongly supports the mathematical model.

4. Moisture migration tendencies are subject to seasonal changes.

5. For a double wall construction, it seems that a vapor retarder located between the walls is a feasible solution. Our test data of panels S3 and S7 showed no condensation, no high concentration of moisture in the walls, and dry insulation.

6. The size of the test panel was found to be insignificant.

7. Sealing the nail trail with Shurtape on the foam sheathing in panel S2 shows an insignificant effect.

8. The fiberglass insulation stayed dry in all panels. This result was true even in panels S8 and S9 during the condensation cycles. Even while water vapor was condensing on polyethylene, the nearby sensors (1.5-in. away) in the insulation registered less than 70% RH.

9. Solar energy transmission on the walls, especially at the south and west orientations, raises the temperature of the outer surfaces; in turn, it affects the amount of moisture driven into the wall cavity. Architects and builders should investigate these walls thoroughly at the design stage.

10. The test results in panels S1, S2, S3, S5, S6, and S7 indicates that the foam sheathing with aluminum foil facing outdoors has a successful vapor retarding effect during the summer in the Gulf Coast 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 a proper way to support it can be utilized.

11. The positive ventilated airspace between siding (wood or brick) and sheathing will reduce heat and moisture flow into the wall cavity. If an aluminum foil vapor retarder is used, it will also act as a radiant barrier by controlling radiation transfer in the walls.

12. The test results in double (with external and interior) vapor retarders, panel S1 in phase I and panel S9 in phase II, showed no condensation and the fiberglass insulation stayed dry. A word of caution: If any side vapor retarder is damaged for any reason, moisture can migrate into the wall cavity. Consequently, the water vapor is very hard to dry out.

If barriers are used on both sides, a method that has been proposed involves the arrangement of each barrier with controlled ports so that the side which is warm can be made vapor tight while the cold side is allowed to breathe.

13. 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.

14. The WARM HUMID region probably includes Texas, Arkansas, Louisiana, Mississippi, Alabama, Georgia, Florida, South Carolina, North Carolina, and Virginia. For this region, moisture definitely moves from the outdoors inward into the building in the cooling season. In order to stop this movement, the vapor retarder should be installed on the warm side, which is the outside in this region.

Some main U.S codes or authorities, however, will not allow the external vapor retarder approach. It is thus apparent and necessary that regional climates be studied thoroughly in order to develop better guidelines. There is importance in regional tailoring to establish effective solutions regarding moisture migration.

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TABLE 1

PHASE I

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

TABLE 2

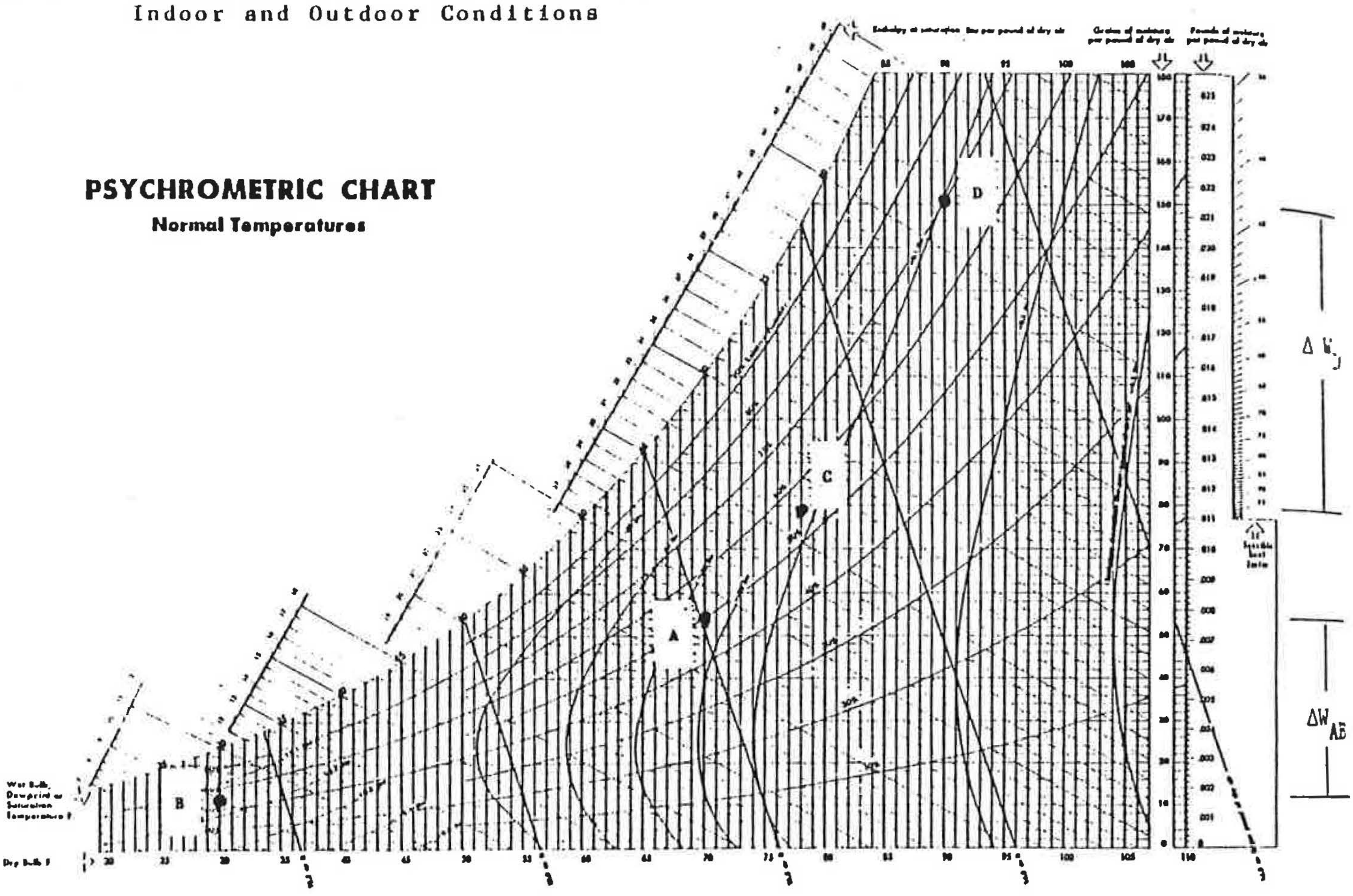
PHASE II

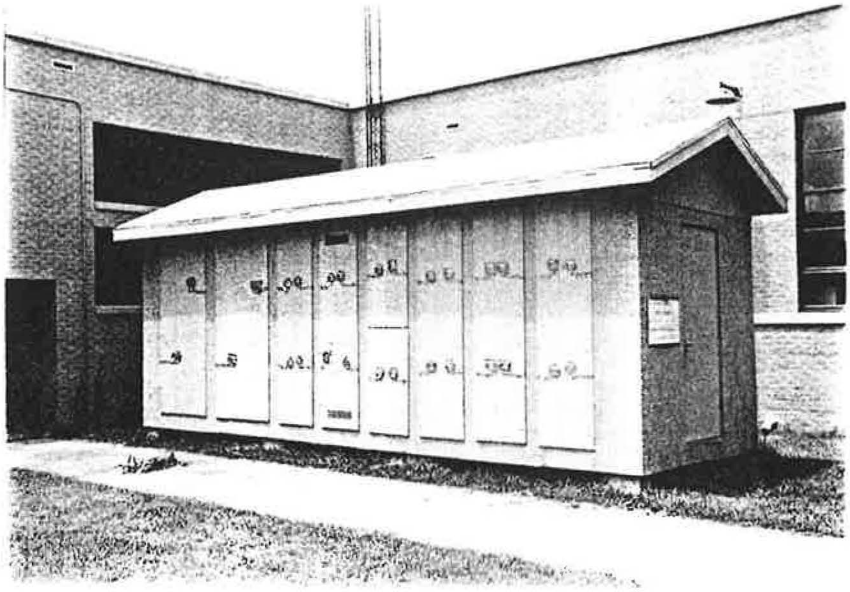
CONSTRUCTION AND DESIGN OF TEST PANELS

PANEL NUMBER	SIZE	SIDING	EXTERIOR VAPOR RETARDER	AIR SPACE	SHEATHING	INSULATION	INTERIOR VAPOR RETARDER	INTERIOR
	ft (m)			in (mm)				
S1	3 x 7 (0.92 x 2.13)	Hardborad	Aluminum foil, untaped joint	---	Polystyrene	Fiberglass	---	Gypsum board
S2	3 x 7 (.92 x 2.13)	4" Brick	Aluminum foil, taped joint	Positive ventilation	Polystyrene	Fiberglass	Kraft paper	Gypsum board
S3	1.5 x 7 (.46 x 2.13)	Hardboard	(2 x 6 - 2 x 4 double wall structure)*					Gypsum board
S4	1.5 x 7 (.46 x 2.13)	Hardboard	---	Positive ventilation	Fiberboard	Fiberglass	Kraft paper	Gypsum board
S5,6	1.5 x 3.5 (.46 x 1.07)	4" Brick	Aluminum foil	Positive ventilation	Polystyrene	Fiberglass	---	Gypsum board
S7	1.5 x 7 (.46 x 2.13)	Hardboard	(2 x 4 - 2 x 4 double wall structure)*					Gypsum board
S8	1.5 x 7 (.46 x 2.13)	4" Brick	---	Positive ventilation	Fiberboard	Fiberglass	Polyethylene	Gypsum board
S9	1.5 x 7 (.46 x 2.13)	Plywood	---	---	Fiberboard	Fiberglass	Polyethylene	Gypsum board

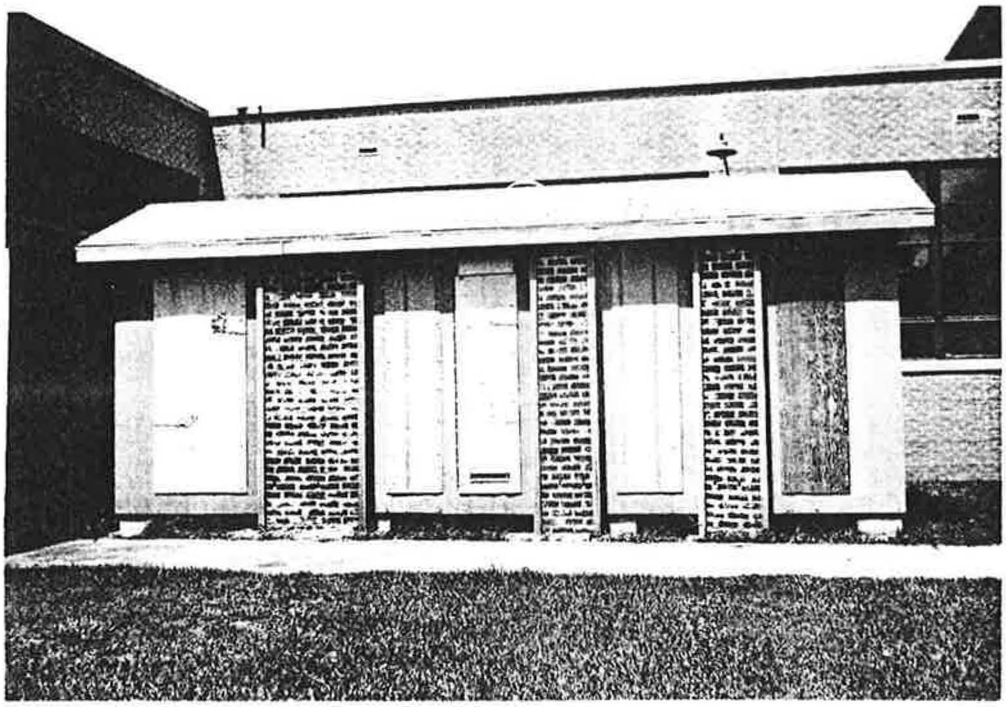
*Between the double walls, there is a layer of 3/4" polystyrene board with aluminum foil facing outside (see Figure 3)

Figure 1 A Psychrometric Chart Indicating Indoor and Outdoor Conditions





Phase I



Phase II

Figure 2 Test Building

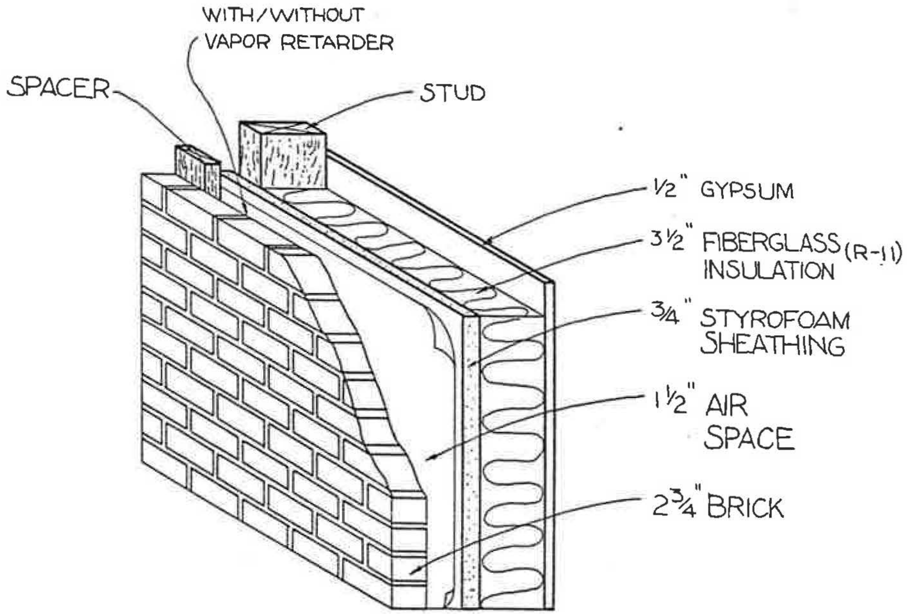


Figure 3 Brick Modification

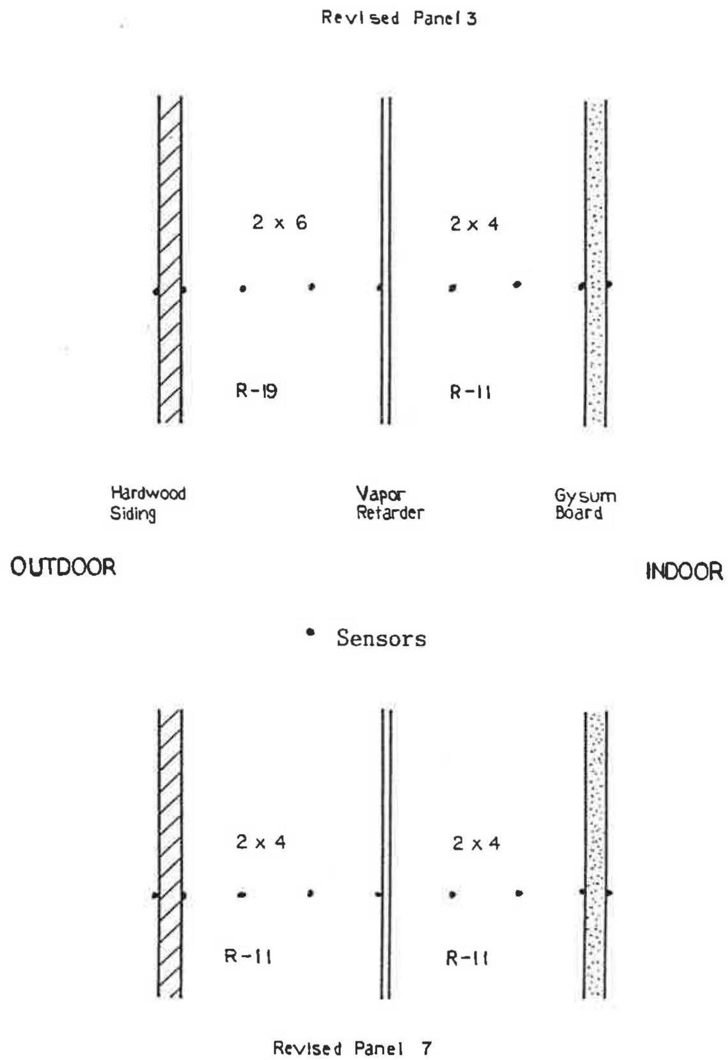


Figure 4 Double Wall Panels

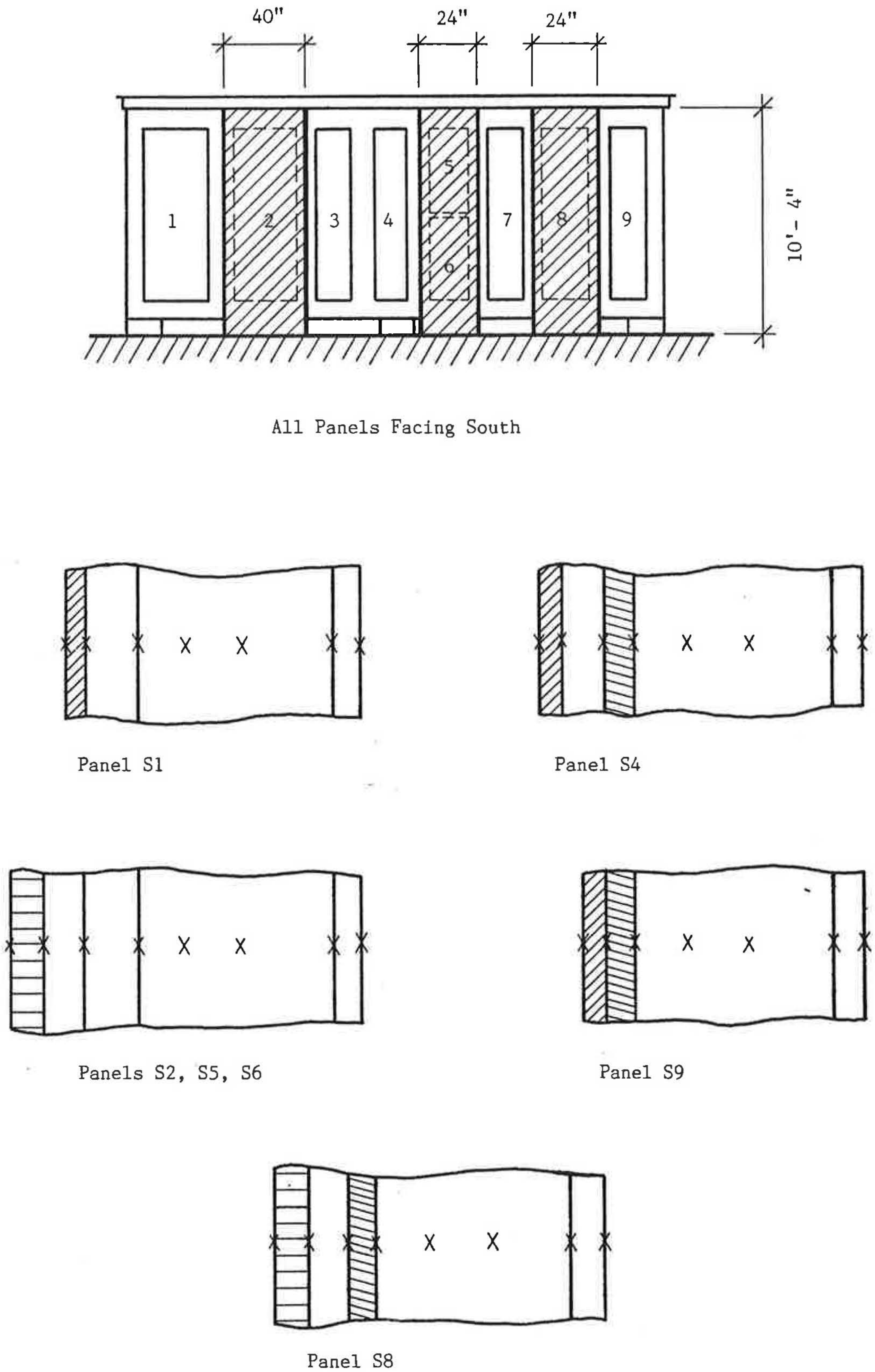
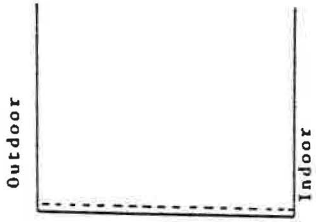


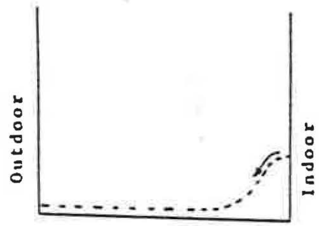
Figure 5 Instrument Locations

Figure 6 General Moisture Migration Trend on all Panels



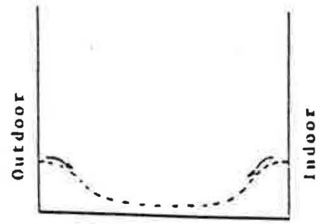
(A) Winter

All panels were dry (about 6 %MC), while first installed, and remained so at the first stage for about two weeks. Then moisture began to accumulate on the indoor side, tending to migrate outwards, while the outdoor temperature and humidity were still low in the winter.



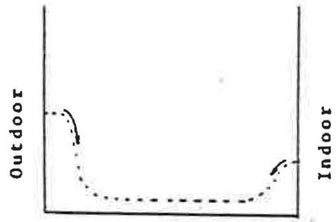
(B) Winter

The outward trend became more significant.



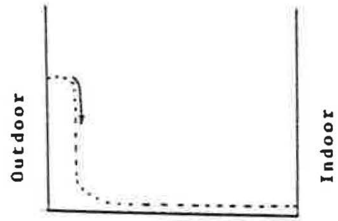
(C) Winter - Spring

As outdoor temperature and relative humidity started to rise, the "reverse flow" occurred.



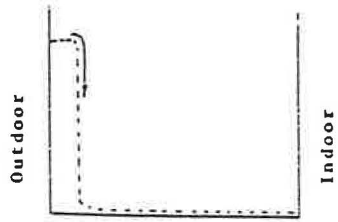
(D) Spring

Inward flow became stronger.



(E) Spring - Summer

The inward wave overruled.



(F) Summer

The inward wave was overwhelming.
This is a typical distribution under the hot humid summer condition.

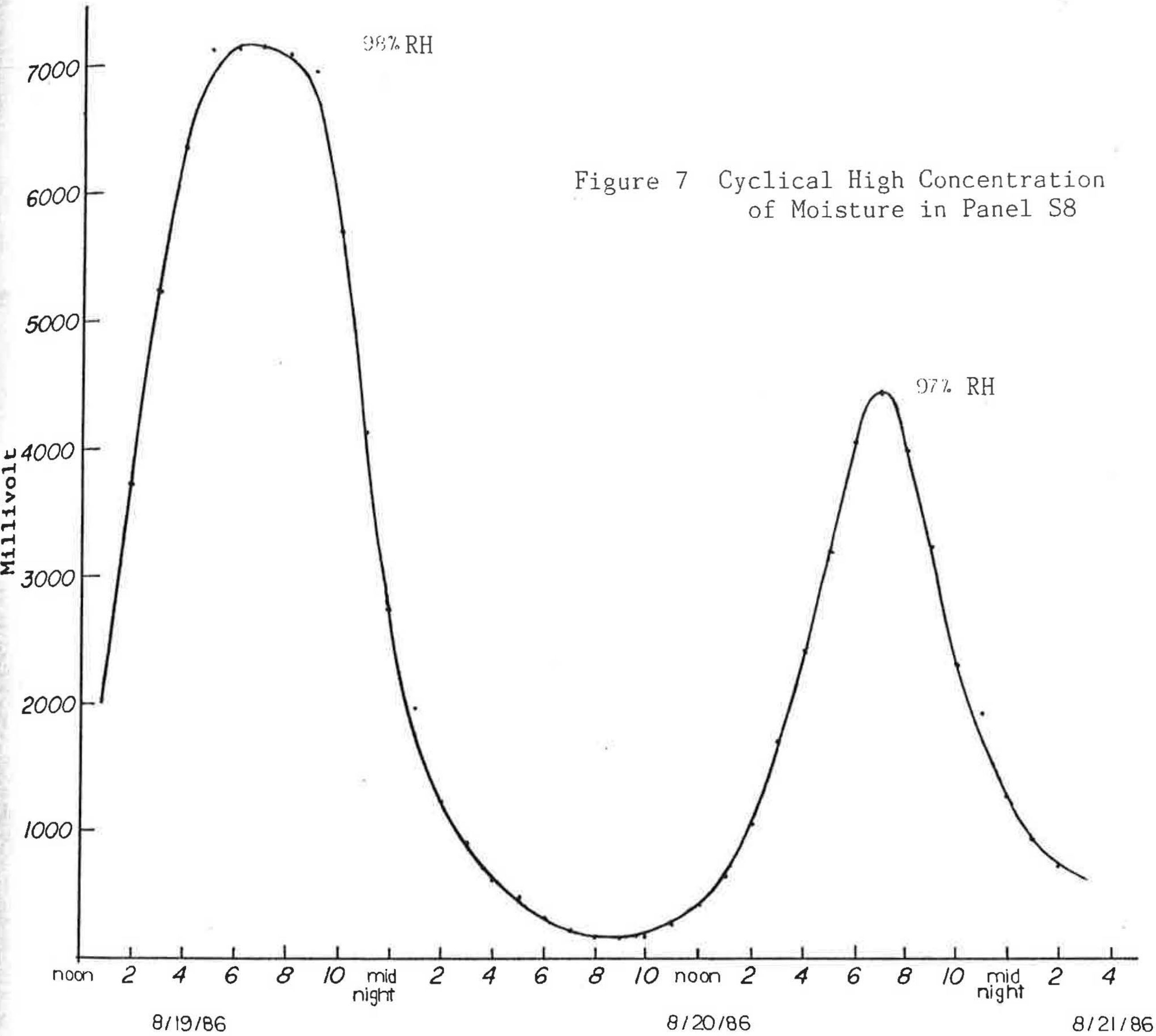


Figure 7 Cyclical High Concentration of Moisture in Panel S8

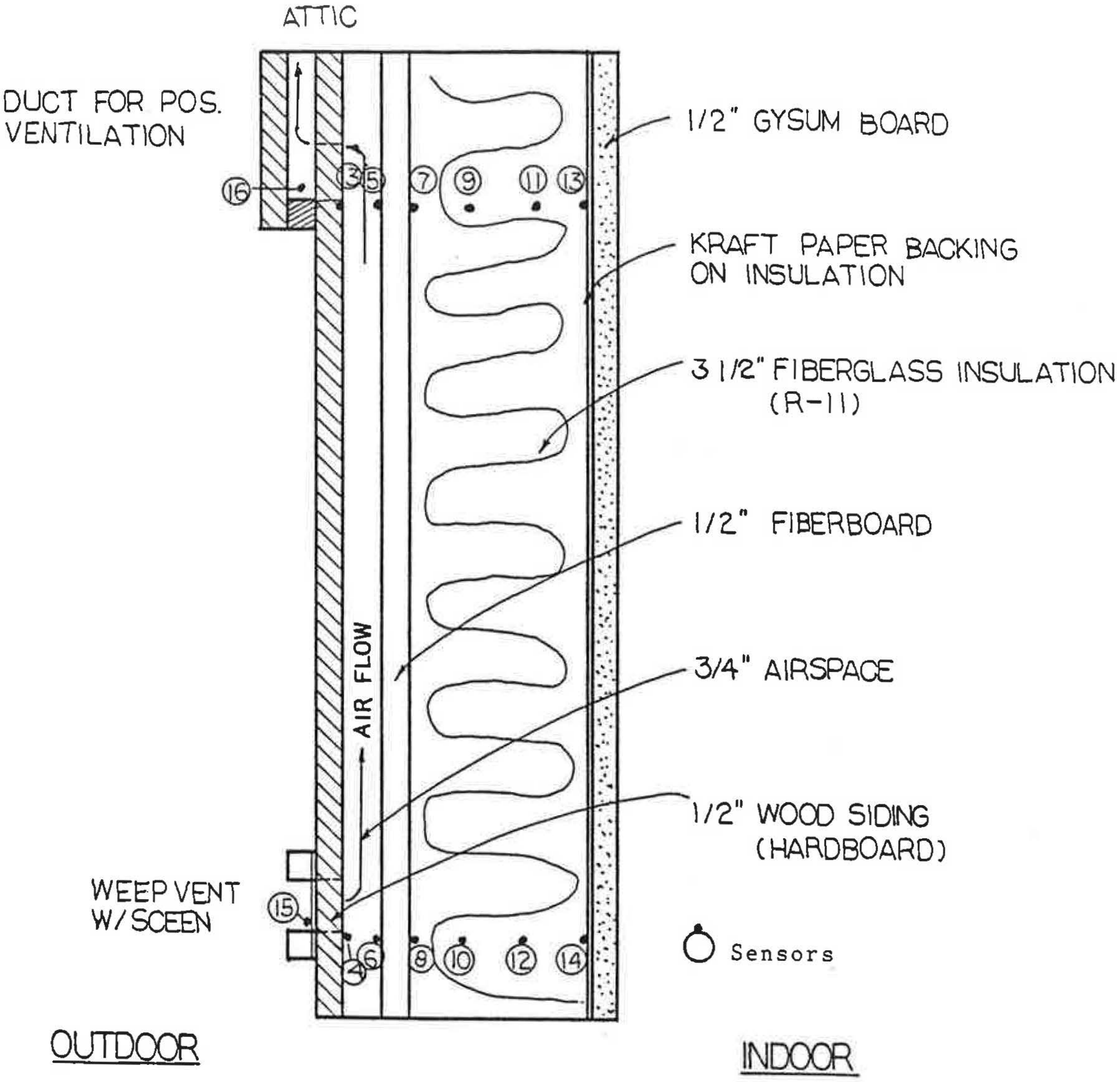


Figure 8 Panel S4