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Evaluation of Cladding and Water-Resistive Barrier Performance in Hot-Humid Climates Using a Real-Weather, Real-Time Test Facility

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ABSTRACT

Residential construction walls are typically composed of several layers of materials, including the exterior cladding, water-resistive barriers (e.g., building paper/housewrap), sheathing, studs with insulation and gypsum wall-board. The water-resistive barrier layer is designed to provide resistance to air and water entering the wall system, while being vapor permeable and allowing the wall to dry to the exterior. The appropriate level of water-resistive barrier vapor permeability in hot-humid climates, however, has been an item of contention in the construction industry. Vapor permeability maximizes wall drying, but in hot-humid climates must be balanced to minimize any potential moisture accumulation due to inward vapor drive; this may be caused by rain absorbed into cladding and subsequently driven inward as the cladding is heated by solar radiation. The objective of this project was to evaluate the performance of typical residential wall systems that incorporate water-resistive barriers with a range of vapor permeability. These systems included both absorbent and nonabsorbent claddings in hot-humid climates for direct comparison.

This paper describes the test design, the test facility construction and installation, and the resulting data. The testing included both environmental exposure and point-source water leakage. The approach chosen was to use a real-time natural exposure test hut located in Tampa, FL. This test facility had wall specimens inserted in the long sides of the hut, 16 wall specimens per side. Duplicate wall specimens were used on each side for exposure related comparisons. There was an on-site weather station to monitor local weather conditions necessary for experimental analysis. The interior conditions were controlled by point-terminated HVAC. Wall specimens were instrumented with a variety of temperature, humidity, and wood moisture content sensors for remote monitoring. In addition to natural weather exposure, the wall specimens were periodically wetted to simulate rain leakage by a water injection system.

The test station was installed in Tampa, FL (climate zone 2) in June 2006. Data were collected from June 2006 until November 2007. The experimental results show that, when no interior vapor barrier was present, all walls performed well, with no significant moisture accumulation. The only occurrence of persistent high moisture content was when an interior vapor barrier was present in conjunction with a major, unplanned water leak. Future work includes modification of the water injection design and protocol to provide higher water challenges to a broader diversity of wall assemblies.

INTRODUCTION

It is important to design wall systems that manage bulk water and moisture properly. No cladding system or installation is perfect; therefore wall systems should be designed to effectively dissipate any water penetrating the wall. It is not a question of *if* a wall will leak, but rather *when* it leaks, what the impact is on the structure. The management of water within walls is complicated by the need to balance the wetting and drying of walls (Baker 2006; Boone 2004; Derome 2010; Straube 2001). Balancing wetting and drying is especially complicated in hot-humid climates, which have a higher potential for inward vapor drive, particularly with reservoir claddings (Lstiburek 2004). Inward vapor drive in wall systems with reservoir or absorbent claddings has been

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Figure 1 Installation of specimen wall framing in container.

reported in several studies and is of most concern in hot-humid climate conditions (French 2002; Kan and Piñon 2007).

Key elements to overall wall performance are the cladding used, the water-resistive barrier (WRB) and sheathing material properties, and vapor permeability of the interior wall. Although marketing claims have been made about the performance of materials and optimum ranges of material properties, little or no systematic testing of these wall system components has been conducted under natural ambient exposure in hot-humid climates.

In order to investigate the performance of typical wall system under these climatic conditions, a test-hut test protocol was chosen. Test huts have been used as part of other studies, most notably a series of studies using the BEGHUT at University of Waterloo (Gatland et al. 2007; Straube and Burnett 1998; Straube et. al. 2004).

EXPERIMENTAL APPARATUS

Construction

Table 1. Water-Resistive Barriers

Water-Resistive Barrier	Description	Water Vapor Permeability[1] (perms)
WRB A	Non-perforated housewrap	54
WRB B	Non-perforated housewrap	6.7
WRB C	Non-perforated housewrap	11.7
WRB D	Non-perforated housewrap with drainage[2]	50

[1] Values as reported by manufacturer

[2] Housewrap has a textured surface texture to increase drainage between cladding and housewrap surface.

The Relocatable Building Enclosure Test Station (RBETS) is an ongoing test program that provides long-term natural exposure of residential wall systems. The RBETS was located in Tampa, FL, to evaluate wall performance in a hot-humid climate.

The RBETS was created from a sea-land container, which allows the unit to be easily relocated. The long sides of this container were modified by cutting out spaces to install wall test specimens and outfitted with 2 in. × 4 in. studs prior to the construction of the chosen wall specimens. These sides were large enough to accommodate 16 different wall assemblies, each of which was 2 ft wide and 8 ft high. The surfaces of the container not used for wall specimens were insulated with spray foam to allow for controlled conditioning of the interior of the chamber. Figure 1 shows the installation of the stud walls in the sides of the container. The RBETS was placed in its test location in June 2006 and was orientated such that the opposing wall sections were exposed directly to the east and the west. This was done in order to take advantage of the local weather patterns. Once the unit was placed on site, construction of the wall assemblies was completed.

The construction of each of the wall systems took into account the local building practices. The walls were of 2 in. × 4 in. base construction. The stud space was insulated with an unfaced R-13 batt, and the interior was covered with gypsum wallboard painted with latex interior paint. In the final stage of the experiment, a vapor barrier wall covering was installed on the interior wall surface. The exterior side of 15 of the wall specimens was covered with orientated strand board (OSB) sheathing, one of four water-resistive barriers, and then one of four types of cladding. One wall specimen was an open stud wall system (no sheathing) common in the Southwest US. The four water-resistive barriers used in the testing varied by their reported vapor permeability and are listed in Table 1. The cladding types used during this phase of testing were as follows: painted fiber-cement siding, vinyl siding, brick, and stucco. Details of the wall assemblies are shown in Table 2. All wall specimens were duplicated on both sides of the container, allowing for them to be monitored with two exposures. Additionally, a limited number of wall assemblies were replicated on each side to determine specimen-to-specimen variability exposed to a single exposure. The replicated wall specimens were those with fiber-cement siding and vinyl siding each with water-resistive barrier WRB-A.

All of the wall assemblies were equipped with sensors that measured wood moisture content, temperature, and relative humidity. Each sensor was placed in predetermined, consistent locations within each wall assembly.

Sensors

Each wall system was broken down into layers; the innermost layer being the interior wall-board, while the outermost layer was the exterior cladding. Every layer was assigned a

Table 2. Wall Specimen Assemblies

Wall #	Exposure	Cladding	Water-Resistive Barrier	Sheathing
1	E and W	Fiber cement	WRB B	OSB
2	E and W	Fiber cement	WRB C	OSB
3	E and W	Fiber cement	WRB A	OSB
4	E and W	Vinyl	WRB A	OSB
5	E and W	Vinyl	WRB C	OSB
6	E and W	Stucco	Paper-backed lath + WRB B	OSB
7	E and W	Stucco	Paper-backed lath + WRB C	OSB
8	E and W	Stucco	Paper-backed lath + WRB A	OSB
9	E and W	Brick	WRB A	OSB
10	E and W	Brick	WRB B	OSB
11	E and W	Brick	WRB C	OSB
12	E and W	Vinyl	WRB A	OSB
13	E and W	Vinyl	WRB B	OSB
14	E and W	Fiber cement	WRB A	OSB
15	E and W	Fiber cement	WRB D	OSB
16	E and W	Fiber cement	WRB A	none

Note: Series was duplicated on both sides of the container.

Table 3. Wall Layer Outline

	Corresponding Wall Layer
A	Exterior face of gypsum
B	Interior face of stud space
C	Middle of stud space; interstitial
D	Bottom of framing/bottom plate
E	Sheathing
F	Water-resistive barrier
G	Drainage gap or interior face of cladding
H	Exterior face of cladding

corresponding letter to identify its location with the wall assembly. See Table 3 for details.

In addition to the lettering system to identify the layer location of a sensor, sensors were also placed at predetermined, consistent heights. To that end, most of the sensors were located at 48 in. from the bottom of the wall, which is the midpoint of the wall system. Others were located at the bottom or base of the wall (i.e., the base plate) and at 16 in. from the bottom of the wall. Sensors were concentrated in the bottom half of the wall, as it was expected that the highest moisture readings would occur in this region due to both the placement of the water injection apparatus at 16 in. and gravity effects. In general, each wall assembly possessed approximately 16 sensors that, combined, measured temperature, relative humidity, and moisture content. Each sensor recorded a measurement every 10 minutes that was stored on the data acquisition system as hourly averages.

Temperature Sensors. Each wall section possessed eight temperature sensors. See Figure 2 for details. The majority of these sensors were placed 48 in. from the bottom of the wall. These sensors were located on the outside of the cladding, in the drainage gap or plane, behind the OSB sheathing, in the stud space, and on the exterior face of the gypsum wallboard. This grouping of sensors allowed for a temperature profile from the interior temperature of the unit to the exterior climate to be observed (as shown in Figure 3). Two temperature sensors were also located at the base plate or bottom of the wall framing: one on the exterior face and the other on the interior face. In many cases, the readings from the temperature sensors were applied to create correction factors for the readings from the moisture wafers and pins. The error for the temperature sensors used in this study was approximately ±0.2°C.

Moisture Content: Pins and Wafers. Moisture content was measured using two different methods. The first used a small pair of nails (pins) placed in layers that contained wood (i.e., OSB sheathing, wood framing). The pins were driven into the wood substrate to a depth of approximately 1/4 in. at a spacing of approximately 1 in. apart and were often paired with a temperature sensor. When the moisture content was

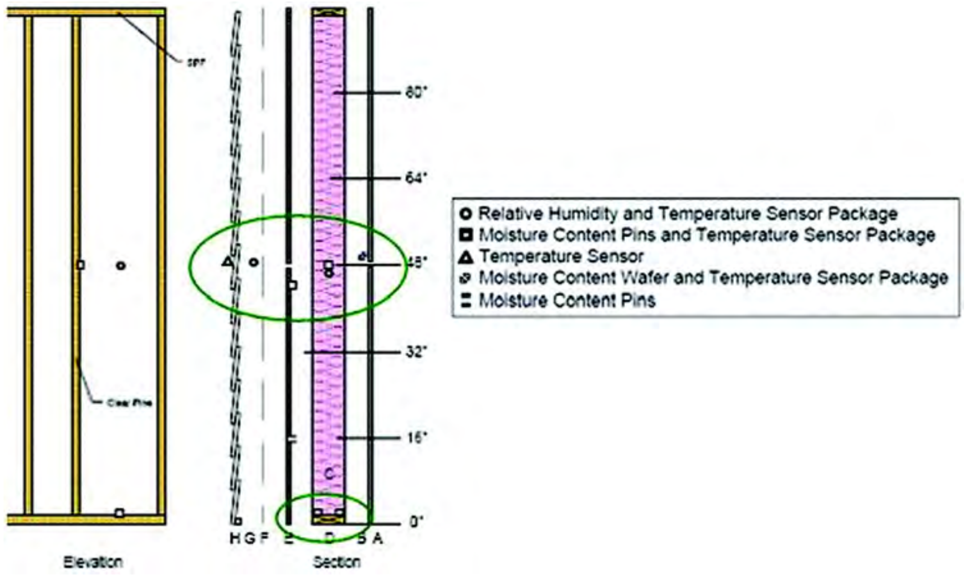

Figure 2 *Location of temperature sensors.*

measured at a location where no wood was available (e.g., gypsum, stud space), a moisture wafer was used. A moisture wafer consists of a small piece of eastern white pine with two moisture pins embedded in it. Moisture content is not measured directly; rather, the pins and wafers measure electrical resistance. Moisture content was found by a calculation involving the measured electrical resistance and temperature. Like the temperature sensors, moisture content sensors were mainly located 48 in. from the bottom of the wall. However, there was also a pair of moisture pins located 16 in. from the bottom of the wall and behind the water injection system. Additionally, there were also two sets of moisture pins at the base of the wall system: one pair close to the exterior face of the wall and the other close to the interior side of the unit. For details, refer to Figure 4. The approximate error for moisture content pins and wafers was dependent on whether the pins were embedded in OSB or a homogeneous wood substrate. Since OSB is a variable material and contains many different species of wood, the moisture content readings from OSB contain a larger error. The associated error of moisture pins in OSB was approximately ±4%. Pins inserted into a homogeneous wood specimen (i.e., pins embedded in the framing, as well as the moisture wafers) result in readings with slightly less error (about ±2%).

Relative Humidity. Each wall section contained two sensors for monitoring relative humidity. Both sensors were located 48 in. from the bottom of the wall. One of the two relative humidity sensors was located just behind the cladding in the drainage gap, while the other was located inside the stud cavity. See Figure 5.

The typical relative humidity sensor has historically been capacitance-based. However, due to availability and scheduling concerns, a micro-electro-mechanical system (MEMS) humidity sensor was used in this study. These sensors initially appeared to have several advantages over the capacitance-based sensors. The manufacturer of the MEMS sensors included a recommended calibration procedure; this calibration was performed when they were installed in the RBETS. When the unit was decommissioned in 2008, the MEMS relative humidity sensors were collected and tested to determine if they were still performing correctly and whether the sensors had drifted over the 18 months of testing. The result showed that the error associated with these sensors was quite large: greater than ±20%. Therefore, these relative humidity sensors were used only to show trends, not to draw any quantitative results.

Wetting Apparatus

Each of the wall systems included a water injection system or wetting apparatus, which allowed water to be introduced into each wall section. The purpose of this system was to simulate a point defect within a wall system, resulting in water intrusion.

The water injection system used was based on that originally developed during ASHRAE Research Project RP-1091 (Burnett et al. 2004). Each wall section apparatus consisted of a shop towel that was attached to each side of the OSB sheathing (i.e., exterior and interior faces). A perforated tube was placed at the top of the towel and was connected to a regular, unperforated vinyl hose. The vinyl hose was passed through either the exterior or the interior face of the wall. The shop towel was used as a distribution medium, which could hold on to the water long enough to allow it to be wicked into the OSB sheathing (see Figure 6). The wetting apparatus was located centered approximately 16 in. above the bottom of the wall. The wetting apparatus location in the wall specimen was

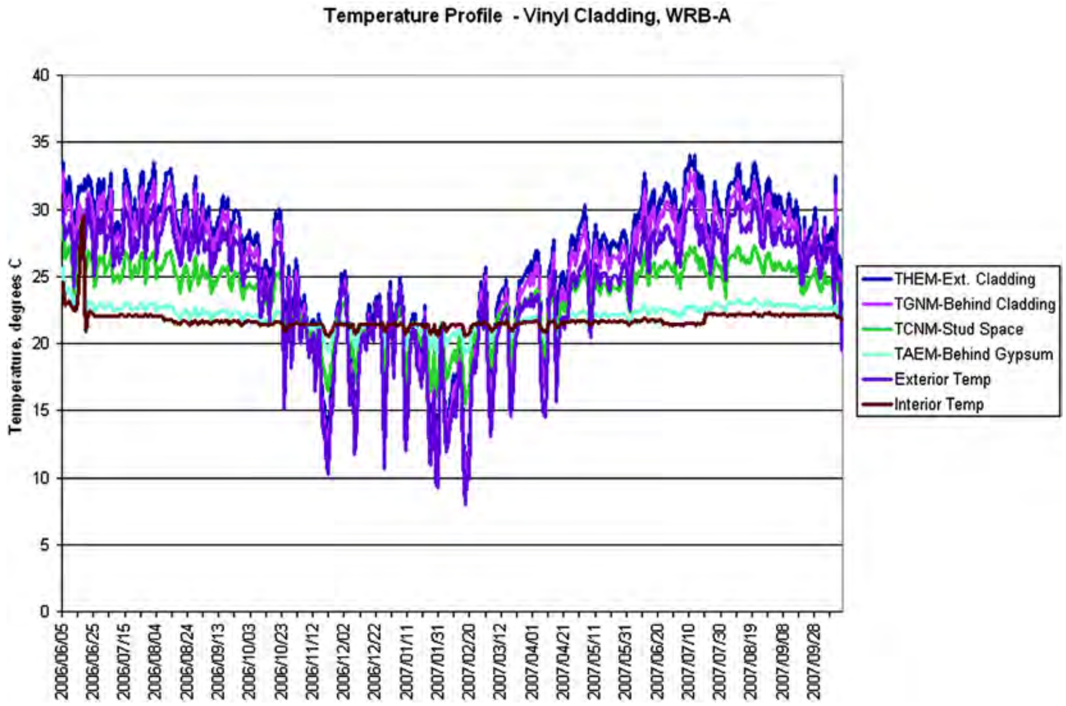

Figure 3 *Temperature profile: vinyl cladding.*

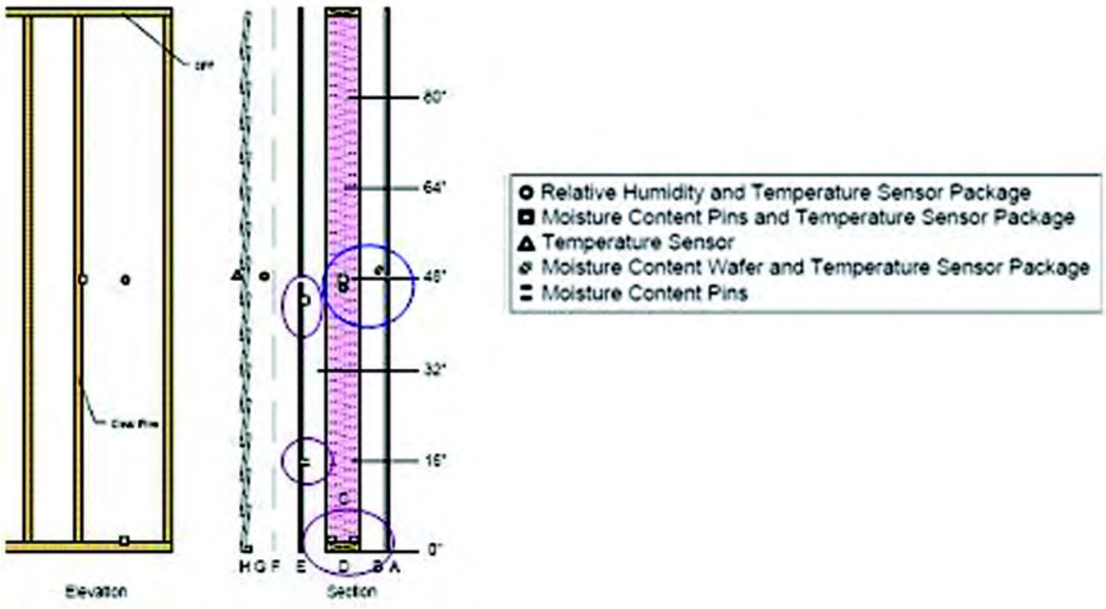

Figure 4 *Location of moisture content pins and wafers (blue = wafers; purple = pins).*

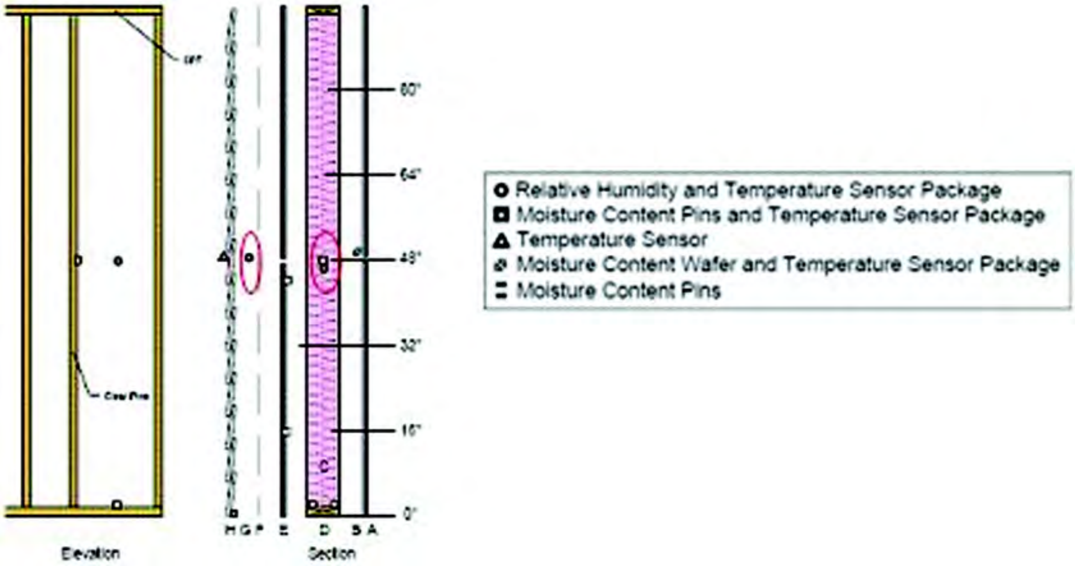

Figure 5 *Location of relative humidity sensors.*

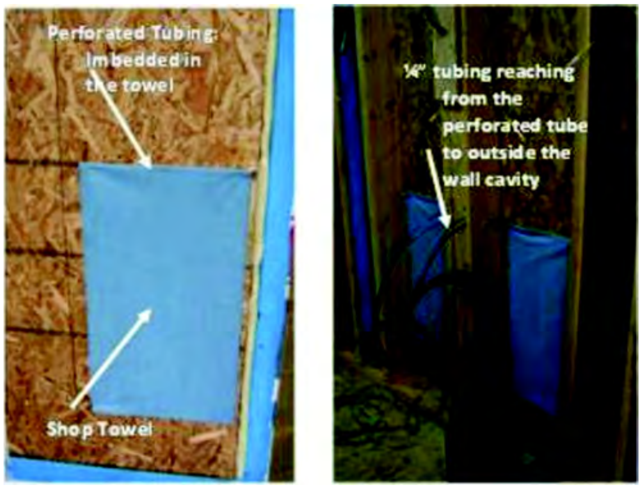

Figure 6 *Internal and external view of soaker hose, distribution media, and 1/4 in. tubing.*

chosen so the water injection would simulate a leak at a wall penetration, and to allow for monitoring of the wall performance above and below that "leak."

Researchers visited the Tampa, FL, site periodically to manually inject water into the walls through the tube located on the exterior and interior face of the wall. Water was introduced using a 50 mL syringe: 25 mL of water was drawn up into the syringe, followed by 25 mL of air. The syringe was then connected to the 1/4 in. tubing and the water was injected into the wall. Injections could be on the interior surface of the OSB, on the exterior surface of the OSB behind the water-resistive barrier, or at both sites. The schedule of wetting events is shown in Table 4. The moisture pins located just behind the OSB at the level of the water injection apparatus were used to monitor the response of the wall system to these injections.

EXPERIMENTAL RESULTS

Temperature and Humidity

The weather conditions experienced during the 18-month test period were recorded by an on-site weather station. Interior temperature and humidity were controlled, with targets of 22°C and 60% RH. The interior temperature conditions were monitored at both the north and south ends of the chamber. The sensors were located approximately 10 ft from the north and south walls of the container. Monitored temperature and humidity results are summarized in Table 5. After an initial break-in period (when the equipment was equilibrating), the temperature remained basically constant throughout the test 18-month test period. The north and south temperature sensor measurements tracked each other almost exactly. The interior humidity was less controlled than the interior temperature. After the initial settling in period, the humidity was more controlled but drifted down. In the last portion of the test period, the humidity exhibited a short uncontrolled period followed by a drop to 50% RH as measured by the south sensor. The north sensor during this period exhibited instability, which may indicate sensor failure. This unstable period caused an increase in the overall measurement standard deviation, as seen in Table 5. Exterior and interior temperatures are shown in Figure 7**.** Exterior and interior humidity is shown in Figure 8.

Table 4. Wetting Event Schedule

Date	Injection Location	Amount Injected, mL	Note
13-Jul-06	Interior	400	
5-Aug-06	Interior and exterior	2 × 200	
11-Sep-06	Exterior	400	
6-Nov-06	Exterior	400	
2-Jan-07	Exterior	700	
5-Feb-07	Interior and exterior	2 × 350	
10-Apr-07	Exterior	700	
7-May-07	Exterior	700	
4-Jun-07	Exterior	700	
2-Jul-07	Exterior	700	
14-Aug-07	Exterior	700	
11-Sep-07	Exterior	700	Installed in conjunction with installation of vapor barrier interior wall covering.
		7200	**Total Water injected, mL**

Table 5. Measured Interior Temperature and Humidity

	Median	Mean	Standard Deviation
Temperature, north, °C	21.6	21.7	0.7
Relative humidity, north, %	58.9	64.7	18.6
Temperature, south, °C	21.7	21.7	0.7
Relative humidity, south, %	61.1	60.7	6.9

Sheathing (OSB) Moisture Content

Figures 9 and 10 show the moisture content of the OSB (interior face) at 48 in. (above the water injection site) for all the walls. All the east- and west-facing walls show the same general behavior at this OSB site. The OSB moisture content stays below 10% with few exceptions during the experimental period. Several of the walls experienced periods in which the moisture content was below the sensor detection limits, and the walls have no reading for those periods. Slightly higher moisture contents appear initially and during the cooler winter months. In general, there does not appear to be a response to the water injected using the water injection system located below this area on the wall. The walls show an increase in moisture content at the end of the experimental period after the internal surface of the walls were covered with vapor barrier film.

Sheathing (OSB) behind at Water Injection System

Figures 11 and 12 show the moisture content in the OSB behind the water injection system. Water injection peaks are clearly visible. When water was injected in the interior or in both the interior and exterior, the peaks are substantially higher and sharper than when the injection was in the exterior side only. The OSB moisture content appeared to return to the baseline level between water injection events.

Moisture Content of Wood Wafer at the Gypsum Wallboard/Insulation Cavity Interface

Figures 13 and 14 show the moisture content of this wafer. The sensor in wall E11 failed. Although the moisture contents remain at modest levels throughout the experimental period, higher contents are seen in the warmer summer months, indicating moisture drive to the interior of the assembly. Water injection events are reflected in moisture content peaks, which return to the baseline level. This indicates drying to the inside is occurring, and the moisture appears to be handled well by all of the walls until the vapor barrier wall covering was installed. Once the vapor barrier interior covering was installed and water was injected through the system, the moisture content continued to increase. The experiment was terminated before the wallboard completely dried out. Wafer moisture content of all walls were in the same general level, except for the west-facing brick veneer walls (W9, W10, W11), which exhibited higher moisture content.

Cavity RH Sensors

Figures 15 and 16 show the relative humidity of the insulation cavity. As previously discussed, the measurements should not be considered quantitatively, due to their calibration issues and drift of the sensors. Qualitatively, all the walls except for the west brick walls seemed to behave the same

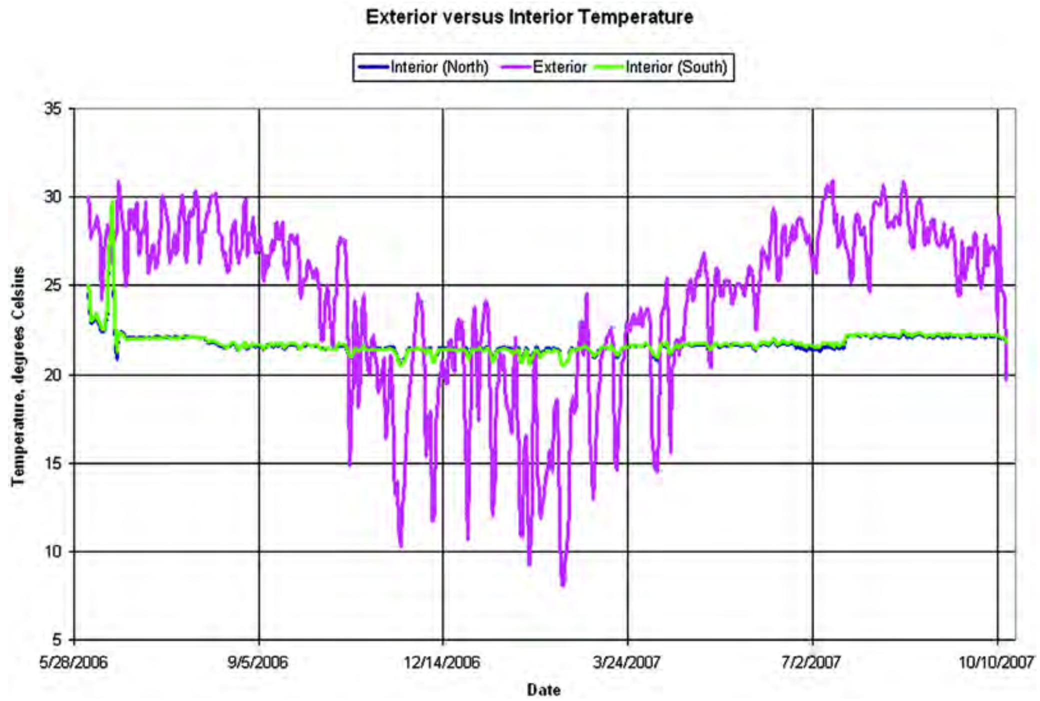

Figure 7 *Measured exterior and interior temperature.*

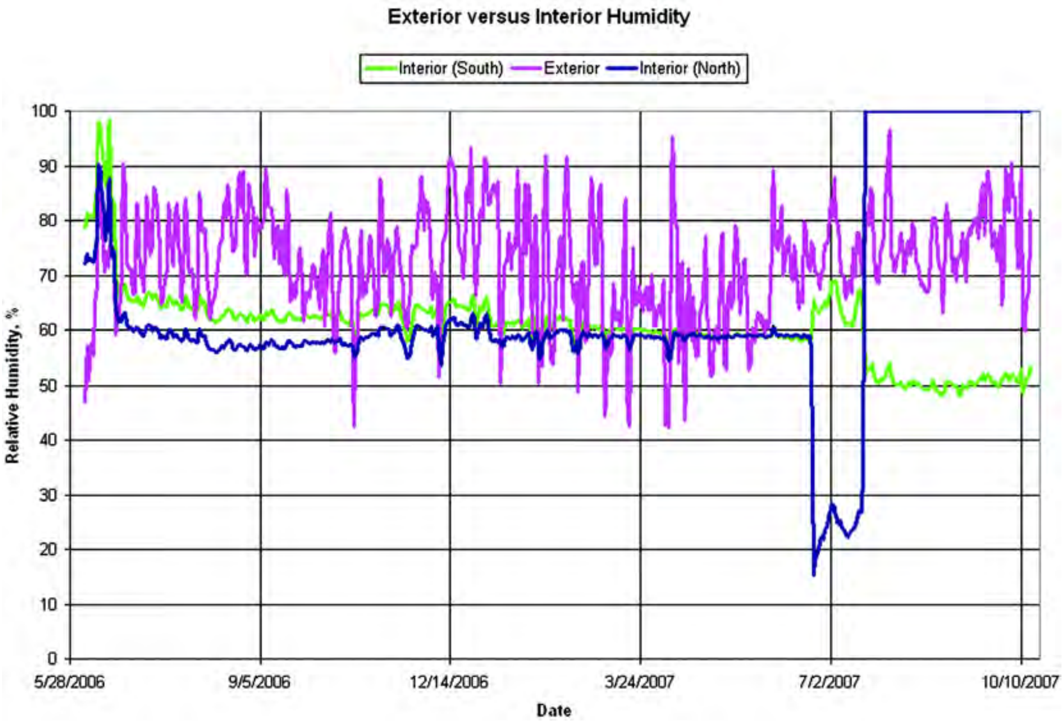

Figure 8 *Measured exterior and interior humidity.*

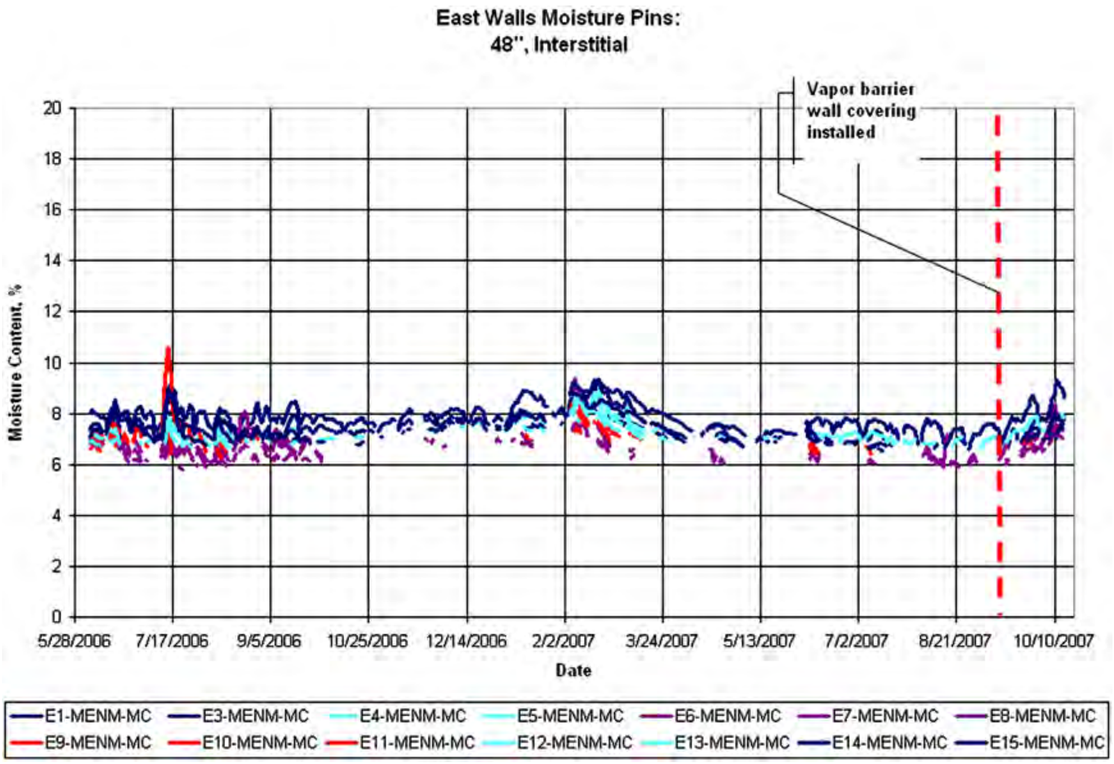

Figure 9 *OSB moisture content at 48 in.: east walls.*

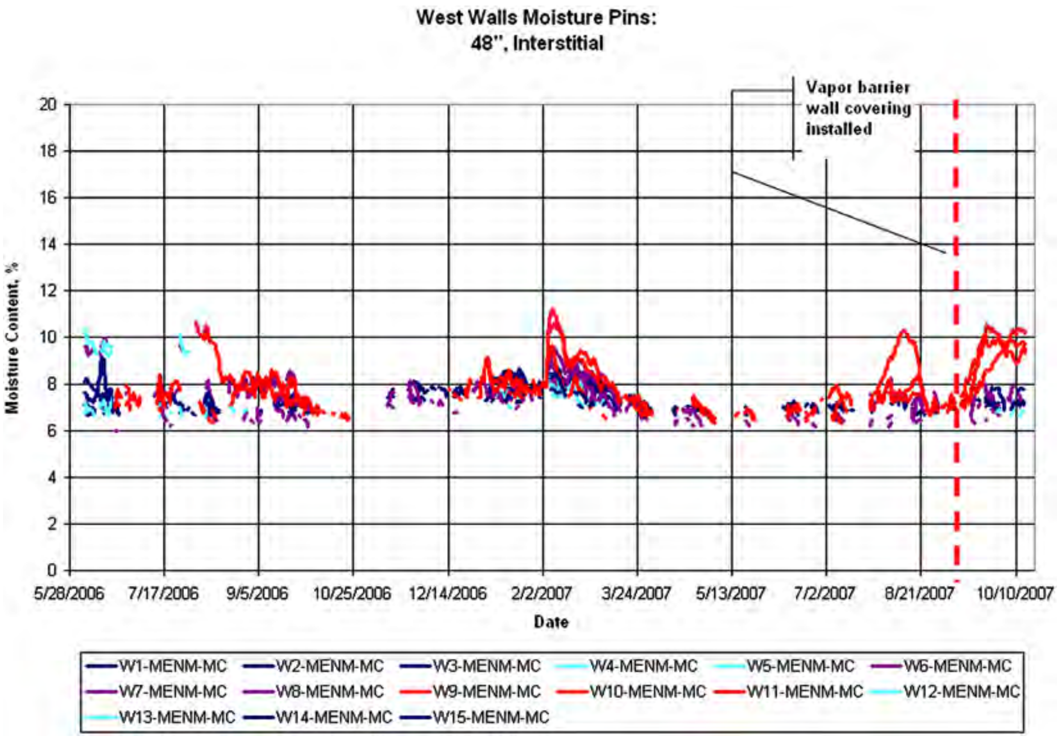

Figure 10 *OSB moisture content at 48 in.: west walls.*

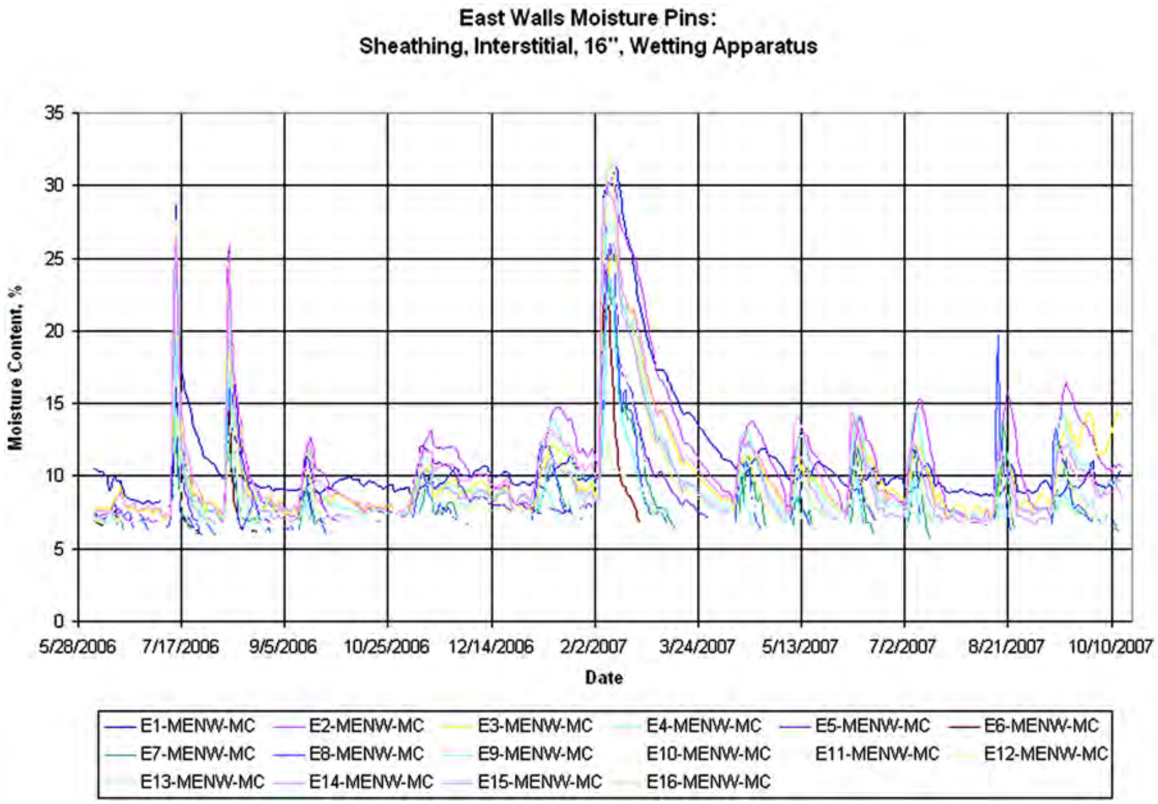

Figure 11 *OSB moisture content behind water injection system: east walls.*

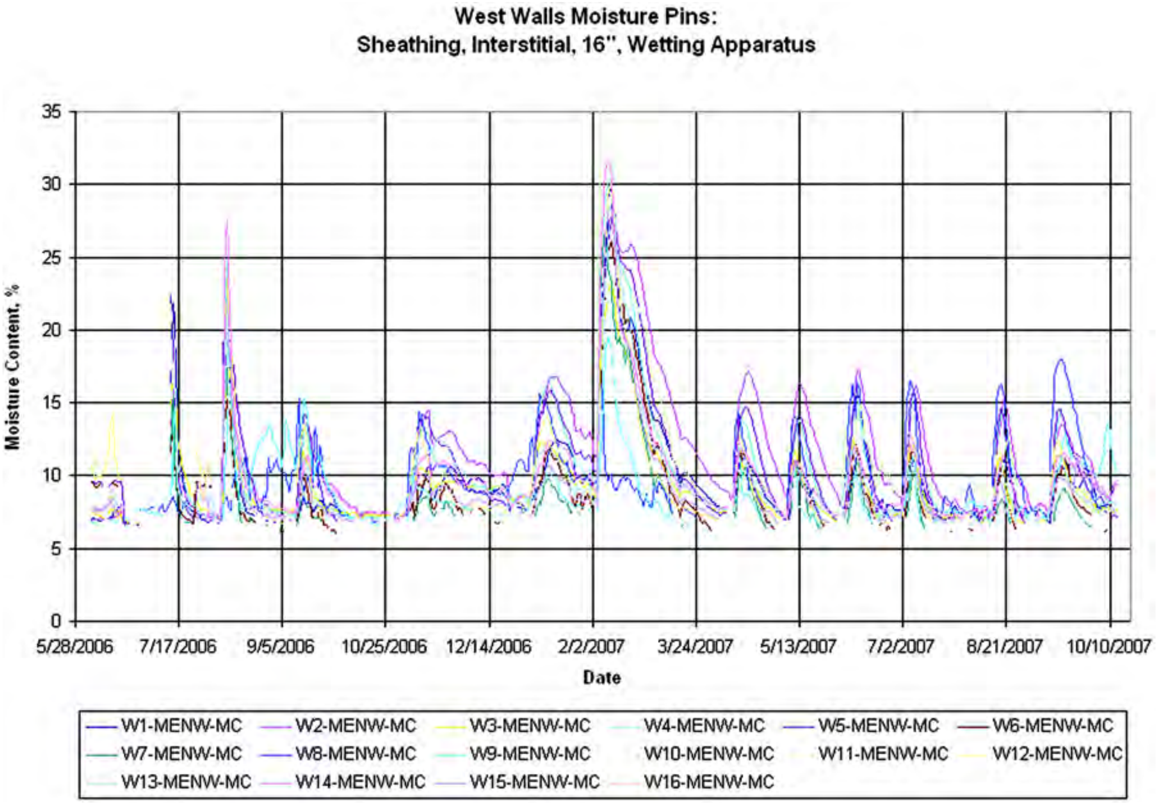

Figure 12 *OSB moisture content behind water injection system: west walls.*

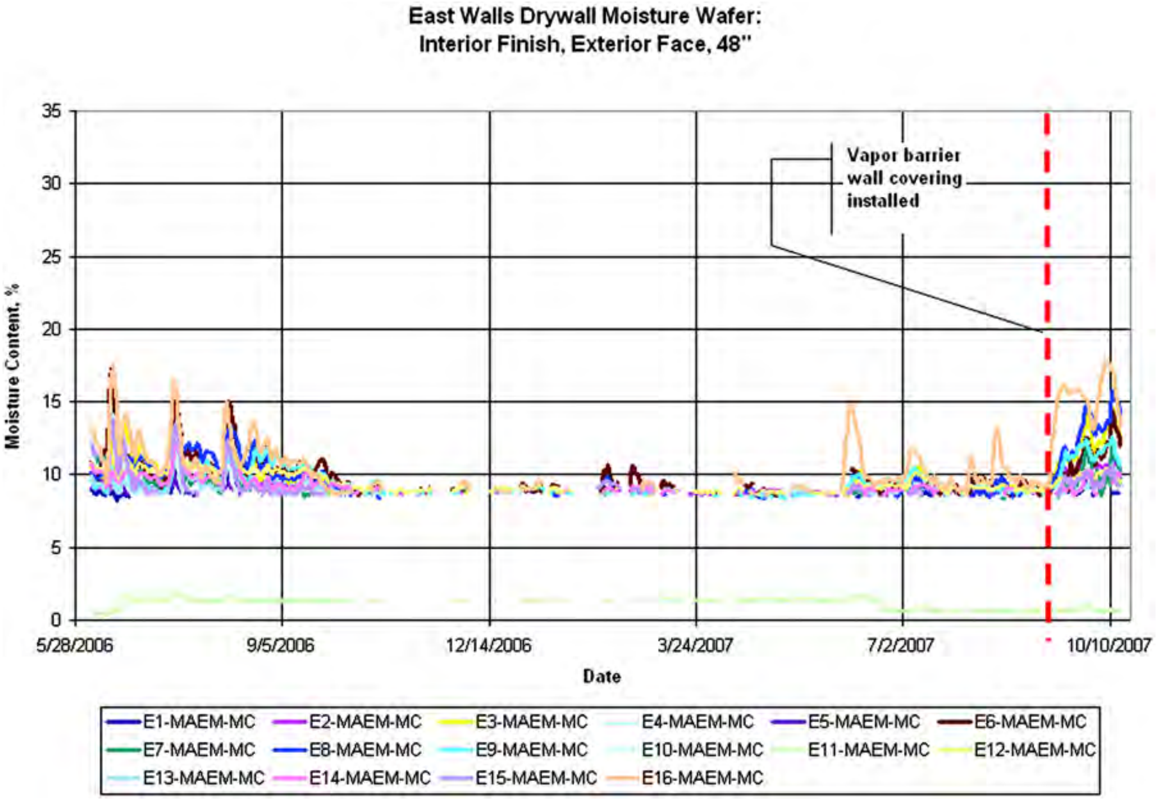

Figure 13 *Moisture content of gypsum wallboard wafer: east walls.*

way, showing a fairly constant RH. RH in the cavity increased after the installation of the vapor barrier covering on the interior walls.

Visual Examination on Deconstruction

At the end of the experimental period, the walls were disassembled and examined for moisture and/or mold. The only significant moisture damage was seen in the west-facing brick walls (Figure 17). It was discovered that these had a leak at the top of the wall–roof interface and had seen a much higher moisture load throughout the experimental period. Indications of moisture was observed at the sill plates of several walls, and appeared to be associated with water runoff variations from the water injection devices (Figure 18). The water injection apparatus had worked well throughout the test period, but a few of the wall sections developed plugged tubes, and some degradation of the shop-towel distribution medium was seen (Figure 19).

DISCUSSION OF RESULTS

Replicate Analysis

As part of this test, replicate wall specimens were included on the both the east and west walls. These walls had vinyl and fiber-cement sidings, both installed over WRB A. The wall replication was evaluated by computing the repeatability of moisture content sensors in the OSB at 48 in. (MENM), behind the water injection system (MENW), and in the gypsum-board wafer (MAEM). A modified Gage R&R analysis was conducted on each of the daily averages of each sensor, and the results are shown in Table 6. A good level of repeatability was seen. The absolute percent study variation is statistically confounded since the measured variation and differences come from a combination of the wall and sensor inputs.

Wetting Events

The water injection events are listed in Table 4. The amounts and location of the water injection differed from event to event. The total water injected into the walls over the 18-month experimental period was 7200 mL. Interior injections caused an immediate sharp peak that dissipated quickly. This phenomenon was not seen when exterior wetting system was used only (see Figure 20). These observations indicate that the OSB sheathing properties and its position relative to the source of water are key to the drying and moisture performance of the wall. The wetting events are also sensitive to exterior climate, as seen when directly comparing performance of events January and July 2007 (Figure 21). As expected, drying occurs more slowly in the winter than in the

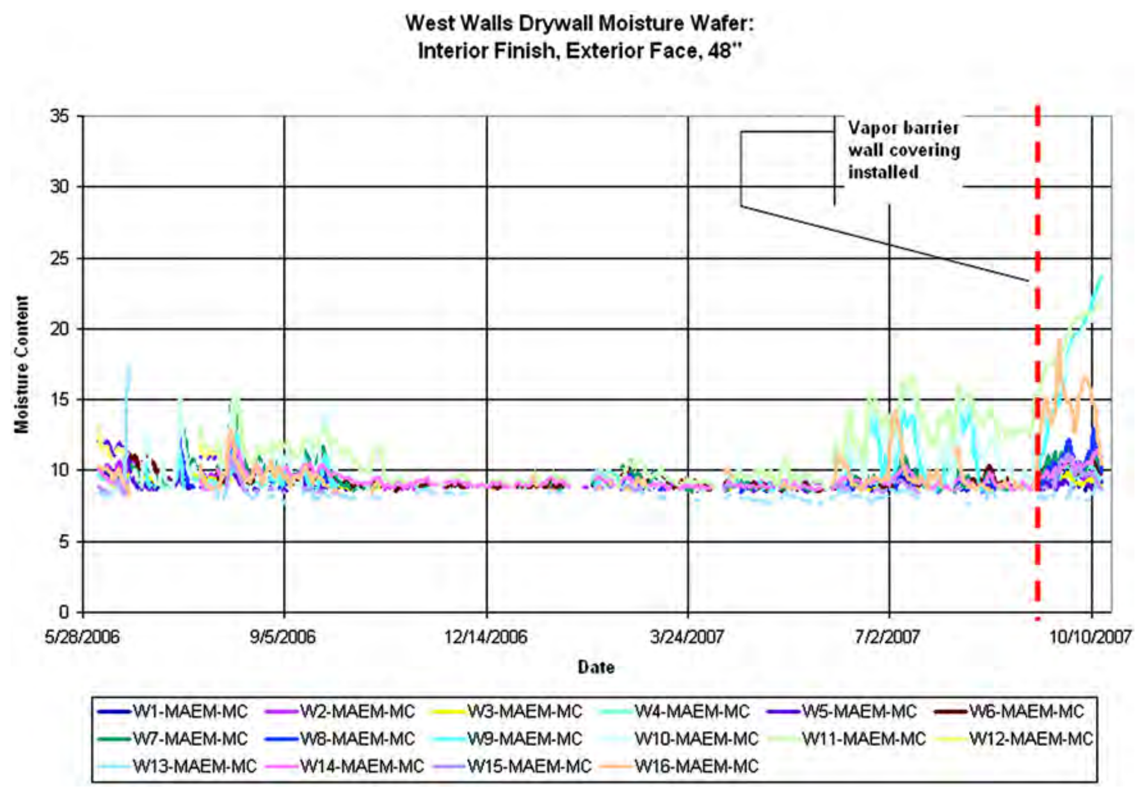

Figure 14 *Moisture content of gypsum wallboard wafer: west walls.*

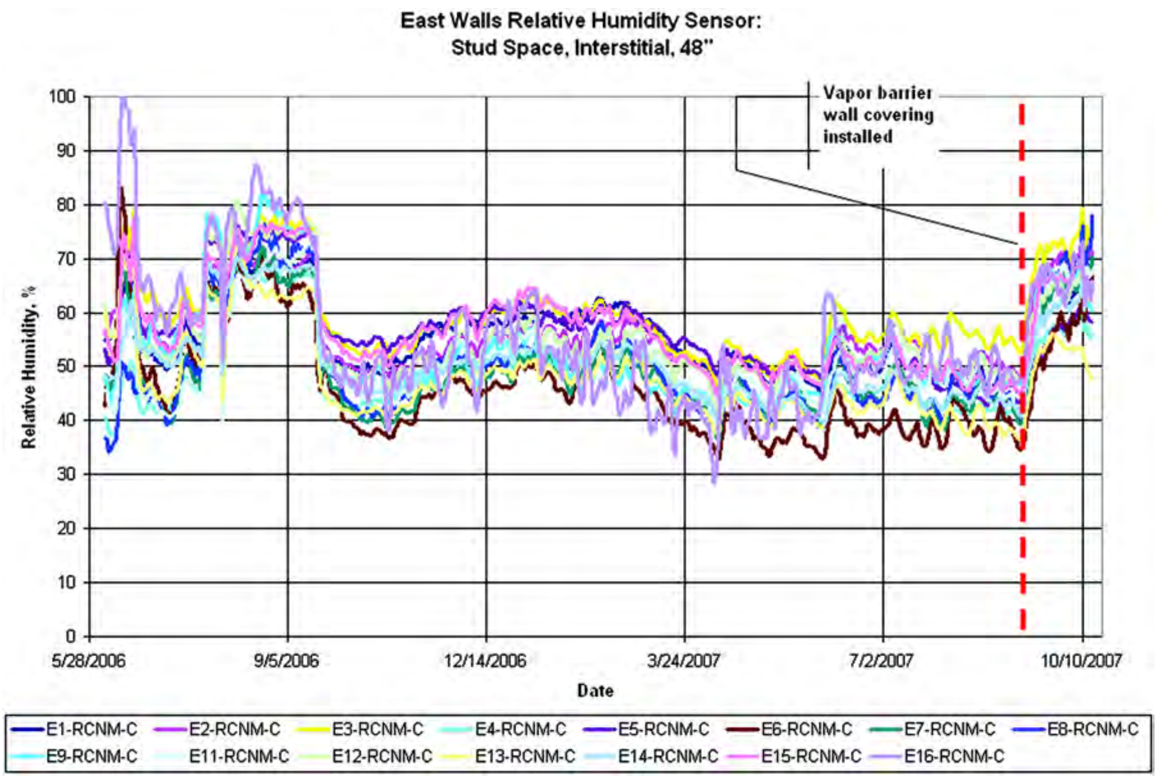

Figure 15 *Relative humidity: east walls.*

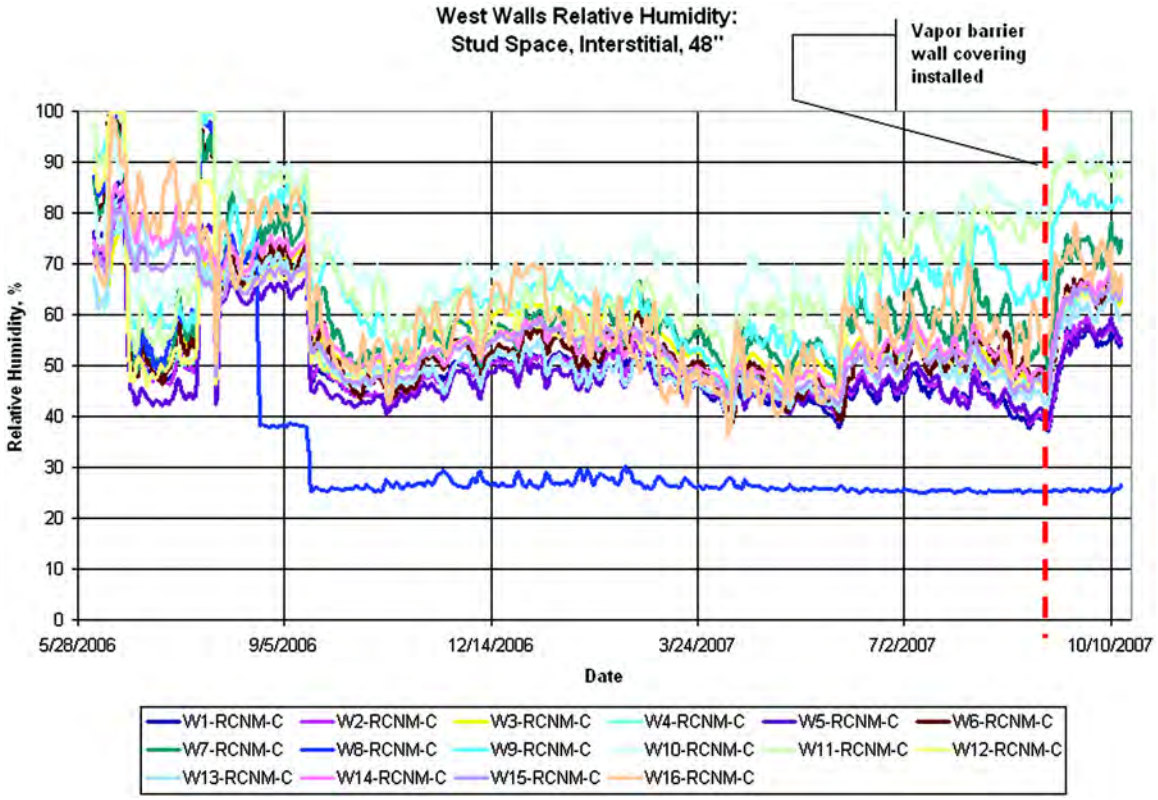

Figure 16 *Relative humidity: west walls.*

Table 6. Summary of Repeatability of Replicate Walls

		Vinyl and WRB A		Fiber Cement and WRB A	
		Std Dev	**Bias**	**Std Dev**	**Bias**
East	MENW	0.907	1.048	1.071	–0.351
East	MENM	0.169	0.101	0.225	0.52
East	MAEM	0.337	–0.528	0.735	0.897
West	MENW	1.28	–1.256	0.955	–0.672
West	MENM	1.191	–1.018	0.457	0.207
West	MAEM	0.858	–1.377	0.355	–0.614

summer. In all cases prior to the installation of the vapor barrier wall covering, the wetting events appeared to dry completely. In the west-facing brick walls, which had an unplanned roof leak, the water from the roof leak overwhelmed the effect of the intentionally injected water. It was concluded that a greater, uniform water challenge would be needed in future experiments. To provide this greater challenge, a water injection system with a more durable and higher-capacity water retention medium is required. Also, automated water injection would be preferred to manual injection to allow for more convenient, higher water injection loading.

Effect of Cladding

The wall performance impact of the claddings was evaluated by comparing the OSB moisture content at 48 in. and the moisture content of the gypsum wallboard wafer. Because of the overall low moisture content in the OSB and the fact that the moisture content reading did not register for significant portions of the test, the data from this sensor did not show any cladding difference or from exposures. As the gypsum wallboard wafer showed the highest moisture content during the two summer exposures, data analysis during these two summer periods was used to determine if there were any cladding effects. The results are summarized in Table 7. Neither

Figure 17 *Mold on brick west wall gypsum wallboard.*

Figure 18 *Moisture on bottom plate.*

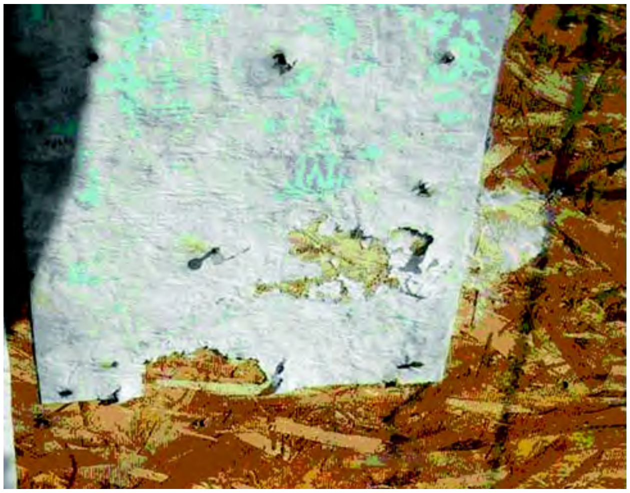

Figure 19 *Water injection system shop towel degradation.*

vinyl nor fiber-cement siding clad walls performed significantly different from each other in either exposure or in the summer seasons. The west-facing brick clad walls showed the highest moisture content due to the inadvertent roof leak, which increased the water loading of those wall specimens. The reservoir claddings (stucco and brick) showed significantly higher moisture content and higher measurement variances than the nonreservoir claddings during the first summer season (both exposures). The wall assemblies during the second summer season showed significantly less moisture than during the first summer season. No difference was seen between the claddings with east exposure during this second summer season. The difference in measured moisture content between the two seasons could be due to residual moisture from construction of the wall assemblies elevating the moisture content during the first summer or because of differences in the water injections during these two periods. The first summer period had 600 mL injected at the internal side and 600 mL injected at the external side of the OSB. The second summer had 1400 mL injected at the external side of the OSB. The difference in the water injection site may have caused a difference in the direction of the drying, internal injections causing more moisture to move to the interior side of the wall and dry through the gypsum wall-board. Means and variances of gypsum board wafer moisture content are compared in Figures 22 to 29.

Effect of WRB and Sheathing

When examined within individual claddings, there was no statistical difference in wall performance found as a result of the water-resistive barrier vapor permeability. This is consistent with reported laboratory testing showing no or only small differences in inward vapor drive between different water-resistive barriers (Carmeliet et al. 2007; Weston et al. 2001). Greater distinction may have been seen if a higher level of moisture challenge had been used during the wetting events.

Effect of Vapor-Impermeable Wall Covering

At the end of the experimental period, a vapor-impermeable film was installed on the interior wall surface. At the same time, water was injected in the exterior water injection system. Moisture content increased in both the OSB and gypsum wall-board, indicating the potential for poor wall performance. The test was stopped before it was determined whether the accumulated moisture would ultimately dry out from the wall or would continue to increase.

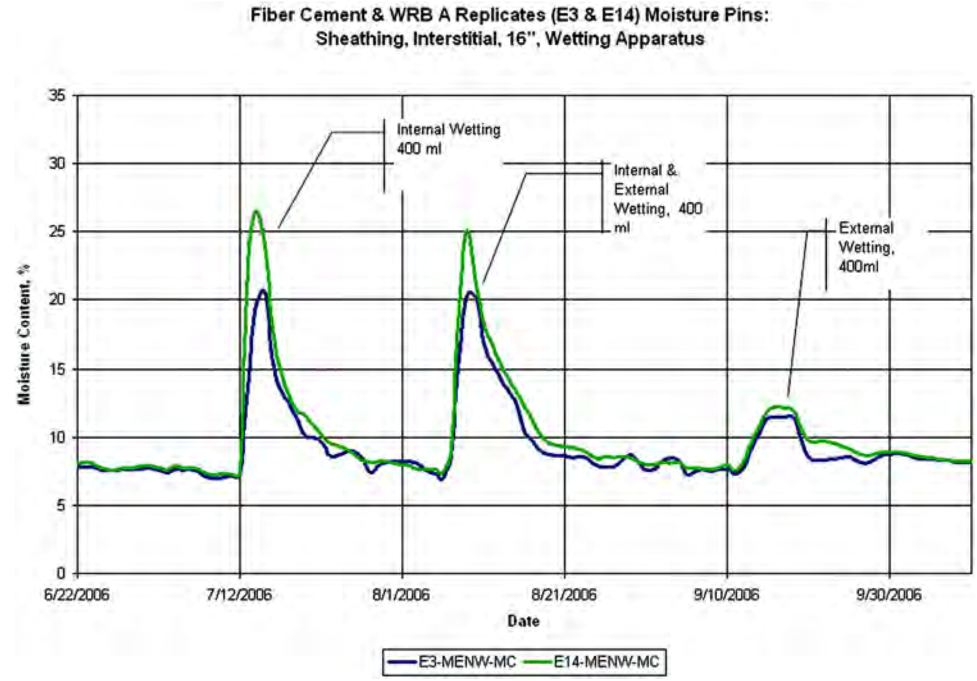

Figure 20 *Moisture content at water injection system; July, August, and September 2006 wetting events: fiber-cement siding and WRB A.*

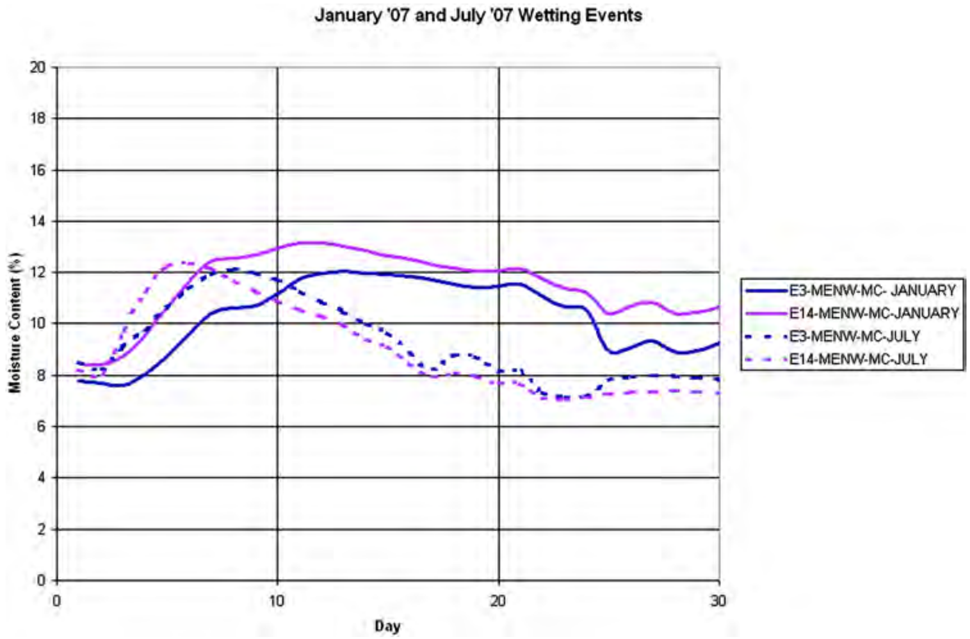

Figure 21 *Moisture content at water injection system; January and July wetting events: fiber-cement siding and WRB A.*

Table 7. Gypsum Wallboard Moisture Content during Summer Seasons

		Vinyl		Fiber-Cement		Stucco		Brick	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
East	Summer 1	9.77	0.78	9.75	0.88	10.53	1.22	10.32	0.85
East	Summer 2	9.14	0.37	9.15	0.4	9.15	0.45	9.2	0.44
West	Summer 1	9.22	0.79	9.47	0.63	10.26	1.16	10.94	1.51
West	Summer 2	8.79	0.48	9.07	0.37	9.34	0.52	12.29	2.16

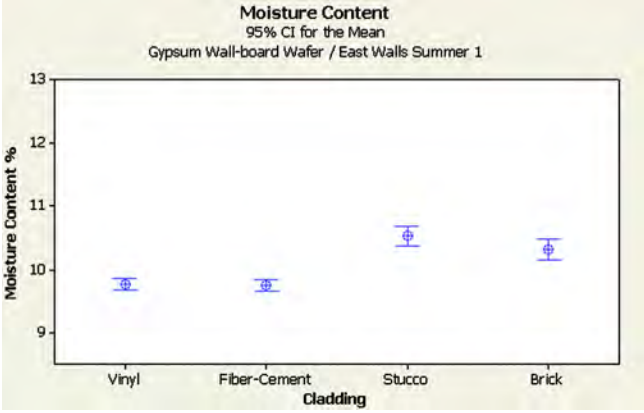

Figure 22 *Gypsum wallboard wafer moisture content: east exposure, summer season 1.*

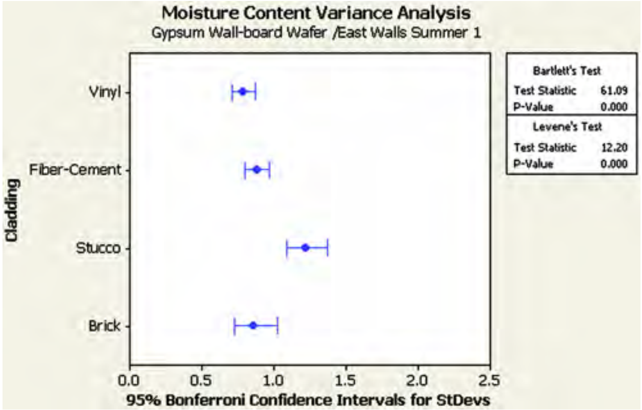

Figure 23 *Gypsum wallboard wafer moisture content variance analysis: east exposure, summer season 1.*

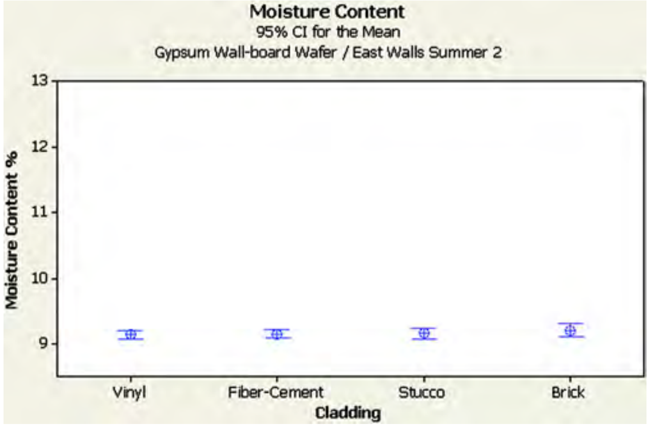

Figure 24 *Gypsum wall-board wafer moisture content: east exposure, summer season 2.*

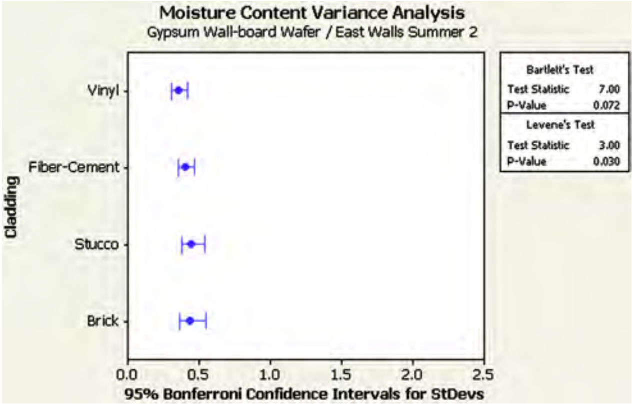

Figure 25 *Gypsum wallboard wafer moisture content variance analysis: east exposure, summer season 2.*

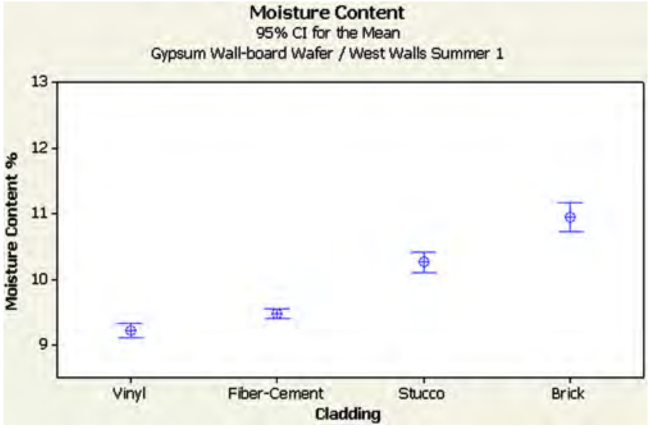

Figure 26 *Gypsum wallboard wafer moisture content: west exposure, summer season 1.*

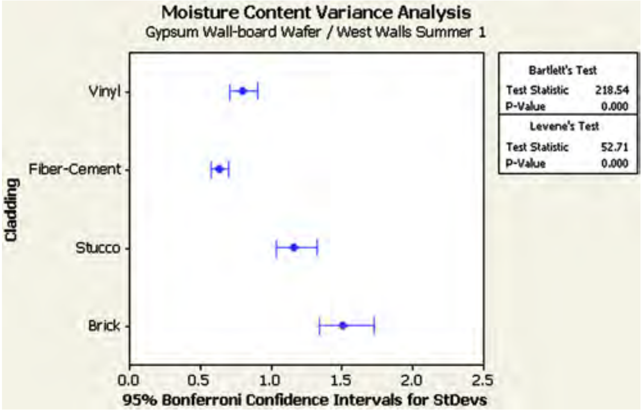

Figure 27 *Gypsum wallboard wafer moisture content variance analysis: west exposure, summer season 1.*

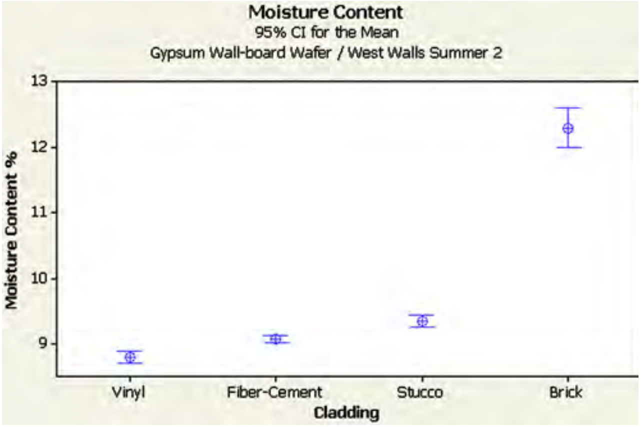

Figure 28 *Gypsum wallboard wafer moisture content: west exposure, summer season 2.*

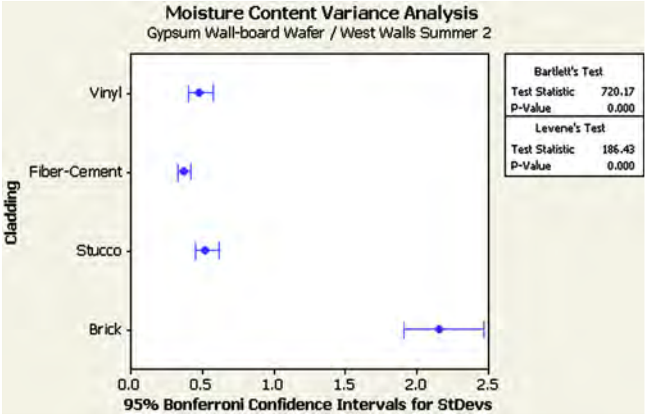

Figure 29 *Gypsum wallboard wafer moisture content variance analysis: west exposure, summer season 2.*

CONCLUSIONS AND RECOMMENDATIONS

This study provided information on the performance of the wall systems considered, as well as on how to improve future studies using natural exposure facilities, which will be used in further testing with the RBETS facilities.

The performance of the walls during this test showed that

- All the walls with no interior vapor barrier performed well in a hot-humid climate. Despite evidence that inward vapor drive was occurring in these systems, moisture that was driven inward was able to be dissipated through the interior wall surface. This was independent of the WRB permeability.
- Water entry from leaks, such as seen at the wall–roof interface, overwhelms any water intrusion due to solar-driven vapor from water absorbed into cladding materials.
- Moisture damage was only evident in the walls where the roof interface leaked significantly, increasing the water load above that designed into the test. Furthermore, the damage was observed only after an internal vapor barrier had been installed.
- Inward vapor drive was most apparent when walls were clad with reservoir claddings.
- No significant difference in inward vapor drive was seen based on water-resistive barrier permeability. Unlike some of the claims made by manufacturers in their literature, no optimum vapor permeability range was observed.
- The installation of an internal vapor barrier produced a difference in the wall performance. However, the test was terminated before long-term effects could be observed.

Replicate wall evaluation indicated that this type of natural exposure facility was suitable for comparing performance of wall assemblies. Further testing could be improved by

- Replacing MEMS humidity sensors because of their poor stability and calibration drift.
- Upgrading the water injection system to provide greater capacity, and therefore a higher challenge to the wall systems. Additionally, the current towels should be replaced with a nondegrading absorbent medium. Furthermore, automating the injection system is desired to make the injection more convenient.

It is recommended that this research be continued to understand these and other wall systems. Specific recommendations are:

- **Test wall systems without sheathing.** Although one wall specimen without sheathing was included in this test program, the single specimen was insufficient to provide a basis for good analysis and was therefore excluded from this paper.
- **Test wall systems with and without interior vapor barriers.** Although during this test one wall had an internal vapor barrier (vinyl wall covering) installed at the end of the test, the amount of time walls were monitored with the internal vapor barrier was insufficient to understand the full performance implications of this construction.
- **Test energy efficient wall** systems. The increasing stringency of energy codes will require the construction of higher-R-value wall systems, including 2 × 6 frame walls and walls with continuous exterior insulation. These high-R-value walls should be tested to further understand the durability consequences of these constructions.

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RR-1011: Evaluation of Cladding and Water-Resistive Barrier Performance in Hot-Humid Climates Using a Real-Weather, Real-Time Test Facility

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