Developing Innovative Drainage and Drying Solutions for the Building Enclosure

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ABSTRACT

Residential building enclosures are experiencing water entrapment and deterioration of wood-based components, even with the use of water resistive barrier (WRB) materials required by national building codes. The purposes of this investigation were to: 1) Obtain qualitative information about water resistance performance of some absorptive claddings when tested in mock-ups built with OSB sheathing, commonly available WRBs, and common fasteners, in conjunction with a prototype furred WRB design approach (using pan flashing and closed cell foam plastic furring strips). 2) Obtain qualitative performance data on moisture management performance by the prototype furred WRB design approach when installed on dwellings in lieu of claddings that lacked drainage/drying features. Laboratory evaluations support the hypothesis that WRBs may not provide sufficient water penetration resistance without supplementary drainage provisions. Field evaluations provide support for the hypothesis that placing furred WRBs and sill pans in exterior walls may reduce the risk of consequential water intrusion into as-built residential construction.

INTRODUCTION

Many residential building enclosures that use absorptive/reservoir type exterior claddings (such as stucco and manufactured stone veneer) have experienced water entrapment, followed by deterioration of wood-based sheathing and framing. Deterioration may occur within several years after the dwellings are built. The problem is becoming more visible in various areas of the country (McCoy 2004; Holladay 2006), and is reminiscent of the barrier EIFS crisis of the mid-1990s (Williams and Williams 1998). This new round of moisture problems is occurring despite widespread use of water resistive barrier (WRB) materials (building papers/felts, or polymer-based "housewraps"), which are required by national building codes for moisture protection behind most exterior claddings. Stakeholders are increasingly concerned about the costs of moisture damage-related repairs, insurance claims, and litigation. Repairs typically involve removing and replacing the exterior wall coverings and WRBs (recladding) as well as replacing underlying structural components. However, reclads have not been totally successful. The author is aware of projects where the building enclosure has sustained similar damage after being reclad.

Some sheathing and framing damage has occurred behind WRBs in field areas of walls, separate and remote from obvious external leakage sites such as window jamb/sill corners, through-wall penetrations, wall/roof junctures, "kickouts," and the like. This problem suggested a need to further investigate factors that may reduce a WRB's performance over its expected service life, and to further explore related drainage, drying and durability issues.

Examining Performance of WRBs

In a previous study, the author (Williams 2004) investigated several factors that would affect WRB performance. Key issues were resistance to surfactants (e.g. powerwashing solutions); solar-driven inward vapor diffusion; and water intrusion through fastener penetrations. The findings most relevant

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to the present study were related to puncture resistance, and these are summarized here.

Mock-ups consisted of WRB specimens placed in water-tight horizontal trays and challenged by a 1 in. (25.4 mm) hydrostatic head of water for 2 hours. In some mock-ups, specimens were installed over wood-based sheathing. For the fastener tests, mock-ups included a single staple fastener installed through the WRB into the substrate sheathing prior to introducing the water. Once the water was introduced, the punctures at fasteners caused significantly more leakage than water alone or water with surfactants on mock-ups without staple fasteners. This demonstrated that bulk water would readily migrate through fastener penetrations. Such water, if entrapped, could degrade the exterior wall's weather resistance performance.

Based on these puncture tests and the author's related field investigations, it appears that water leakage through fastener punctures may be a significant leakage pathway for bulk water in the building enclosure, no matter what type of WRB material is used. The implications of this become clearer when one considers that a 1,000-square-foot area of wood siding may be fastened to a wall with approximately 1,100 to 4,000 nails, depending on fastener spacing and type of siding (Manasquan, 2003). These penetrations are in addition to the many fasteners (such as staples) that are used to attach the WRB materials to the substrate sheathing.

Others have recognized that leakage through fastener penetrations in exterior wall claddings may contribute to moisture related problems. In a survey of Pennsylvania building sites to evaluate actual housewrap usage, Bosack and Burnett (1998) found that housewraps were typically not installed in accordance with the manufacturer's instructions. At 70% of building sites, the housewrap was installed with staples, which often caused tears or holes in the membrane. The investigators focused on air barrier issues and did not further explore moisture related implications. Ruggiero and Spagna (2001) pointed out that some paper-based WRBs are easily damaged and vulnerable to multiple fastener punctures at lath and accessories. A study of drainage of various claddings by Straube, *et al.* (*In:* Karagiozis 2002) mentioned the occurrence of water intrusion through "defects" in a layer of No. 15 felt in one test, but the moisture did not reach the sheathing. A recent standard guide document (ASTM 2004) states, "Securing some cladding systems requires that fasteners engage the framing and not only the sheathing. In these systems, fasteners that do not engage the framing can result in excessive leakage through the fastener penetration of the WRB and excessive warping, deflection or misalignment of the cladding, which can result in increased water penetration through the cladding." No references were given for this information. Finally, Weston et al. (2006) tested a variety of perforated and nonperforated housewraps and found that staple penetrations caused perforated products to pass far more water than nonperforated products, when subjected to a "rain spray test" based on AATCC Test Method 35.

Wall Drainage and Drying Concerns

National building codes have long required WRBs to be installed behind certain types of wall claddings. The *2006 International Residential Code* raises the bar by requiring WRBs to be installed (in all but a few exceptional cases) behind every type of exterior cladding, and by requiring "a means of draining water that enters the assembly to the exterior" (International Code Council, 2006). Drainage is generally achieved by providing a cavity or gap in the assembly sufficient to overcome capillary forces to allow bulk water to migrate downward by gravity. However, the Code does not define what constitutes adequate "drainage" or a related performance standard. While many WRB materials are available (e.g., asphalt saturated roofing felts, kraft building papers, polymer-based housewraps, "drainage enhanced" sheet materials, and the like), there is little comparative information about their drainage performance.

A test method has been developed to explore this performance factor for some claddings (ASTM 2003). The author has recently evaluated the drainage characteristics of various types of WRB materials (with and without enhancements) for another study, utilizing a variant of this ASTM test procedure (Williams, 2007, in press). The WRB specimens included traditional #15 and #30 building felts, "traditional" polymer based housewraps, surface-modified (drainage-enhanced) housewraps, "profiled sheet" (drainage board) material, and drainage mediums that incorporated a drainage mat or furring strips. Furring strips were composed of closed cell foam plastic or plywood.

Preliminary results from this study, which involved approximately 40 mock-ups, each 4 ft x 8 ft (121 cm x 244 cm) in size, are briefly summarized as follows: "Traditional" WRBs (building felts, polymer based housewraps), when installed alone, provided little drainage. "Drainage-enhanced" WRBs performed better than traditional WRBs. "Drainage board" outperformed "drainage-enhanced" WRBs, and was on a par with WRBs used together with furring or a drainage mat. Building felt, when used together with "drainage-enhanced" WRBs, negated the drainage benefits of the latter, because the water could not readily migrate to the "drainage-enhanced" WRB.

Furring installed *behind* the WRB (i.e., the side away from the fault slot where water was introduced) enhanced drainage. Furring, or a drainage mat placed *in front* of the WRB (i.e., exposed to the fault slot), dramatically enhanced drainage. Finally, furring strips placed on *both sides* of the WRB performed better than when only placed *in front* of the WRB.

While some WRBs appear to drain water more "efficiently" than others, little is known about what degree of drainage is adequate. In most cases, some water still remained trapped within the typical wall assembly. It is not known if, for example, an assembly with a 90% "drainage efficiency" will dry out more or less quickly than an assembly rated at 80%. It is not clear what happens to the 10% of moisture presumably retained by the latter. Some moisture may cling by surface tension to the backside of a cladding and/or to the front side of inner wall layers, and some may be absorbed by hygroscopic wall components.

To further explore drying processes, the referenced study also measured a parameter called "time to first water," i.e., the time that elapsed from the initial introduction of water to its first appearance at the bottom of the mock-up. Some WRB products with high drainage efficiencies retained water in the drainage space over a longer time until it "first emerged," than some less efficient products. Overall, the "time to first water" interval was generally shorter with "furring strip/ drainage mat/drainage board" products than with "drainage-enhanced" WRB products. This may be significant, given that products having a long "time to first water" may allow bulk water to migrate past fastener/staple penetrations, potentially affecting the long-term performance of the underlying sheathing/framing.

The foregoing work casts serious doubt on the ability of WRBs, when installed behind certain claddings, to provide a weather-resistant exterior building enclosure. Some of the testing discussed herein will show that WRBs that are fastened to sheathing in the field areas of walls do not prevent water intrusion, whether they are installed in one layer or two layers (as more recently required by the Code). There is a need to further investigate the effects of fastener penetrations upon the water resistance performance of commonly used WRB materials, and to develop ways to reduce or prevent water from leaking through the WRBs at the fasteners.

Recent research by others lends support to the need for a drainage space behind exterior absorptive claddings. Van Straaten (2003) investigated ventilation and drying in vinyl siding and brick masonry veneer wall mock-ups in a 3-year study. Drainage/drying behavior of furred vinyl cladding was similar to contact-applied vinyl. Ventilated brick veneer performed better than non-ventilated brick veneer; however, changing the cavity depth from 20 mm to 50 mm (± 0.75 in. – 2 in.) did not significantly increase ventilation. Overall, increasing cladding ventilation significantly increased drying rates, and reduces internal wall assembly moisture levels.

Smegal (2006) investigated drainage and drying in small gaps behind various claddings, including stucco. A modification of the ASTM E-2273 methodology was used. Results indicated that a gap as narrow as 1 mm was able to drain water, "… at a rate considerably greater than it is expected to penetrate most walls." Ventilation drying also occurred at gap spaces of ≥ 1 mm, and appeared to be highly effective at 19 mm (0.75 in.) but it was unclear if the gap needed to be any larger. Finally, all test mock-ups stored some bulk water, presumably due to surface tension effects at nonabsorptive cladding surfaces (such as housewraps).

Onysko *et al*. (2007) investigated drainage and drying behavior of drainable EIFS, vinyl siding, hardboard siding, wood siding, and fiber cement siding, in conjunction with several types of drainage mats. Researchers concluded, *inter alia,* that wall designs using furring strips as the drainage medium dry out more readily than designs utilizing drainage mat materials. However, the actual amounts of water retained are as dependent upon the cladding type as on the drainage medium used, and by the way that water entry occurs.

This paper suggests that an innovative design approach, using a WRB with integral foam plastic furring strips preapplied on both sides of the WRB, appears to be useful in reducing water intrusion and entrapment in exterior walls. The foam strips exert a gasketing (self sealing) effect at fasteners, and their thickness provides a separation space. The gasketing effect minimizes the quantity of water that can reach the sheathing through faster punctures. The integral furring strips provide two-sided drainage and drying, by essentially "separating" most of the WRB sheet material from the back of the cladding and the substrate sheathing. This approach offers a simple way to help enhance drainage and drying capabilities behind absorptive exterior claddings.

METHODOLOGY

The laboratory and field studies set forth below are intended to provide qualitative results. Moisture meters were used to obtain "order of magnitude" moisture content data. The wood moisture scale was used, however no attempt was made to calibrate for the project-specific wood-based substrates, nor were readings analyzed statistically. Additionally, the field studies were intended to evaluate the feasibility of using an innovative furred WRB product behind absorptive type claddings, which previously lacked specific drainage and drying features.

The author used only OSB sheathing in mock-up testing, because this wood based sheathing product is most commonly used for residential construction (as it was in the homes included in this study). OSB overtook plywood for this purpose in the mid-1990s (Fisette 2005). OSB and plywood can tolerate some amount of wetting and drying without significant damage. However, OSB is less permeable than plywood, expands and swells when wetted, and dries out more slowly than plywood (Nofal and Kumaran 2000). Foam plastic insulating sheathing with a WRB beneath it would be more resistant to moisture damage, since it is not affected by water. However, because it has very low permeability, it should still be installed with provision for drainage and drying in most climates, when used behind absorptive claddings such as wood siding, shakes, or stucco (Lstiburek and Baker 2005).

Laboratory Evaluations

A summary of laboratory evaluations is presented in Table 1. Evaluations #1 through #5 were performed to obtain qualitative information about water resistance performance of selected exterior claddings when installed in wall assembly mock-ups with OSB sheathing, common water resistive barriers (WRBs), and common fasteners and attachment patterns. Additionally, one of these evaluations included closed cell foam plastic furring strips, which the author believes is a new use for this material. These evaluations were based on ASTM

Table 1. Overview of Laboratory Evaluations

Lab Evaluation	Number of Mock-ups	Mock-up Construction
# 1	2	1 layer 60 min. grade D paper; lath; MSV One mock-up with defects (pre-formed cracks) in grout between MSV stone units, one mock-up without defects.
# 2	2	2 layers 60 min. Grade D paper; lath; MSV One mock-up with defects (pre-formed cracks) in grout between MSV stone units, one mock-up without defects.
# 3	2	1 layer 60 min. grade D paper; lath; sensor instrumentation; MSV with sensor instrumentation One mock-up with defects (pre-formed cracks) in grout between MSV stone units, one mock-up without defects.
#4	1	1 layer traditional housewrap, 1 layer drainage-enhanced housewrap, stapled in field areas; lath; Portland cement stucco Defects (pre-formed cracks) in field areas of stucco face.
# 5	1	1 layer traditional housewrap, 1 layer drainage-enhanced housewrap with closed-cell foam plastic furring strips; lath; WRBs and lath stapled only through furring strips to sheathing; Portland cement stucco Defects (pre-formed cracks) in field areas of stucco face.

E 514-90, "Standard Test Method for Water Penetration and Leakage Through Masonry." A positive air pressure (10 psf [500 Pa]) was applied and water was sprayed on the exterior face of the mock-ups at 3.4 gal/ft^2 (138 L/m^2) for 4 hours. However, spray water was not collected, and mock-up components were not weighed. Alternatively, the mock-ups were inspected visually for qualitative evaluation of water intrusion, and the test procedures were documented photographically. Two types of absorptive/reservoir type claddings, manufactured stone veneer (MSV) and stucco, were tested**.**

For the present study, ASTM E-514 was conducted as follows. A pressure chamber was built large enough to accommodate two mock-ups placed side by side (see Figure 1). This chamber is constructed of plywood sheathing on wood studs, and is 8 ft (244 cm) wide, 5 ft (183 cm) high, and 2 feet (61 cm) deep. A central partition subdivides the interior chamber space, except for a 3 in. (8 cm) gap at the bottom to allow airflow between the two mock-ups. The front side includes two 40 in. (102 cm) x 45 in. (114 cm) openings which are covered with clear acrylic sheet panels to allow observation during testing. The mock-ups were installed in the chamber and sealed in place with self-adhering membrane and mastic. Water was applied to the front face of each mock-up from a spray rack. Water flow was monitored by a digital flowmeter, and the rack was calibrated to deliver the required quantity of water at the required application rate. The bottom portion of both mock-up areas was provided with drain outlets. Air pressure was applied with a variable speed air blower and monitored by a manometer. The flowmeter, blower, and manometer were all mounted at one end of the chamber.

The typical 3 ft x 4 ft (91 cm x 121 cm) mock-up was constructed as follows. Each mock-up included 2 ft x 4 ft (61 cm x 121 cm) wood frame construction, covered with 7/16 in. (11 mm) oriented strand board (OSB). The OSB includes two removable panels, which were fitted side by side within the 2 ft x 4 ft (61 cm x 121 cm) frame. To help document water intrusion pathways, the front surface of the sheathing was previously coated with a marker dye powder that changes color on contact with moisture. The sheathing was then covered with the WRB material(s), which were attached with 3/8 in. (9.5 mm) staples placed 8" (204 mm) on center. Metal lath was then attached with 7/8 in. (22 mm) staples through the WRB and into the sheathing and wood studs, and was covered by the cladding material. The completed mock-ups were sealed at their edges with sealant and self-adhering membrane flashing, and installed in the chamber.

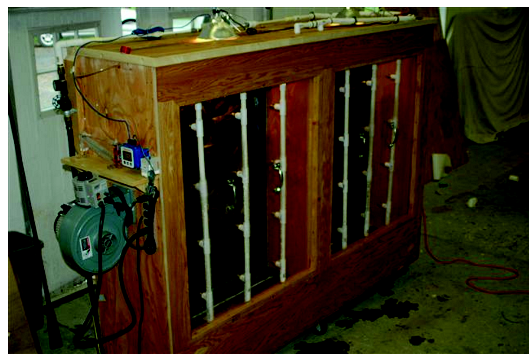

Figure 1 *Pressure chamber for two ASTM E-514 cladding mock-ups.*

In manufactured stone veneer (MSV) evaluations #1 through #3, one of each pair of mock-ups included pre-formed "crack defects" at some mortar joints, which extended through the cladding to the lath layer. The other mock-up did not include any "crack defects." All MSV was from a single manufacturer. In one MSV evaluation (#3), the sheathing behind the WRB was omitted, leaving an open stud framing that supported an array of sensor wires, which was covered by the

WRB. The wires were connected to pairs of brads inserted in the studs approximately 1 in. (25 mm) apart, and spaced approximately 12 in. (30 cm) on center. These sensors were used to check for any moisture that penetrated the WRB layer and reached the stud face. One of these instrumented mock-ups included pre-formed "crack defects," while the other did not. Sensor readings were taken with a resistance type moisture meter every 30 minutes during this 4-hour procedure.

In stucco evaluation #4, a mock-up evaluated the performance of a "traditional" housewrap and a "drainage enhanced" housewrap installed together. In stucco evaluation #5, closed-cell foam plastic furring strips measuring 1-1/4 in. (32 mm) wide and ¼ in. (6 mm) thick, and spaced 8 in. (23 cm) on center, were installed between the "traditional" housewrap and the "drainage enhanced" product. Each of these mock-ups included a preformed "crack defect" in the stucco.

At the end of each evaluation (except #3, which had open framing), the 1.5 ft x 4 ft (46 cm x 121 cm) sheathing panels were removed from the backside of the mock-up, and the sheathing surfaces were examined for evidence of water leakage. Next, the WRB layer(s) were peeled away from the backside of the claddings and similarly examined. Spot readings of moisture levels were obtained with a resistance type moisture meter.

Field Evaluations

A prototype furred WRB design approach (using closed cell foam plastic furring strips) was installed behind the stucco cladding of five single-family homes located in the Philadelphia, Pennsylvania metropolitan area. The homes are two-story single-family residences with attached garages. They are located in a Temperate (Mixed/Humid) Climate Zone, which has approximately 4,900 heating degree-days and receives approximately 41 in. (104 cm) of precipitation (including 28 in. [71 cm] of snow) per year. Average monthly exterior air temperatures fall below 45° F (7.2° C) during the winter. All the homes were originally constructed in approximately 2001-2002. In 2005 and 2006, the author examined several of these dwellings, and found evidence of moisture related deterioration. Sometime later, the author designed the remedial solution, and specified the materials and details for remedial work needed to address water-related concerns. In each home, the furred WRB product was installed as part this remedial approach.

The original underlying wall construction included oriented strand board (OSB) sheathing attached to wood stud framing. In the original stucco cladding, one layer of a water resistive barrier (#15 building felt) was installed over the sheathing behind the stucco and lath. No drainage space was provided. Water entrapment had occurred behind the felts, causing damage to the substrate sheathing and framing, as well as to the felts themselves.

During the remedial work, pan flashing was also installed below each window. A furred housewrap WRB product, which included foam plastic furring strips on both sides of the housewrap, was placed over the sheathing. The WRB was integrated with the pan flashing and covered by #15 building felt, lath, and stucco. These installations included "hard-wired" moisture sensors (similar to those used in Laboratory Evaluation #3), which were placed in certain project wall locations (e.g., below window corners) to monitor moisture levels at the sheathing plane over time. A resistance type moisture meter is used to collect data on a weekly basis. Data collection commenced at one of the homes in May 2006. Because of construction scheduling, data collection began at the remaining homes in the early fall of 2006 and has been ongoing. These field evaluations began as part of another study that focuses on drainage efficiency of WRB materials (Williams 2007, in press). Preliminary results are summarized later in this paper.

RESULTS AND DISCUSSION

Laboratory Evaluations

Manufactured Stone Veneer (Evaluations #1 - #3). Dye patterns indicating water intrusion occurred on the exterior face of all sheathing panels in MSV mock-ups. The staining originated primarily at fastener punctures, and spread over most of the OSB surfaces. As might be expected, the mock-ups with defects showed larger areas of water intrusion than those without defects.

Overall, one layer of WRB did not prevent water from reaching the sheathing, regardless of whether the mortar included "crack defects" or not. Two layers of WRB offered better protection, but water still reached the sheathing via fastener punctures (see Figure 2). Resistance meter readings taken at puncture sites from either configuration ranged from 30% to 40%. In Evaluation #3, which included a sensor array (but no sheathing; staples installed only into the studs), readings were consistently high (approximately 30% to 40%) in the mock-up with cladding defects, and consistently low (approx-

Figure 2 *Mock-ups for MSV Evaluation #1 (one layer Grade D WRB). Note increased water staining on sheathing and backside of MSV in mock-up with "crack defect" (left).*

imately 10% to 16%) in the mock-up without defects. These observations suggest that, with an absorptive cladding such as MSV, water resistive barriers in themselves are inadequate to manage unwanted water. It appears that these installations would benefit from inclusion of a drainage space to help divert water that penetrates the WRB layers away from the sheathing layer. This idea was explored further, using a different absorptive cladding (stucco), in Evaluations #4 and #5.

Portland Cement Plaster (Stucco) Tests (Evaluations #4 and #5). In Evaluation #4, dye patterns indicating water intrusion occurred between both WRB layers ("traditional" housewrap and "drainage enhanced" housewrap) and on the inside face of the sheathing. The staining originated at staple punctures. There was some evidence of water penetration on the backside of the stucco itself. Resistance type meter readings at the OSB sheathing were 30%-40% (see Figure 3).

Evaluation #5 tested the same types of WRB materials as used in Evaluation #4, but the two products were separated by closed-cell foam plastic furring strips to create a drainage gap. Lath and WRB materials were fastened to the sheathing panels through these furring strips, which appear to offer some self-sealing properties. In contrast to other evaluations, only one very limited dye pattern was observed, indicating that water was almost totally prevented from penetrating the WRBs and reaching the sheathing. Resistance type meter readings were also very low (typically 5% to 8%). This evaluation demonstrated that the closed-cell foam plastic furring strips were useful in preventing water from reaching the sheathing plane (see Figures 4 and 5). The furred WRB /stucco cladding design approach exemplified in Evaluation #5 is currently being further assessed under real-world conditions, as explained in the Field Evaluations section of this paper.

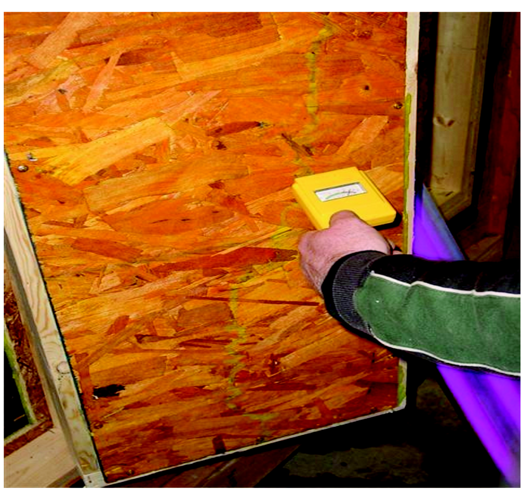

Figure 3 *Mock-up for Stucco Evaluation #4 (two layers housewrap, one drainage –enhanced). Several areas of sheathing are waterstained. Resistance meter registers 30%.*

Field Evaluations

Results of Field Evaluations are summarized in Table 2. Preliminary moisture monitoring results from five single-family dwellings are presented. Moisture meters were used to obtain qualitative "order of magnitude" data on changes in moisture levels in these building enclosures. Based on the moisture meter data, it appears that the remedial cladding approach (WRB with foam plastic furring strips and pan flashings) has achieved satisfactory results to date. At some sensor

Figure 4 *Mock-up for Stucco Evaluation #5 (two layers housewrap, one drainage–enhanced, with furring strips). Left side. Very limited waterstaining on sheathing. Resistance meter registers 8%.*

Figure 5 *Mock-up for Stucco Evaluation #5 (two layers housewrap, one drainage-enhanced, with furring strips). Right side. No water intrusion evident on WRB layers or sheathing. (Note closed-cell foam plastic furring strips).*

Table 2. Summary of Preliminary Sensor Data for Five Dwellings

House	Total # Sensors	Sensors Reporting ≥ 20% Levels	Sensor Readings Listed Chronologically (Last readings taken June 15, 2007)
# 1	11	2 (S-6, S-10)	S-6 (Below LL corner of garage window): 36 weeks @ 10% - 20%; next 1 week @ 25%; next 21 weeks @ 9% - 11% S-10 (Below LL corner kitchen window): 6 weeks @ 25% - 40%; next 7 weeks @ 15% - 20%; next 8 weeks @ 21% - 25%; next 9 weeks @ 15% - 17%; next 1 week @ 25%; next 26 weeks @ 10% - 20%; next 1 week @ 40%. All other sensors ≤ 20% (9 of 11). (58 weeks reported.)
# 2	20	2 (S-1, S-2)	S-1 (Below LR corner of garage window): 37 weeks @ 11% - 20%; next 1 week @ 21%; next 3 weeks @ 18% - 20%; next 3 weeks @ 21% - 22%; next 5 weeks @12% - 15%. S-2 (Below LL corner of same garage window as S-1): 12 weeks @ 15% - 20%; next 4 weeks @ 22% - 25%; next 12 weeks @ 12% - 20%. All other sensors ≤ 20% (18 of 20). (49 weeks reported.)
# 3	11	0	All sensors ≤ 20%. (43 weeks reported.)
# 4	21	1 (S-4)	S-4 (Below LL corner of bay window on front elevation): 6 weeks @ 10% - 20%; next 5 weeks @ 22% - 24%; next 2 weeks @ 20%; next 2 weeks @ 22% - 24%; next 5 weeks @14% - 18%; next 1 week @ 22%; next 6 weeks @ 18% - 20%; next 2 weeks @ 22% - 25%; next 5 weeks @ 15% - 20%; next 1 week @ 22%; next 1 week @ 18%. All other sensors ≤ 20% (20 of 21). (36 weeks reported.)

Table 2. Summary of Preliminary Sensor Data for Five Dwellings *(continued)*

# 5	42	9 (S-1, S-2, S-11, S-12, S-13, S-19, S-33, S-35, S-36)	S-1 (Below LR corner of window in front): 1 week @ 12%; next 2 weeks @ 21% - 23%; next 35 weeks @ 11% - 20%. S-2 (Below LL corner of same window): 2 weeks @ 12% - 20%; next 6 weeks @ 21% - 25%; next 30 weeks @ 10% - 20%. S-11 (Below LR corner of window on left elevation, above HVAC penetration): 5 weeks @ 12% - 20%; next 6 weeks @ 21% - 23%; next 5 weeks @ 15% - 20%; next 1 week @ 25%; next 2 weeks @ 20% -21%; next 3 weeks @ 14% - 15%; next 3 weeks @ 40%; next 4 weeks @ 15% - 18%; next 2 weeks @ 23% - 40%; next 7 weeks @ 9% - 18%. S-12 (Below LR corner of same window): 18 weeks @ 13% - 20%; next 1 week @ 21%; next 19 weeks @ 10% - 20%. S-13 (Below LR corner of window on left elevation, near chimney chase): 3 weeks @ 21% - 23%; next 6 weeks @ 20%; next 1 week @ 21%; next 28 weeks @ 11% - 20%. S-19 (Below LL corner of a rear window): 6 weeks @ 19% - 20%; next 4 weeks @ 21% - 23%; next 28 weeks @ 8% to 20%. S-33 (Below ganged window on rear sunroom): 28 weeks @ 10% - 20%; next 1 week @ 22%; next 9 weeks @ 7% - 20%. S-35 (Below RH corner of double window at rear elevation): 22 weeks @ 10% -18%; next 2 weeks @ 21% -22%; next 14 weeks @ 8% - 20%. S-36 (Below LH corner of same window): 24 weeks @ 8% -16%; next 6 weeks @ 21% - 25%; next 8 weeks @ 8% - 19%. All other sensors ≤ 20% (33 of 42). (38 weeks reported.)

locations, moisture levels increased (above 20%) for several weeks and then returned to drier conditions after several weeks. At one sensor location, fluctuating moisture levels were traced to an interior problem in the home's kitchen, rather than from a weather event at the building exterior. While the majority of sensors at each home have registered consistently "dry" readings, moisture levels at some sensors have increased and decreased repeatedly. The observed "drying" effect is important, but it is not clear at this time why the fluctuations occur. No attempt was made to analyze the data relative to other environmental factors such as interior/exterior vapor drives, diffusion, wind pressures, stack effects, moisture loads from occupants, and the like. One or more of these factors may be at work. Project results are considered informative but not authoritative. Additional research is needed to further evaluate the observed results in light of the many variables likely to be operating in "real world" residential wall assemblies.

Meter readings in Table 2 are expressed as a percentage of moisture in "wood moisture equivalents." Most water induced deterioration of wood-based products and mold formation requires wood moisture content above 20% (Morris, 1998). Readings from 20% to 28% are typically considered moderate and indicate that damage may occur if moisture levels are sustained. Readings of 30% and above indicate that wood-based components are saturated and damage is likely if sustained (Morris and Winandy, 2002).

SUMMARY AND CONCLUSIONS

Certain exterior walls (those which trap water) continue to experience moisture related damage and deterioration, despite Model Code requirements. Recent research by the author and others indicates that certain "drainage-enhanced" WRB products can improve drainage performance, but the issue of "drying" must also be addressed. "Drainage-enhanced" products still retain water that can migrate through fastener punctures and cause damage to the underlying sheathing. This has implications for absorptive /reservoir type claddings (such as stucco and manufactured stone). Laboratory evaluations presented here show that adding a drainage gap, in the form of a WRB with integral closed-cell plastic furring strips, appears to improve the water resistance performance of wall assemblies behind absorptive/reservoir type claddings. This innovative design approach, when used in conjunction with other protective measures such as pan flashings, is currently under study and appears to be viable in "real world" field evaluations.

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