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Water Management in Exterior Wall Claddings

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ABSTRACT: This paper presents results of laboratory testing on the performance of wall claddings using direct-applied (DEFS) and exterior insulation finish systems (EIFS) that incorporate water management features into their design and construction. The work presented in this paper is a continuation of earlier work conducted by the Institute for Research in Construction (IRC) of the National Research Council, Canada (NRCC) and the United States Gypsum Company (USG) evaluating the water penetration and moisture performance of barrier EIFS clad walls (Brown et al., 1997).

Direct-applied exterior finish systems (DEFS) are exterior wall claddings that use a water durable substrate, typically cement board, mechanically fastened to the wall framing over a sheathing membrane. A cementitious basecoat and textured acrylic synthetic stucco finish is then applied directly over the substrate. Insulation for the DEFS system is in the stud cavity. EIFS systems use a layer of foam insulation applied over the wall substrate, with basecoat and finish applied over the foam.

The performance of three water managed wall cladding designs in protecting wood framed construction from water intrusion by wind-driven rain is described. Three different drainage systems were evaluated. Performance measures evaluated included cladding airtightness, pressure equalization potential, and water drainage under wind-driven rain conditions. In each of the three systems, partial pressure

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equalization was observed, and any water that did breach the exterior skin was stopped at the sheathing membrane and directed down and out of the wall through the flashing and weep openings.

KEY WORDS: airtightness, barrier EIFS, direct-applied exterior finish system (DEFS), drainage cavity, pressure equalization, rain screen, water management.

INTRODUCTION

THIS PAPER PRESENTS results of laboratory testing on the performance of wall claddings using direct-applied exterior finish systems (DEFS) and exterior insulation finish systems (EIFS) that incorporate water management features into their design and construction. The work presented in this paper is a continuation of earlier work conducted by the Institute for Research in Construction (IRC) of the National Research Council, Canada (NRCC) and the United States Gypsum Company (USG) evaluating the water penetration and moisture performance of barrier EIFS clad walls (Brown et al., 1997).

The traditional barrier type EIFS design assumes that all water penetration can be stopped at the exterior face of the wall. The barrier approach uses adhesive attachment of the foam to the wall sheathing. Barrier EIFS does not incorporate a sheathing membrane combined with a system of flashing and weeps to direct all intruding water out of the cladding. The practical limitations of this concept have come into question following recent failures of EIFS clad houses in the Wilmington, North Carolina, area.

This study has been undertaken to better understand water management in DEFS and drainable EIFS systems. Water managed systems, designed around a "rainscreen principle" have been developed to raise wall performance reliability. Rainscreen designs assume that some water will penetrate beyond the exterior face of the wall that must be removed through a second line of defense. This paper describes the performance of three water managed wall cladding designs in protecting wood framed construction from water intrusion caused by wind-driven rain.

In DEFS, the wall cladding includes a cement board mechanically attached into the wall. Cementitious basecoat is applied over the cement board and acrylic synthetic stucco finish is applied over the basecoat. Insulation for the wall is in the stud cavity. For EIFS, the wall cladding includes a layer of foam insulation, with cementitious basecoat and finish applied over the foam. The foam can be attached using mechanical fasteners or adhesive.

EXPERIMENTAL PROCEDURE

All experimental work was conducted at the NRCC laboratory in Ottawa,

Canada. The three wall assemblies tested were evaluated by characterizing the airtightness, pressure equalization, and water management characteristics of full-scale test specimens using the NRCC Dynamic Wall Test Facility (DWTF). Airtightness was evaluated using static pressure, while pressure equalization was measured using dynamic pressure. The DWTF facility accepts a 2440 mm $\times$ 2440 mm (8' $\times$ 8') test specimen. The specimens were mounted in a steel test frame and the test frame was mounted to the DWTF. A typical test specimen is shown in Figure 1. The specimens were sealed to the steel frame with backer rod and silicone sealant in a single stage joint. The interior face of the specimens was exposed to the laboratory which allowed for observation of the stud cavities during testing.

Airtightness characteristics were evaluated by measuring the air flow rate under an applied static air pressure difference across the specimens of 500 Pa (10.4 psf). The air flow rate was measured with and without the face of the specimen sealed. The difference between the two measurements represented the airtightness of the specimens. The test pressure difference was chosen because previous NRCC experience with similar specimens had demonstrated that they were relatively airtight and a pressure difference of 500 Pa produced a measurable air leakage rate. This air pressure difference corresponds to a wind speed of 42 m/s (64 mph).

Pressure equalization characteristics of the drainage cavities were evaluated by measuring the frequency response of the drainage cavity to an applied air pressure difference across the specimen of a sinusoidal component with an amplitude of 200 Pa (4.18 psf) superimposed on a mean value of 300 Pa (6.27 psf). The response was measured for seven frequencies ranging from 0.05 Hz to 5 Hz. Measuring the pressure equalization response of the cavity under a dynamic pressure difference is a means of assessing the effectiveness of the venting provided by the drainage area at the base of the cavity.

Water management characteristics of the test specimens were evaluated by measuring and observing the transport of water through the specimen under simulated wind and rain test conditions. The evaluation, which proceeded in three stages, is summarized as follows:

1. Water was sprayed on the exterior of the specimen at a rate of 4.2 L/min/m² (6.2 gal/hr/ft²), while a static air pressure difference of 137 Pa (2.86 psf) was applied for 15 minutes, and then increased to 300 Pa (6.27 psf) for an additional 60 minutes.
2. Water was sprayed on the exterior of the specimen at a rate of 4.2 L/min/m² (6.2 gal/hr/ft²), while a dynamic air pressure difference, consisting of a sinusoidal component of 200 Pa (4.18 psf) at 0.5 Hz superimposed on a mean value of 300 Pa (6.27 psf) was applied for 60 minutes.

FIGURE 1. Test specimen mounted in DWTF (view from laboratory side).

3. The specimen was left undisturbed for the remainder of a 24-hour period (72 hours if over a weekend) in order to monitor how moisture stored in the specimen would move with time.

Moisture pins were designed and calibrated for installation in the wall to sense the presence of moisture in selected locations in the exterior cladding. Water entry paths were also determined by observation, and the rate of water intrusion was determined by measuring the amount of water collected on

the sill of the rough opening of the window and at the bottom of the drainage cavity.

TEST SPECIMENS

Three full-scale wall assemblies were evaluated, a direct applied assembly without a furred cavity, a direct applied assembly with a furred cavity, and an EIFS system with a furred cavity. The wall assemblies tested were constructed in the NRCC laboratory by USG personnel. Each specimen was 2430 mm $\times$ 2430 mm (8' $\times$ 8'). All specimens used wood stud framing, 38 mm $\times$ 89 mm (2" $\times$ 4") with studs spaced 406 mm (16") on center, with a double top plate and single bottom plate. A combination wood window was installed in each test specimen. The combination wood window consisted of two single hung window units, with brick mold sill extensions, which were factory mulled together. OSB sheathing 11 mm (7/16") thick, was nailed to the outside of the stud frame and 15# asphalt building felt was stapled to the exterior of the sheathing. 12 mm (1/2") PlexiglasTM was installed on the inside of the stud frame to act as a plane of airtightness for the air barrier system of the test specimens (the transparent PlexiglasTM also allowed for observation of the stud cavities on the interior side of the specimen). Figure 1 shows a specimen installed in the Dynamic Wall Test Facility (DWTF). The view is looking from the laboratory floor at the back, or interior side of the wall assembly. Continuity of the air barrier system at the wall/window interface was provided by taping the gap between the PlexiglasTM and the window frame, the plane of airtightness for the air barrier system. Dimensional lumber for the specimens was obtained in Canada. DEFS and EIFS materials were supplied by USG.

The first wall assembly evaluated was the direct applied system without furring lath (Wall Assembly 1). This assembly was clad with DUROCK[®] cement board DEFS fastened directly over the 15# building felt (Figure 2). In this assembly, water drainage is provided by the cement board and the interface between the cement board and the building felt. Care was taken during assembly construction to insure that the window sill area included the sill wedge, sill flashing, and proper lapping of the 15# felt (Figure 3). These are key features in the water management system. The second assembly evaluated used a furring lath installed behind DUROCK[®] cement board DEFS cladding (Wall Assembly 2). The furring was 50 mm (2") wide strips of a polyethylene diagonal mesh lath (Ultra-Lath[®]) 1/8" deep (Figure 4), which was stapled to the sheathing through the sheathing membrane. The mesh is ribbed with channels at the back of the lath to enable water to drain freely in the space created between the cement board cladding and the building felt. Flashing and drainage details at the window sill of Assembly 2 were similar

FIGURE 2. Isometric view of Wall Assembly 1.

to those described for Assembly 1. The third assembly evaluated was clad with EIFS (Wall Assembly 3). In this assembly, shown in Figure 5, EPS was adhered to the polyethylene mesh furring lath using cementitious basecoat on the back of the EPS. Basecoat was applied to the back of the EPS board using a notched trowel. The notched trowel created ribbons of basecoat on the back of the EPS, which were pressed in place onto the furring lath. When the basecoat cured, the EPS was well bonded to the furring lath. The drainage plane in this system is created by the furring lath between the EPS

FIGURE 3. Sill wedge, flashing, and lapping of felt at windowsill.

FIGURE 4. Isometric view of Wall Assembly 2.

FIGURE 5. Isometric view of Wall Assembly 3.

and the building felt (Figure 6). Flashing and drainage details under the window sill were again similar to Assembly 1.

Water management in the wall assemblies for this study was evaluated for the specimens as built and for the specimens with four typical wall/window interface defects. Details of the interface defects were determined following a review of typical design and construction defects.

The test specimen variations are summarized as follows:

- (a) As-built—the specimens as described above, in which appropriate due care and caution was exercised during construction.
- (b) Center caulk defect—a 2 mm wide by 75 mm (1/16") horizontal cut was made in the caulk directly below the mullion in the combination window.
- (c) Corner caulk defect—an L shaped cut, with legs 2 mm wide by 38 mm (1/16" by 1 1/2") was made in the caulk at the lower left corner of the window.
- (d) Air barrier system defect—holes were drilled in the plane of airtightness (Plexiglas™) in each stud cavity and in the plane of airtightness (tape) in the wall/window interface.
- (e) Total caulk defect—a 2 mm wide (1/16") cut was made in the caulk at the bottom window and 38 mm (1 1/2") cut up each side.

FIGURE 6. Wall Assembly 3—plan view showing drainage plane.

For all specimen variations, the previous defect was repaired before the next defect was introduced. All water management tests were conducted with the exteriors of the window units sealed with polyethylene sheets. The sheets were taped to the perimeter of each window unit, and also covered the mullion and frame of the combination window. This was done to exclude window leakage from the evaluation of the water penetration characteristics of the wall. In addition, the joint between the window sill and the sill brick mold extension was also sealed.

Electrical resistance moisture pins were installed on the exterior face of the three wall specimens to monitor the moisture content in the cladding during the static and dynamic portions of each test. The sensors were installed directly into the cement board in Wall Assemblies 1 and 2, and into the EPS in Wall Assembly 3. As water entered or left the wall, the change in moisture content was indicated by the change in electrical resistance at the measured area.

Each moisture pin sensor consisted of a pair of insulated wires. One end of each wire was attached, in pairs, to an automated data acquisition system (DAS). The other ends have a 3 mm (1/8") section of insulation removed from their tips and were embedded in the wall separated by a distance of 6 mm (1/4"). The exposed tips were inserted into the wall at a depth of 8 mm (5/16") [through 2 mm (1/16") of finish coat and 6 mm (1/4") into the cement board or EPS]. The locations on the wall specimen for each of the fourteen moisture sensors are illustrated in Figure 7. A small bead of epoxy was used to seal the insertion holes to prevent water from entering the cladding at these points. During the tests, the DAS continually measured the electrical resistance of the gap between the embedded wires and stored the information on a computer.

EXPERIMENTAL RESULTS

Wall Assembly 1—DEFS without a Furred Cavity

Testing on Wall Assembly 1 evaluated the water management capability of a direct applied exterior finish system with a non-furred drainage cavity. A DEFS system was used, with DUROCK® cement board panels mechanically fastened to the studs over the building felt, described earlier in Figure 2. The drainage cavity consisted of the interface between the cement board cladding and the 15# felt, and the cement board cladding itself.

Air leakage tests indicated that the assembly was relatively airtight with the operable portions of the combination window observed to be a location of significant leakage.

Pressure equalization tests indicated that the pressure equalization was not achieved over the evaluated frequency range. Approximately 39 percent of

FIGURE 7. Moisture pin sensor locations.

the driving pressure difference was occurring across the lamina/cement board cladding at 0.5 Hz.

During the water management test, no water was observed in the stud cavities or on the surface of the OSB sheathing. Some water was observed on the sill of the rough opening, but it drained through the drainage cavity and did not enter the interior of the wall. Measured water penetration of the specimen is summarized in Figure 8. The data show that the system drains water through the drainage plane under all test variations for both static and dynamic conditions. Measured drainage rates were typically higher under dynamic pressure conditions. Any water that penetrated past the cladding was drained through the drainage plane and directed out of the wall. This behavior was observed in all five test variations, including the case where the caulk under the sill was cut for the entire width of the window.

The moisture pins indicated that water entered the cement board cladding in all test specimen variations, including the "as-built" variation. For the most part, this happened shortly after the application of water in the water penetration test. Saturation conditions were evident below the window, suggesting that water entered through the window and wall/window inter-

FIGURE 8. Measured water through drainage cavity in Wall Assembly 1.

FIGURE 9. Percent moisture by weight vs. time for DUROCK® cement board in Wall Assembly 1, tested in the as-built variation.

face. Saturation conditions were also evident above the window, indicating that water entered through the face of the wall as well. Figure 9 shows a plot of moisture pin data from the "as-built" test of Wall Assembly 1. The plot displays data for the portion of the wall to the left of the window. Overall percent moisture by weight measured ranges from zero to a maximum of approximately 14 percent. A typical moisture content for DUROCK® cement board at ambient conditions (20°C, 50% RH) is 8 to 10 percent. The test result indicates that some moisture (4 to 6 percent by weight) is retained in the board during the test exposure. Drainage occurs during and after the test, with the upper portions of the assembly drying out relatively quickly. The lower part of the wall increases in moisture content during the first few hours and reaches a plateau during the first day. The cladding generally remained saturated for at least twenty-four hours, the minimum period between tests. The data indicate that a considerable quantity of water remains in the cladding for at least a day. The impact of this retained moisture is discussed in more detail below.

Wall Assembly 2—DEFS with a Furred Cavity

Testing on Wall Assembly 2 evaluated the water management capability of

a direct applied exterior finish system with a furred drainage cavity. The cavity was furred with 50 mm (2") wide strips of 3 mm (1/8") thick Ultra-Lath™ polyethylene diamond mesh furring. As noted earlier, Figure 4 shows the details of the assembly in isometric view. The Ultra-Lath™ strips were fastened vertically to the studs and horizontally at all terminations over the 15# building felt. The DEFS system was applied over the furring lath, with DUROCK® cement board panels mechanically fastened to the studs through the lath.

Air leakage tests indicated that the assembly was relatively airtight with the operable portions of the combination window observed to be a location of significant leakage.

Pressure equalization tests indicated that the pressure equalization was not achieved over the evaluated frequency range. Approximately 50 percent of the driving pressure difference was occurring across the lamina/cement board at 0.5 Hz.

In the water management test, no water was observed in the stud cavities or on the surface of the OSB sheathing. Some water was observed on the sill of the rough opening, but it drained through the drainage cavity and did not enter the interior of the wall. In order to evaluate the effect of the joint at the window sill brick mold extension on drainage through the wall, Assembly 2 was tested in the as-built condition with the joint both sealed and unsealed with tape. Measured water penetration of the specimen is summarized in Figure 10. Measured water penetration into the drainage plane in Wall Assembly 2 was significantly higher than in Assembly 1. This is likely due to the drainage cavity created by the furring lath in Assembly 2. The cavity created behind the lamina/cement board cladding has the effect of reducing flow resistance in the system, enabling more water to enter into the drainage plane. It is also interesting to note that in Assembly 2, the water penetration was greater in the static case than the dynamic. As with Assembly 1, any water that penetrated past the cladding was drained through the drainage plane and directed out of the wall. This behavior was observed in all five test variations, including the case where the caulk under the sill was cut for the entire width of the window. In this case, over 90 liters of water were drained through the drainage plane in the total caulk defect condition in both the static and dynamic cases.

The moisture pins indicated that water entered the cement board cladding in all test specimen variations, including the "as-built" variation, shortly after the application of water in the water penetration test. Saturation conditions were evident above and below the window, suggesting that water entered through the window and wall/window interface; but were also evident above the window, indicating that water entered through the face of the wall as well. The cladding generally remained saturated for at least twenty-four

FIGURE 10. Measured water through drainage cavity in Wall Assembly 2.

hours, the minimum period between tests.

For Wall Assembly 2, in addition to the water penetration tests, a heat lamp was used to simulate the effects of solar radiation on moisture transport through the cement board cladding. The lamp was focused on one half of the wall while the other was shaded. The lamp was placed approximately 1.5 m (5 feet) from the wall at a height of 1.2 m (4 feet). Four thermocouples were used to measure surface temperature in four locations on the wall surface: shaded interior, shaded exterior, radiated interior, and radiated exterior. The four thermocouples were arranged symmetrically around the specimen at a distance of approximately 160 mm (6.3") toward the center and 130 mm (5") down from the window edge on each side of the wall. The experiment ran for approximately four days. Thermocouple data, showing the difference in surface temperature, is illustrated in Figure 11. The temperature difference across the wall in the area of the heat lamp is approximately 6°C. The temperature difference between the shaded wall and radiated wall is, at most, 9°C. Moisture pin data were collected during this time to monitor the drying of the wall and are shown in Figure 12. The moisture pins in the radiated area dried to under 5 percent moisture by weight in less than two days. This

FIGURE 11. Wall Assembly 2—DEFS with furred cavity, surface temperature vs. time for heat lamp test.

FIGURE 12. Percent moisture by weight vs. time for DUROCK® cement board: Wall Assembly 2—heat lamp test.

indicates that small amounts of radiation, corresponding to a relatively small increase in surface temperature, have a significant effect on the drying potential of the wall.

Wall Assembly 3—EIFS with a Furred Cavity

Wall Assembly 3 was designed to evaluate the water management capability of an EIFS wall cladding with a continuous drainage cavity behind the cladding. The drainage cavity in this assembly is formed by using a 3 mm thick continuous layer of Ultra-Lath™ behind the EPS foam in an EIFS cladding. The cavity was finished on the exterior with 25 mm (1") thick EPS which was adhered to the Ultra-Lath™ with vertical ribbons of basecoat as described earlier (Figures 5 and 6).

Air leakage tests indicated that the assembly was relatively airtight with the operable portions of the combination window observed to be a location of significant leakage.

Pressure equalization tests indicated that pressure equalization was not achieved over the evaluated frequency range. Approximately 43 percent of the driving pressure difference was occurring across the lamina at 0.5 Hz.

In the water management tests, no water was observed in the stud cavities

or on the surface of the OSB sheathing. Some water was observed on the sill of the rough opening, but it drained through the drainage cavity and did not enter the interior of the wall. Measured water penetration rates into Wall Assembly 3 are summarized in Figure 13. In the "as-built" condition, water penetration to the drainage plane was greater under static pressure than dynamic. For the variations where a defect was introduced, drainage was higher under dynamic pressure.

The moisture pins indicated that little water entered the EPS cladding in any test specimen variation. Especially notable is that no significant water was measured in the EPS cladding below the window. The moisture pins located directly under the window indicated that the moisture content in that area did not exceed 6 percent at any point during the test. The EIFS with a furred cavity test specimen more than adequately managed water under all test conditions.

DISCUSSION AND CONCLUSIONS

The performance characteristics of three exterior wall cladding systems with combination wood windows have been experimentally determined in large-scale laboratory tests using the NRCC Dynamic Wall Test Facility. Performance measures included cladding airtightness, pressure equalization potential, and water drainage under wind-driven rain conditions. Three different drainage systems were evaluated. Two DEFS systems were tested, one with DUROCK® cement board furred 3 mm off the weather resistive barrier, and one without furring. The EIFS system evaluated used 3 mm thick polyethylene mesh as a furring material, with the EIFS adhesively bonded to the mesh with basecoat.

All three wall systems were found to be effective air barriers, with the exception of the operable portions of the combination wood windows. Partial pressure equalization was observed in the tests, with 39 to 50 percent of the driving pressure occurring across the claddings. The DEFS clad walls with DUROCK® cement board and furred cavity exhibited the highest pressure equalization, while the DEFS clad walls without furring had the lowest. This indicates that each of the wall assemblies acts as a partial pressure equalization system, where the exterior cladding reduces the driving pressure that occurs across the sheathing material and into the wall cavity.

All three systems performed as effective rain screen systems. Any water that did breach the exterior skin was stopped at the 15# felt and directed down and out of the wall through the flashing and weep details. This included water that migrated through the window assembly and through defects intentionally introduced into the sealant joints. In all static and dynamic test conditions, the moisture sensitive OSB structural sheathing

FIGURE 13. Measured water through drainage cavity in Wall Assembly 3.

and wood framing materials were completely protected from water exposure. The performance of the water managed systems stands in sharp contrast to previous research work on barrier EIFS clad walls where, under similar exposure conditions, structural wall components were compromised by water intrusion.

While the DEFS clad walls managed water effectively and exhibited drainage, the DUROCK® cement board used in two of the three walls were observed to reach nearly 16 percent moisture content by weight under prolonged water exposure. Typically, the moisture content by weight of these panels is 8 to 10 percent at ambient conditions. Solar exposure of these walls was simulated using radiant heat lamps and panel moisture content monitored using electrical resistance sensors. Cladding drying time was one to two days. Further research work has been initiated to determine how water stored in cement board panels dissipates under a range of climatic conditions. Additionally, this work will assess the performance of a variety of commercially available weather resistive barrier materials in water managed designs where some wall components can store or release moisture over normal climatic cycles.

In summary, this study has demonstrated the ability of exterior wall claddings designed with a "rainscreen" approach to be highly effective in protecting building structures from moisture-related damage caused by water intrusion from wind-driven rain. These systems are practical to construct and reliable in performance.

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