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Features:

11 Measuring the Impact of Interior Insulation on Solid Masonry Walls in a Cold Climate

23 A Study of Drainage and Retention of Water by EIFS Materials and Systems

31 Adhered Veneers and Inward Vapor Drives: Significance, Problems and Solutions

Messages:

7 Message from Institute President
   Henry L. Green

9 Message from BETEC Chairman
   Wagdy Anis

Industry Updates:

36 BEC Corner

38 Buyer’s Guide

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PROVIDING FORUMS WHERE industry professionals can share information about building enclosures, address the current problems that exist and find the multitude of solutions to improve our building environment is important because it benefits our communities and our planet. That is why the National Institute of Building Sciences is so supportive of efforts to establish local Building Enclosure Councils (BECs) and assist their work where possible.

Earlier this year, the Institute recognized one individual who made it his own work to aid in the establishment of local BECs. In January 2009, the Institute bestowed David Altenhofen the 2008 Institute Honor Award for his efforts to help form the Philadelphia BEC and kick off six other chapters. By sharing his knowledge and talent, Mr. Altenhofen was instrumental in providing the guidance and leadership to get new BECs off the ground.

Raising awareness about ways to improve building enclosures is one of our primary goals. In May, I participated in the BEC Breakfast Meeting at the AIA Conference. It was an opportunity to share information with other BEC members from throughout the United States.

The 12th Canadian Conference on Building Science and Technology is another excellent example of sharing information, knowledge and ideals. Highlighted in this edition of the Journal of Building Enclosure Design (JBED), this year’s Conference programs focused on environmental loading, energy sustainability, and materials performance and monitoring—all areas that we need to be aware of when addressing building enclosures. Peruse the enclosed technical papers resulting from these presentations to learn how the goal of achieving an energy-efficient, high-performing built environment is within reach.

In fact, for the first time ever, the United States Congress declared a week this year to recognize the importance of high-performance buildings. June 15 to 19 was the inaugural celebration of High Performing Building Week. A resolution adopted by the United States House of Representatives, recognized the nation’s commitment to high-performing buildings and supported the goals and ideals of high-performing buildings.

“The impact of implementing new technologies in new and existing buildings has not only an environmental impact but an economic impact by creating jobs right here in the U.S.,” said Congressman Russ Carnahan during the celebration. Carnahan, who is the co-founder of the High Performance Building Congressional Caucus, noted the need for the industry to set high, sustainable standards, and to provide workable incentives to help meet these standards to benefit the health and well-being of American citizens.

There are several exciting events approaching where you can expand your professional knowledge related to building enclosures so you can indeed benefit both the health and well-being of the building's occupants as well as the environment. The Building Enclosure Technology and Environmental Council Symposium on Retrofitting Building Enclosures for Energy Efficiency and Sustainability, featured at the National Institute of Building Sciences Annual Meeting, to be held December 8 to 10, in conjunction with the EcoBuild Conference in Washington, D.C., will have a great selection of programs and speakers. Next year, the BEST 2 Conference scheduled for April 12 to 14, 2010, in Portland, Ore., is also shaping up to be a fantastic event. These conferences are wonderful opportunities for you to attend presentations, join discussions and share your experiences with other knowledgeable practitioners and researchers in the building industry.

With the nation’s increased focus on the built environment and the vast amount of energy consumption attributed to buildings, we need to start examining and placing into practice the technology currently available, including cutting edge products, materials and processes. New concepts and ideas under development also have the potential to bring about results that can greatly achieve increased energy efficiency in building envelopes. It is time to assure building envelopes perform effectively to prevent penetration of moisture, resist exfiltration and assist in the proper operation of building environments. None of these concepts should be viewed in isolation, but rather should be a part of an overall collaborative effort measured in terms of total building performance.

What better way to learn about these new ideas than to get involved in your local BEC Chapter (or start a new one), attend industry conferences and read JBED? I hope you enjoy this edition of the magazine and look forward to seeing you at an upcoming event as you join your colleagues to share knowledge and improve your understanding of building enclosure design.

Henry L. Green, Hon. AIA
President
National Institute of Building Sciences
Judd Allen Group specializes in helping our clients achieve the highest level of quality, design, and energy efficiency by focusing on exterior envelope assessments, thermal analysis, & design recommendations that comprise many exterior components, such as waterproofing, masonry, window/curtain wall installation, metal panels, rain screen & many other exterior envelope materials. We pride ourselves in being up-to-date with all exterior materials and methods to help guide our clients with attention to efficiency and aesthetics.
GREETINGS AND WELCOME to the summer edition of JBED. There sure are a lot of exciting activities happening related to the building enclosure industry these days.

In May, I attended the Canadian National Building Envelope Council’s (NBEC) Conference. The Conference was a tremendous success, well-organized by QBEC, with Mario Goncalves and Dominique Derome leading the proceedings. Mes felicitations, CEBQ! The setting was at the Palais des Congrès de Montréal—wonderful city, people and food. All-in-all, a rich conference. There was one sad note when Mario Goncalves announced to the 300 attendees that the visionary physicist, Tony Woods of Canam Building Envelope Specialists and Zerodraft, had passed away. Tony was a friend indeed and I will miss his cheerful wit and his “Happy Friday!” on the phone. This edition of JBED is dedicated to capturing some of the marvelous content of the NBEC 11th conference, and to Tony.

As a special privilege, I was invited to the NBEC Annual Meeting of the Board of Directors when they selected Winnipeg and the Manitoba Building Envelope Council as the 12th organizer and venue of the 2011 NBEC Conference. Ryan Dalgleish, MBEC/NBEC chair, accepted the challenge, and promised that all the snow would be gone for the conference.

The BEC Portland and BETEC Board members Bomberg, Onysko and Mathis are busy finalizing the content of the BEST 2 Conference in Portland, Oregon (www.thebestconference.org) to be held on April 12 to 14 in 2010. The conference is organized by BEC Portland and supported by the National Institute of Building Sciences, BETEC, BEC-National, AIA, DOE and its Oak Ridge National Laboratory. The conference theme is A New Design Paradigm for Energy Efficient Buildings. I hope to see you all there.

Another important event coming soon is the BETEC Symposium, to be held December 10, 2009, in Washington D.C., in conjunction with the Institute’s Annual Meeting and the Ecobuild America Conference, (www.NIBS.org/annualmeeting). This one-day symposium focuses on the all-important subject of Retrofitting Building Enclosures for Energy Efficiency and Sustainability, a topic vital to energy independence and security. Both the Institute and BETEC Boards will hold their meetings during the conference, which runs from December 7 to 10, 2009.

Lastly, both personally and on behalf of the BETEC Board, I wish to congratulate Anton TenWolde on achieving the milestone publication of ANSI/ASHRAE Standard 160-2009, Criteria for Moisture-Control Design Analysis in Buildings. Anton served as chair of ASHRAE’s SP 160, which worked on this standard for several years. Anton is a physicist formerly with the USDA Forest Products Laboratory in Madison, Wisconsin, and a former BETEC Board member. For many years, Anton was BETEC’s leader of the moisture research coordinating committee and organizer of the Bugs, Mold and Rot series of conferences along with Don Onysko and Bill Rose. Congratulations Anton!

I hope you enjoy this edition of JBED. I look forward to seeing you soon at the Ecobuild and BEST 2 Conferences!

Wagdy Anis, AIA, LEED AP
Chairman, BETEC Board
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Principal, Wiss Janney Elstner

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Building Owners and designers are increasingly considering upgrading the exterior enclosure’s thermal performance in existing buildings. Our aging building stock provides tremendous opportunities to reduce our overall environmental footprint through upgrades to the exterior enclosure.

Given the embodied energy inherent in existing buildings, it is often preferable to modify existing assemblies instead of tearing them out and sending waste to the landfill. Buildings with solid or load-bearing masonry walls typically employ interior insulation retrofit strategies as these buildings often have heritage or historical significance that preclude work from the exterior. This may result in accelerated masonry freeze-thaw deterioration, embedded steel (lateral ties and supporting angles) corrosion, interior plaster finish deterioration and/or mould growth.

This paper describes a fully instrumented large-scale mock-up completed in a southern Ontario private school to allow direct comparisons between insulated and non-insulated walls with a focus on the evaluation of freeze-thaw and corrosion risks. Climate conditions and wall temperature, relative humidity and moisture content are compared and discussed. Climate conditions (wetting and temperature) over the monitoring period were less severe than average. As a result, measured values were used to refine computer models to simulate wall performance under more severe climate conditions.

Findings show low freeze-thaw risk to the insulated brick, but an increased risk for embedded steel corrosion. Further study is recommended to evaluate sensor response, confirm selected freeze-thaw thresholds and monitor walls under more severe climate conditions.

**INTRODUCTION**

The objective of this study was to evaluate the risks associated with insulating exterior masonry walls from the interior. The building reviewed is a three-storey school constructed in Toronto, Ontario in the late 1950s. The exterior walls are load-bearing masonry measuring three wythes thick. The wall interior is finished with hollow clay tile and painted plaster.

A literature review on insulating masonry walls revealed case studies demonstrating adequate performance, recommended practices to minimize risks and preferred insulating methods. Specifically, two case studies of insulated masonry walls in a cold climate were reviewed; Dumont (2001), shows walls performing as designed up to 14 years after retrofitted. General practices to minimize risks as outlined by Goncalves (2003) are: minimize exterior rain penetration into the wall, minimize penetration of interior humidity into the wall (from vapor diffusion and/or air flow), limit the thickness of the insulation, and minimize air pressure difference across the wall. Some risks associated with fiberglass batt insulation have also been highlighted by Straube (2007); in particular, convective loops promote condensation where the insulation is not applied tightly against the masonry wall.

There are numerous methods to insulate masonry walls from the interior, each with specific risks and benefits in particular situations. Common materials used to insulate masonry from the interior are:

1. Fiberglass insulation (with independent air flow and/or vapor control layer(s));
2. Open-cell spray-foam insulation; and
3. Closed-cell spray-foam insulation.

Mechanical system interventions can also be employed to supply warm/dry air to wall cavities inboard or outboard of the retrofit insulation to promote wall drying and reduce deterioration risks.

Our study is focused on the use of interior closed-cell spray foam insulation at a building in Toronto without supplying conditioned air to any of the wall cavities. For this specific case study, several deterioration risks were identified in a feasibility study and examined through computer modeling, including: freeze-thaw deterioration, embedded steel corrosion, organic growth, plaster deterioration and differential thermal expansion. These risks were further evaluated through field measurements of insulated and un-insulated mock-up walls, and simulated further under more severe climate conditions. This paper focuses on the more significant risks raised in the field study:

1. Freeze-thaw deterioration: Applying insulation to the building interior can increase the risk of freeze-thaw deterioration in the exterior brick and mortar since the drying potential is reduced and materials outboard of the insulation are colder during winter conditions.
2. Embedded metal component corrosion: Insulating the masonry from the interior can increase the embedded metal corrosion risk, since relative humidity increases as temperatures and drying potential decreases. However, lower temperatures may also reduce corrosion risk, since corrosion rates slow down as temperatures decrease.

**METHODOLOGY**

Work completed for this evaluation included:

1. Mock-up wall monitoring: Four exterior wall areas were instrumented...
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in one room. Hourly measurements were taken on existing (un-insulated) and upgraded (insulated) wall assemblies on the east and south elevations. Details of this installation are outlined below.

2. Brick testing: Nine brick samples were removed from the exterior wall and tested to determine their water absorption properties (A-value, Straube 2005). These bricks were also used to calibrate the moisture content sensors (wood wafers) with the corresponding brick moisture content.

3. Climate analysis: The exterior climate during the monitoring period was evaluated by comparing local temperature and rain data to climatic normals (tipping rain buckets were also set-up to directly measure driving rain at the mock-up locations).

4. Computer model extrapolations: Our previous computer models were refined using measured brick properties and verified against measured data. Models were then completed with more severe climatic conditions than those measured (due to less than normal wetting conditions during the initial monitoring period), to further evaluate wall performance. This work was completed using a computer based analytical program (WUFI® Pro 4.1, Fraunhofer Institute for Building Physics 2006).

Mock-up wall monitoring set-up

Four mock-up walls were constructed. A room was selected on the top floor and at an outside corner facing south and east since this was expected to be the most severe climate exposure for this building. FIGURE 1 contains the wall sections and sensor locations. FIGURE 1 shows the mock-up wall locations from the exterior. A description of the tested wall assemblies is as follows:

1. Zone A: Existing (un-insulated) wall assembly, east elevation: Three wythes brick; 50 mm (1.9 inches) hollow clay tile; 20 mm (0.78 inches) plaster; 2 coats paint (likely oil);

2. Zone B: Modified (insulated) wall assembly, east elevation: Three wythes brick; 50 mm (1.9 inches) SPF insulation; 25 mm (0.98 inches) air space; 12 mm (0.47 inches) drywall; 1 coat primer; 2 coats latex paint;

3. Zone C: Modified (insulated) wall assembly, south elevation: Three wythes brick; 50 mm (1.9 inches) SPF insulation; 25 mm (0.98 inches) air space; 12 mm (0.47 inches) drywall; 1 coat primer; 2 coats latex paint; and

4. Zone D: Existing (un-insulated) wall assembly, south elevation: Three wythes brick; 50 mm (1.9 inches) hollow clay tile; 20 mm (0.78 inches) plaster; 2 coats paint (likely oil).

Nine sensors were installed in each wall to measure temperature, relative humidity and moisture content at various locations across the wall (see FIGURE 1). Exterior temperature and relative humidity were measured directly outside the test walls. Driving rain was measured on the exterior of the walls, at the bottom of Zones B and C (south and east). Interior temperature and relative humidity were also measured at two locations within the test room.

The temperature sensors are 10K Ohm NTC thermistors, and the relative humidity sensors are capacitance based sensing elements housed in vapor permeable covers to protect them from liquid water. The moisture content in the brick and mortar was measured using surrogate wood resistance sensors. These sensors are a plug of eastern white pine with the resistance measured across the material by a pin on one end and a ring around the other. These sensors are similar to those examined by Carll & TenWolde (1996) and Ueno & Straube (2008).

All wall sensors were installed from the interior, through 13 mm (0.51 inches) diameter holes drilled to the depth of interest. The temperature and relative humidity sensors had a prefabricated plastic plug matching the diameter of the hole attached to the back of the sensor. Once in place, the back of the plugs were sealed in place with epoxy. The balance of the drilled hole was then filled with spray foam insulation.

The moisture content sensors were also installed through drilled holes, but were encapsulated with bentonite clay to provide full contact between each sensor and the parent material. The balance of these holes was also filled with spray foam insulation. The wood

---

Figure 1. Mock-up wall sections. Zones A&D: existing un-insulated wall assembly. Zones B&C: modified insulated wall.
resistance sensors were tested in a lab to calibrate the wood moisture content readings with the moisture content of the parent brick and mortar. Further details about similar sensors used are described in Straube et al. (2002).

The driving rain gauge uses a standard tipping bucket to measure water volume, mounted in a custom housing. The housing mounts flush to the wall, covering an area about 300 mm x 300 mm (11.8 inches), and is delineated at its perimeter by 75 mm (2.9 inches) long returns, perpendicular to the wall.

The monitoring system was commissioned on September 18, 2007. This paper reviews data collected over the first winter, from September 19, 2007 to June 1, 2008.

**KEY FINDINGS**

Our key findings from the work performed are as follows:

**Below-average climate conditions during monitoring period**

The climatic conditions at the site over the monitored period were less severe than average for Toronto. The key climatic variables for this evaluation are rain wetting and exterior temperatures as they dictate the number of expected freeze-thaw cycles and conditions for embedded metal corrosion.

Below-average wall wetting: Expected driving rain at the site was calculated using publicly available vertical rainfall, wind direction and wind speed data from nearby Queens Park (calculated per procedures described in Straube and Burnett (2005)). A rain deposition factor of 0.5 was used, as determined by comparing calculated wind driven rain from the data noted above against measured wind driven rain on site. Based on this evaluation, the monitored walls were only exposed to about half the driving rain that occurs in an average year, as shown in **FIGURE 2**.

While there was less-than-average driving rain on the south and east elevations over the period under review, there was significant vertical rainfall over this period. Unfortunately, most of this rain was driven onto the N, W and SW elevations. In fact, these elevations experienced 2.5 times the average rainfall. In short, this was an uncharacteristic year for driving rain, with less driving rain from typical directions and more from atypical directions. As the conditions on the monitored walls provide below-average conditions for evaluating freeze-thaw or corrosion risks, the monitoring results were used in combination with computer modeling to further evaluate deterioration risks.

**Below-average number of zero degree-crossings:** The monitored walls were exposed to 70 percent of the zero degree-crossings that would result during the third coldest year in thirty (10th percentile) from the computer model database. The number of zero-crossings is comparable to the amount seen in the third warmest year in thirty (10th percentile) from the computer model database.

As these are also below-average conditions for evaluating freeze-thaw risks, the monitoring results were used in combination with computer modeling to further evaluate deterioration risks.

**Bricks tested may not meet modern freeze-thaw performance standards**

The water absorption properties of the tested brick show that they are highly absorptive. **TABLE 1** contains a summary of measured brick properties.

When brick properties are compared to modern CSA standards, the bricks may not meet the specified freeze-thaw resistance performance. While this testing is not designed for existing or aged brick, it could give insight into expected brick freeze-thaw resistance.

The bricks tested did not pass the first two of three CSA test thresholds. These first two tests evaluate the amount of water absorbed into the brick relative to the amount of air remaining in the brick pores (i.e. the room remaining for freezing water to expand). A brick can still have reasonable freeze-thaw resistance during the third coldest year in thirty (10th percentile) from the computer model database.
if it fails these two thresholds, but must pass the third test to prove this under the CSA standard. This third test, a freeze-thaw test, which cycles partially saturated brick through 50 freeze-thaw cycles, is costly and its reliability is controversial in the industry (Robinson 1995, Vickers 1993). An alternative freeze-thaw test could be performed to evaluate the critical degree of saturation.

**Walls demonstrated low freeze-thaw deterioration risk**

The measured and modeled insulated walls demonstrated low freeze-thaw deterioration risk.

The measured insulated walls were cooler than the measured un-insulated walls throughout the winter. At wall locations critical for freeze-thaw damage (exterior brick and exterior collar joint), the insulated walls were up to 12°C (53.6°F) cooler than the un-insulated walls (see **Figure 3**). This resulted in up to five times as many zero crossings in the insulated walls. The increase in zero crossings was most pronounced on the south exposure, where cooler walls were subject to increased daily heating from the sun (see **Figure 4**).

The moisture content in the measured walls was low throughout the monitoring period and, as a result, there were no hours where freeze-thaw damage was likely to occur (see **Figures 5 and 6**). The maximum monitored moisture content was 4 percent in the brick and mortar, which is below the estimated 12 percent threshold where freeze-thaw damage is expected to occur (this 12 percent threshold corresponds to 85 percent of the free water saturation). This threshold is expected to be conservative since there should be sufficient room remaining in the pores to alleviate pressures from freezing water.

Given that the low moisture content in the measured walls (and no freeze-thaw risk) likely resulted from less than average wetting conditions discussed earlier, modeling was used to evaluate the freeze-thaw risk in these walls under more severe climate conditions.

The hygrothermal performance of the modeled and measured walls generally compared well (see **Figure 7**), particularly at locations sensitive to freeze-thaw (exterior brick and exterior collar joint). The thermal properties of the components are well understood. The relative humidity trends are also consistent between the measured and modeled results, but the modeled values are typically within 10 percent of the measured values.

These results seem reasonable given that a one-dimensional model is being used to represent two-dimensional moisture flow through the mortar and bricks.

The moisture contents are generally comparable between the calculated/modeled and measured results (see **Figure 8**). However, there are spikes in the modeled exterior brick moisture content soon after rain events, which do not appear as significantly in the measured walls. This discrepancy is discussed in more detail later in this article. The model was used to evaluate these peak moisture content values, as they are important to freeze-thaw performance.

In the modeled walls subjected to more severe weather conditions than those experienced in the field (using rain deposition factor of 0.5), there were no instances where freeze-thaw damage was likely to occur (see **Figure 9**). The maximum moisture content was 10.6 percent (peaking in the brick soon after rain events).

The moisture content in the brick between rain events is typically near 0 percent. The mortar moisture content is fairly constant between 2 and 8 percent. These moisture contents are below the estimated threshold levels of 12 percent and 13 percent (brick and mortar respectively) where freeze-thaw damage is expected to occur.

**Minor increase in risk for embedded metal component corrosion in insulated walls**

There may be a minor increase in embedded metal component corrosion risks for the insulated walls compared to the existing un-insulated walls.

<table>
<thead>
<tr>
<th>Brick</th>
<th>Brick Type</th>
<th>24 h cold water absorption (kg) / Brick dry mass (kg)</th>
<th>Saturation Coefficient</th>
<th>Meet Freeze-thaw thresholds for Exterior Brick (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interior</td>
<td>9.8%</td>
<td>0.97</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>Interior</td>
<td>9.6%</td>
<td>0.99</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Interior</td>
<td>9.9%</td>
<td>0.96</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>Interior</td>
<td>10.0%</td>
<td>0.95</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>Exterior</td>
<td>10.0%</td>
<td>0.83</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>Exterior</td>
<td>9.2%</td>
<td>0.83</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>Exterior</td>
<td>13.6%</td>
<td>0.86</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>Exterior</td>
<td>13.9%</td>
<td>0.89</td>
<td>N</td>
</tr>
<tr>
<td>10</td>
<td>Exterior</td>
<td>11.8%</td>
<td>0.87</td>
<td>N</td>
</tr>
</tbody>
</table>

Table 1. Comparison of brick test results to CSA Standard. The water absorption properties were evaluated for 9 bricks taken from walls near the mock-up location (4 bricks from the interior and 5 from the exterior). These results are compared to the CSA Standard A82-06 “Fired masonry brick made from clay or shale” (see Section 6 - Freeze-thaw durability/6.2.2 - Absorption testing).
**FIGURE 10** shows the time above corrosion thresholds. Corrosion threshold is Time of Wetness (i.e. hours above 0°C and 80 percent relative humidity) as defined in ISO (1992).

The modelled walls show no increase in corrosion risk between un-insulated and insulated walls. However, the measured walls show an increased risk. We believe this discrepancy is, in part, due to the nature of the sensor installation, with a wood resistance sensor embedded in the parent material using bentonite clay. In addition, moisture transport in the model may occur by liquid transport, while moisture transfer to the sensors is predominantly by vapor diffusion (i.e. slower process). This may result in the sensors showing more time above thresholds after a rain event.

When conditions in the wall support corrosion, it does not necessarily mean corrosion is occurring. The high pH of mortar provides a passive oxidation layer that protects embedded metal from corroding. The pH drops over time as CO2 enters pores in the mortar or where CO2 has direct access to metal through cracks. When and if carbonation reaches the location of metal in the wall, corrosion could begin. Carbonation is, generally, a slow process.

**DISCUSSION**

The moisture content sensors used are not suitable to detect critical moisture content levels in this brick for a freeze-thaw analysis, since their time response was not fast enough to capture short-term moisture content spikes after rain events and their range of sensitivity is below that of critical levels of interest.

The measured and modeled moisture contents (both over a 25 mm slice at same location in wall) compare well outside of short-term peaks, where the measured values are less than the modeled values. The MC spikes are important to a freeze-thaw analysis, as this is the time when materials could be saturated enough to cause freeze-thaw damage when coincident with below 0°C temperatures. We speculate that the MC spikes are not

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**Figure 5.** Measured RH and MC in east existing wall. Actual relative humidity and moisture content (wood wafer) measured in the existing east wall. The moisture content is well below thresholds for freeze-thaw. MC values shown are for the wood resistance sensors embedded in the brick, instead of the corresponding brick moisture content in order to increase measurement resolution.

**Figure 6.** Measured RH and MC in east insulated wall. Actual relative humidity and moisture content (wood wafer) measured in the insulated east wall. The moisture content is well below thresholds for freeze-thaw. MC values shown are for the wood resistance sensors embedded in the brick, instead of the corresponding brick moisture content in order to increase measurement resolution.

**Figure 7.** Temperatures shown are similar between modeled and measured walls. Other locations also compare well.

**Figure 8.** Moisture contents are generally similar, apart from severe spikes in modeled moisture content soon after rain events that are not observed in measured values. This discrepancy should be resolved with artificial wetting of the field sensors to test reaction time to wetting events.
as pronounced in the measured values due to slow sensor response, given sensor size and encasement in bentonite clay (which may impact capillary connectivity). After a rain event, the moisture may dry or be redistributed before the sensor can fully react.

The wood moisture content sensors used to evaluate the brick moisture content operated accurately in the 20 percent to 50 percent wood MC range (corresponding to 0 percent to 8 percent MC in this brick), as shown in **Figure 11 and Figure 12**. The wood moisture content did not exceed 30 percent (4 percent in this brick) over the monitoring period due to a lack of wetting, so the upper range of the sensors was not an issue in this case (see **Figure 10**). However, given that critical limits for freeze-thaw damage correspond to approximately 70 percent in wood (12 percent in this brick), these wood sensors would not adequately evaluate moisture content near the threshold in this brick.

In summary, the sensors used can indicate safe freeze-thaw performance, but have poor accuracy as one approaches critical moisture content levels in this brick. In addition, the size and capillary connectivity of the sensors should be further investigated and improved to provide a sensor that reacts more quickly.

**CONCLUSIONS**

**Insulated walls**

The walls evaluated may be insulated from the interior with a low increase in freeze-thaw risk, as the moisture levels in brick and mortar are not likely to reach freeze-thaw damage thresholds. Proactive measures should be taken to ensure excessive wetting of the wall is avoided (regular re-pointing, and effective water-shedding details, etc.).

**Investigate condition of embedded steel prior to insulating walls**

Inspection openings in the walls should be used to determine the function, extent and condition of the embedded metal components prior to insulating walls given the high number of hours above corrosion thresholds even for the existing walls. The depth of carbonation in the mortar (passive protection of metal by mortar) should also be checked. Metal components could be replaced with stainless steel components where embedded metal corrosion risk is expected to increase (e.g. stainless steel helical ties could be used to replace or supplement metal ties).

**Further monitoring and testing**

As climatic conditions experienced over the 2007/2008 winter were less severe than average, continued monitoring of the walls over another winter should be checked in the hopes of providing additional insight into the wall behavior under average or extreme conditions.

The moisture content sensors in the monitored walls should be checked to confirm their reaction time to rain events. This evaluation could be performed by applying water to the area in question, which would allow for a constant wetting condition with

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**Figure 9.** Brick moisture content in most severe modeled case is 10.6 percent, which is below the 12 percent MC freeze-thaw threshold.

**Figure 10.** Insulated walls have significantly more time above corrosion thresholds than existing walls, increasing risks for embedded steel corrosion in insulated walls.

**Figure 11.** Measurements taken during lab testing of wood sensor installed in brick, as done in the field.

**Figure 12.** Corresponding brick MC for given wood MC reading. Wood sensors operate accurately in the range circled in yellow. Critical moisture content range for brick freeze-thaw analysis (and corresponding wood moisture content), shown with dotted red arrows.
greater frequency of sensor measurement. If, as we suspect, they do not react quickly, then supplementary sensors could be added that register peak moisture contents, and brick moisture contents near critical thresholds.

The freeze-thaw resistance of the bricks could also be evaluated with an additional test to determine at what moisture/temperature threshold they begin to exhibit freeze-thaw damage. These thresholds (critical degree of saturation) would confirm if the threshold levels set in our analysis are actually conservative as we believe them to be.

J. Wilkinson, D. De Rose, and B. Sullivan are all part of the team at Halsall Associates Limited involved with building restoration. J.F. Straube is a Principal at Building Science Consulting and an Associate Professor in the Dept. of Civil Engineering and School of Architecture at the University of Waterloo.

EDITOR’S NOTE: To obtain a full list of references for this article, email shannonl@matrixgroupinc.net.
Airtightness Testing - Not Just for Homes Anymore

Airtightness testing of homes has been around for more than 20 years. Various energy programs and fluctuating energy bills have provided homeowners an incentive to improve the airtightness of their homes. Energy tax credits can also be received by the homeowner but only if the house airtightness has been verified that it is less leaky after remodeling than before.

In England, airtightness testing of buildings over 10,000 square feet was the first regulation initiated to reduce energy consumption. Efforts to make commercial buildings more energy efficient in the U.S. has only recently been incorporated into various “green” initiatives. Tests of commercial buildings show that they tend to be more leaky than the average house, based on air leakage per square foot of surface area. That means that commercial buildings are less energy efficient than the average house.

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STUDIES OF DRAINAGE and retention of water by cladding systems in accordance with a modified ASTM test standard have demonstrated that properly built exterior insulation and finish systems (EIFS) can effectively drain rain water that may penetrate through the primary EIFS. Relative to some other cladding systems, tests of EIFS have shown lower retention of water; but the manner that moisture is held influences the rate at which drying will subsequently take place.

A consortium of six EIFS manufacturers (Sto Corp, Dryvit Systems Canada, DuRock Alfacings International Limited, Durabond Products Ltd., BASF Wall Systems, and Adex Systems Inc.), together with the Canadian Construction Materials Centre (CCMC), undertook a research program to determine in greater detail how water was retained in different materials in EIFS test walls and how their construction influenced their retention and drying performance.

All systems investigated in this test program involved liquid applied water penetration barriers (LA-WPB) applied to wood-based sheathing with the expanded polystyrene foam (EPS) attached to the wall with trowel-applied adhesive ribbons. Experience has shown that the use of LA-WPB coatings and adhesive ribbon attachment offers one approach to provide EIFS systems that can be both drainable and durable in the long term.

INTRODUCTION

It is now well accepted that rainscreen design for the outer wall elements leads to more durable construction. Proper drainage of water that intrudes behind the cladding is the key to satisfactory performance. While there is some debate as to what constitutes an adequate drainage space, the materials used to define that space can not be ignored for their impact on retention of moisture. The retention of water by those materials, once wetted, affects the local (within-cavity) microclimate for some time after wetting has been experienced.

External insulated finish systems (EIFS) adhered to backup walls provide a nominal two to three millimeter gap for drainage between the expanded polystyrene (EPS) and the wall. Of interest to both the Canadian Construction Materials Centre (CCMC) and the EIFS industry was to determine the moisture retention capacity of different materials used to define those drainage spaces. The design of the test program was intended to provide information on how these materials and the way that they are assembled in EIFS walls handle water that intrudes into the drainage space. The specific class of EIFS studied here use liquid-applied water resistive barriers (LA-WRB) on wood-based framing systems.

TEST PROGRAM

Six manufacturers participated in this test program. The main questions that were addressed include:

- How much water can be retained by different surfaces in the drainage cavity, including the LA-WRB coatings and the adhesive residue left on the back of the EPS panels in the process of trowelling the adhesive ribbons in place?
- How much water can be retained by the adhesive ribbons used to attach the EPS foam to the wall?
- How much water can be retained in joints in the EPS insulation and common WRB materials?
- How much water can be retained in starter tracks (if any are provided)?
- What are the drying characteristics of the different EIFS systems for each of the above retentions?

The test program is summarized in TABLE 1.

<table>
<thead>
<tr>
<th>TEST CASE</th>
<th>TEST WALL DESCRIPTION</th>
<th>TEST DESIGNATION</th>
<th>NUMBER OF TESTS</th>
<th>DURATION OF TEST (HOURS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drainage on LA-WRB surface</td>
<td>1-1</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Adhesive Residue on EPS (thin)</td>
<td>2-1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Adhesive Residue on EPS (thick)</td>
<td>2-2</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Full Wall – no starter track</td>
<td>3-1</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Test 3-1 repeated with EPS removed</td>
<td>3-1a</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Full Wall – no starter track/panel</td>
<td>3-2</td>
<td>7</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>Full Wall with starter track/panel</td>
<td>3-3</td>
<td>7</td>
<td>48</td>
</tr>
<tr>
<td>8</td>
<td>Full Wall – no starter track or base coat – tight joints</td>
<td>7-1</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Full Wall – no starter track or basecoat – 6 mm taped joints</td>
<td>7-2</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Starter Tracks, lower 150 mm of test walls</td>
<td>9-1</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>WRB materials (EPS, SBPO, BP lapped, BP taped)</td>
<td>-</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
One test wall or test surface was constructed for each manufacturer for each case. Surface drainage of specific materials and cavity drainage tests of completed EIFS walls provided the information needed.

**DRAINAGE TEST METHODOLOGIES**

The intent of drainage testing is to introduce water into the space between the cladding and the rest of a wall assembly in a controlled way over a specific time period and to monitor the amount of water retained. To this end, the ASTM E2273-03 test method provided the starting point. In development work for the CCMC Technical Guide, many of the detailed methods described in the ASTM standard were changed and improved upon. The main changes involved continuous weighing of the test wall to obtain an accurate wetting and drying history of a wetting event, and the use of a trickle wand instead of spray nozzles to create that event.

**Weighing walls during drainage testing**

There are several ways to weigh wall assemblies with high accuracy. All make use of weight counterbalancing to reduce the weight actually needed to be measured, allowing more accurate load cells to be employed to get the desired resolution. The weight balancing system used at the CAN-BEST laboratory is shown in **FIGURE 1**.

Two such set-ups were located beside each other allowing two test walls to be tested at a time. No special flashing details or collection gutter were used. Starter tracks were installed in some walls. Each hanging wall was stabilized against swaying by positioning adjustable tensioned rope slings at the bottom of each wall.

The drained water pooled in a collection tray that was common to both test walls. The set-up for two test walls was sheltered by a shallow chamber (~2 m/6.5 ft) that was open to the front. Relative humidity and temperature sensors were located in several places to monitor conditions.

Load cell calibration was required for each test set-up because of changes in the positioning of the counterbalancing forces from one test to another. Nominal calibration was accomplished by adding a 10 g or 20 g calibrated weight to the wall to monitor the measured change in weight.

**Introduction of water to a test surface or the drainage cavity**

Prior drainage testing had employed a trickle trough that relied on gravity flow to drip water droplets into the drainage space. CAN-BEST devised an improvement to avoid uncertainties related to lack of plumbness of the wall throughout the test. Off-the-shelf rotating fluid metering pumps having a capacity of 8000 g/hr were obtained for the test program. A photo of one of the trickle wands used is shown in **FIGURE 2**.

The trickle wand was supported independently from the test wall and was supplied with a pulsed flow by the metering pump. A uniform and repeatable trickle was formed using the low internal water pressure generated by the metering pump. The formation of drops was uniform from all holes. Flow was calibrated to be near the delivery rate required. The total quantity delivered by the pumps in one hour was adjusted and was found to be between 8040 and 8100 g. For weight measuring test protocols, the wetting time was far more critical to absorption than the exact weight of water delivered to the wall.

The trickle wand was outfitted with a serrated fiberglass mesh fabric. Only the tips of the flexible serrated delivery skirt make contact with the wall. Silicone spray was used on that skirt to make the surface more hydrophobic, and to further facilitate and direct the flow of water down to the tips. Each wand had 16 holes spaced 38 mm (1.49 inches) apart. At a pump pulse frequency of 150 per minute, and at a target pumping rate of 8000 g/hr, the mass of each squirt from each hole was 0.0556 g which represents a spherical droplet size of 2.37 mm (0.093 inches). Droplets of that size were not formed but that was the quantity of water delivered in each gush from each hole. Once power to a pump was turned off, flow stopped instantly. Water for testing was stored in a domestic heating water tank heated to 25°C (77°F) to ensure all tests had the same water temperature.
TEST PROTOCOLS

Water was supplied to the drainage cavity of a wall or to a specific surface for a one hour period followed by drainage and drying for a further hour to the two hour reference point. Drying for some walls was monitored for an additional 48 hours at nominal isothermal conditions, specified as 50 percent ± 10 percent relative humidity (RH) and 23°C ± 5°C (73°F ± 41°F) temperature (T).

The ASTM E 2237-03 test requirement for water spray is 106 g/min for 75 minutes (6.36 kg/h) for a total target mass of 7.950 kg. Based on some unpublished work involving inflow rates of 1 L/hr and 10 L/hr, similar retention of water was attained for small EIFS walls at both rates of wetting which suggested that retention was not very sensitive to the exact flow rate. On the basis of some preliminary testing it was concluded that 8 L/h (133.33 g/min) represented an arbitrary yet defensible level of water entry for examining relative performance of test walls.

Drainage and retention criteria

The CCMC water retention test criteria for EIFS walls adhesively attached to LA-WRB coated wood-based sheathing was 30 g/m² at the end of the one-hour drainage period, and 15 g/m² at the end of the 48-hour drying period. These normalized water retention weights are based on water retention on a wetted area defined as the product of the width of water entry and the height of the EIFS wall tested. The projected area was 1.3 m² (2 ft by 7 ft). The choice of 30 g/m² was originally chosen assuming it was typical for that type of system based on some commercial testing to the ASTM test standard. Based on more recent commercial testing to the CCMC Technical Guide and the CMHC cladding drainage project, accurate evaluation of water retained has confirmed that a moderately higher level should have been specified for typical EIFS constructions. That research also showed that test walls for other cladding, vinyl and wood-based siding systems that have a proven track record of performance in the field.

CONSTRUCTION OF TEST ASSEMBLIES

The fabrication of all EIFS walls materials was performed by a single tradesman having the required experience. Construction of the base walls and supporting frames was done by CAN-BEST personnel.

The essential details describing the test wall construction follow. The 1.22 by 2.44 m (4 ft by 8 ft) wood frames consisted of 38 x 89 mm (2 x 4) studs at about 400 mm (16 inches) spacing. The sheathing consisted of 11.1 mm (7/16 inch) OSB. Two 1.22 by 1.22 m OSB sheathing panels were installed with a 3.2 mm horizontal gap between them. The OSB faces bearing the grade stamps were turned to the inside of the wall, i.e., with the textured or skip sanded surfaces facing out. The 50 mm thick EPS Foam Insulation was 16 kg/m³ (1 lb/ft³) nominal density from one source.

Liquid Applied Water Resistant Barrier (LA-WRB) consisted of various polymer-based formulations unique to each manufacturer that were applied by rollers or trowels. Two coats were applied to OSB sheathing. Prior to application, nail heads and imperfections were spotted with the coating or with a compatible filler material. Adhesive ribbons were applied to the EPS foam boards with notched trowels prior to placing them against the wall and flattening the beads so formed. The nominal spacing of adhesive ribbons was 2.5 inches on centers, except for one system that used a wider spacing. Drainage tests on simple prepared surfaces were done without wood framing backup.

A base coat and fiberglass mesh were applied to the front and sides of the EPS foam after the adhesive had cured. Mesh was applied to the edges of the walls prior to application of the EPS panels which was then wrapped to lap the mesh applied on the face of the insulation. For the test set involving starter tracks, the bottom edge treatment with mesh and coatings depended on the type of starter track or panel used. Some were completely pre-wrapped and coated, while others were back-wrapped while being incorporated with the starter tracks. No final finish coats were applied to the EIFS as these were not involved in retention of water inside the drainage plane. Results for starter tracks will not be reported in this paper.

The total height of EIFS cladding on full test walls was 2.134 m (7 ft). This dimension was based on the ASTM E 2273-03 test protocol. The top of the cladding was straight and not blocked off so that the boundary conditions for air flow in at the base and the top were the same.

The 50 mm EPS panels were adhesively applied to the wall with the joint pattern shown in Figure 3. This ensured that both vertical and horizontal joints were represented in the drainage pathway from the trickle wand. The location of the trickle wand is shown diagrammatically at the top of the EPS insulation in this figure.

Figure 2. A trickle wand with a serrated fabric drip edge.

Figure 3.
RESULTS
Characterization of drainage test results
The wetting, drainage and drying behavior of a completed wall depends on the ability of wetted materials to absorb water that comes in contact with them and the ability of the assembly to dissipate this water back to the environment. There is a similarity in the load/time weight change signature from one test to another. To facilitate the comparative analysis, key positions and rates on the signature were evaluated. These key elements are shown in Figure 4 and were used to interpret the moisture management within drainage spaces. One characteristic also included in the analysis (not shown in Figure 4) was the drying rate for the period between 2 hours and 48 hours (for some test sets).

The drying rates were critically dependent on the environmental conditions in the test facility. Drying was also dependent on how the water is stored within the assembly. Water absorbed by materials tended to dry at a uniform rate. However, water that collected in EPS joints, or in pockets formed by intersecting ribbons, dried slowly because of the concentration and reduced exposure to environmental drying forces.

Drainage on LA-WRB surfaces
The plots of weight change for all drainage tests on LA-WRB coatings are shown in Figure 5. There are some differences between them and are best described by obtaining the wetting rate in the last half hour of wetting, and the drying rate after all free water had drained. The rate of absorption appeared to level off in the last 30 minutes of wetting. From a drainage point of view, free water appeared to have completely drained within 10 to 15 minutes after the supply of water to the trickle wand ceased—leaving 45 minutes for drying to the 2-hour point in the test.

The key points on each signature plot were obtained to assess which were most relevant to the end point retentions at 2 hours. Multiple regression on retention at 2 hours revealed that most of the correlation was with the load after drainage of free water had finished. The strength of association between the wetting load at 1.25 hours with that at 2 hours was p<0.001. The mean environmental conditions during the tests were sufficiently similar that drying rates after 1.25 hours into the test were not a factor in describing the variation in retention at the end of the 2 hour test. That does not mean that the conditions along the face of the wetted surfaces do not have an influence on drying rates. The differences noted were similar enough that almost all dried at a similar rate.

All of the LA-WRB were relatively hydrophobic materials, shed water well and retained little water. At the conclusion of the 2 hour test, the total amount of water retained ranged from 1.1 to 6.9 g. The water trickles released from 16 individual spaced delivery points were sensitive to surface irregularities and the plumbness of the test surface. The actual wetted area varied because some trickles merged during the test, something less likely to occur in the drainage cavities of EIFS walls because the adhesive ribbons would keep trickles apart.

Drainage on EPS surfaces coated with thin and thick adhesive residues
The second main material to come into contact with water flowing within drainage cavities is that used for adhesive ribbons. Adhesive residues are deposited on the back of EPS panels in the process of forming adhesive ribbons using notched trowels. Water trickling down narrow drainage spaces is bound to wet some of those residue surfaces. Two wall-sized EPS sheets were coated with a thin and a thick residue layer for each manufacturer to assess the relative sensitivity of these proprietary materials to retain water when tested in the same way at the LA-WRB materials.

The 2 hour drainage tests were done in parallel for each type of adhesive residue used. The application of residue was not strictly controlled except to instruct the applicator that thin and thick coats of residue be trowelled on...
the 75 mm (3 inch) EPS panels provided for these tests. Panels with residues identified as C and G were identical and were from the same manufacturer.

Comparing Figure 6 and Figure 7, there is a noticeable difference between the retention by some coatings, with the thickness class. The rank order of retention within the group was largely maintained for most materials. Retention by two coatings (B and F) was largely unaffected by their thickness.

These drainage tests showed that large quantities of water can be held by adhesive residues. Retention at the end point of the 2 hour drainage test ranged from 1.3 to 28.4 g for the light coating, and essentially zero to 221 g for the heavy coating. The implication is that workmanship will heavily affect water retention if the adhesive used is relatively absorbent. The corollary is that retention by at least two of the adhesives reported on here would be relatively insensitive to workmanship with respect to the quantity of adhesive residue deposited.

**Drainage on various materials used for outer wall construction**

For the purpose of comparison and maintaining a sense of perspective, surface drainage tests were also performed on a number of other materials, largely conventional WRB membranes. The number of tests was limited to one test per material or case. The materials chosen included an EPS sheet without joints, building paper with laps, spun bonded polyolefin (SBPO) full height house wrap (without joints), and building paper positioned horizontally with laps taped. These drainage tests are shown plotted in Figure 8.

The EPS and SBPO were hydrophobic and essentially, once wetted by water trickles, did not adsorb any further moisture droplets or water films. The relatively constant weight throughout the wetting cycle was testament to that. However the SBPO appeared to retain more water on its surface once drainage stopped. The building paper, with and without joints taped, was less hydrophobic and held more water during initial wetting, and exhibited a weight gain throughout the one hour wetting phase.
The test on building paper with joints taped experienced a temporary spike in weight. This occurred because of the way that the tape was applied. A “fish mouth” in the tape allowed water to initially accumulate in the crease before it broke its way through and drained to essentially the same order of magnitude as the non-taped building paper.

In the case of EPS, very little water was held shortly after water delivery was halted, and the majority of that water evaporated quickly at about the same rate as from the other materials. The EPS sheet and LA-WRB coatings (Figure 5) retained less than half of the moisture retained by these conventional WRB membranes when tested in an identical way.

**Drainage tests of full EIFS wall assemblies: no starter tracks**

Most of the drainage tests in this test program were done on fully representative EIFS walls. Wall set 3-1 was built and tested for the 2 hour drainage test to be followed by removal of the EPS and retesting with the adhesive ribbons exposed. Wall set 3-2 was built to experience the full 48 hour drainage/drying test and for direct comparison with set 3-1. A similar paired set of 14 walls (7-1 and 7-2) were also tested to examine the potential retention of water in gapped horizontal joints.

These tests were found to mimic the retentions found in the tests of the 3-1 and 3-2 wall sets and the results are shown in Figure 9. Although not presented here, the results for wall sets 7-1 and 7-2 contributed to the findings which are reported in this paper.

Viewing the results for both sets of walls in Figure 9, for all manufacturers, provides some idea of the differences that might be found between only two replications. These plots also illustrate the complexity of interpreting actual wetting and retention of water within some EIFS assemblies.

The main purpose of these two sets of tests was to compare supposedly identical EIFS walls without the potential restriction of starter tracks. Out of the 14 walls monitored for 2 hours, only one pair stood out as having one wall retaining distinctly higher quantities of water relative to the other. This was characterized by a higher initial wetting that persisted throughout the test. This wall (C), and others in test set 3-1, were subsequently stripped of its EIFS and retested. It was found that some of the water trickled in to closely placed ribbons that merged at butt joints in the EPS foam boards. These ribbons formed pockets that allowed more water to be collected, with some being drained into the joint itself. Excluding this pair, the difference in retention at 2 hours for the remaining 6 pairs ranged from 1.6 to 9.9 g with a mean difference of 3.7 g, while the total retention at 2 hours ranged from a maximum of 91.4 g to a minimum of 7.5 g. The rank order largely reflected tests on retention by adhesive mixtures. Given the small quantities of water retained it would not be unusual to see differences ranging from 5 to 10 g at that point in a drainage test of matching EIFS walls.

Accounting for the additional test sets 7-1 and 7-2, which provided additional legitimate replications not experiencing storage of water in joints, a standard deviation in retention of 7 g could be expected for any one manufacturer, with a range of up to 10 to 15 g.

The implications of these drainage tests on full EIFS walls done in the manner described are that both workmanship and the materials used affect the amount of water that is retained in drainage spaces. The variation experienced, in comparison with the CCMC permissible limit mentioned earlier, suggests that this be accounted when the requirements are revised. These tests also reflect the important contribution to retention made by the adhesive formulation used for wall assemblies.

**SUMMARY OF ADDITIONAL FINDINGS**

Additional tests were conducted as part of the overall test program and could not be fully reported here. These include:

- Drainage retests of walls stripped of their EIFS, leaving only the adhesive ribbons intact (7 tests);
- Drainage tests of walls built to assess potential collection of water in spaced and tight EPS joints (14 walls); and
- Drainage tests of walls with starter details (tracks or panels), and tests of those abbreviated details (14 tests).

Some drainage tests of walls exhibited uncharacteristically greater...
collection of water (storage). Two cases out of 14 were attributed to trickles that meandered into pockets created by adhesive ribbons that were too close to each other, either as a result of poor workmanship, or by having ribbons too close to the edges of EPS panels at butt joints. This was confirmed by examining the ribbon structure in these walls when the foam panels were removed.

Potential storage of water in EPS joints was investigated by building 14 wall panels, 7 with normal placement of EPS panels, and 7 with intentional 6 mm gaps between all EPS panels in the wall. Despite provision of these large gaps, only one of those walls allowed significant collection of water. The wetting/drying signature readily revealed storage of this type. No walls with normal placement of EPS panels experienced apparent collection of water in joints.

Drainage tests on walls with starter tracks/panels did not consistently retain more water than matching walls without such details. This was because of the inherent variability between pairs of test walls that were presumed to have identical composition. The bottom 300 mm of walls in this test series were subsequently cut off for further drainage testing of only the bottom 150 mm of the EIFS wall. These tests showed that starter tracks tended to retain more water than starter panels but the type of detailing used specific to each manufacturer affected the amounts retained. It was concluded that water retained in those details would not cause harm to the backup wall and, hence, a retention criterion for starter tracks may not be needed.

Finally, recommendations were made to modify the normalized retention criterion for the CCMC drainage test to 40 g/m² from 30 g/m² at the 2 hour point in the drainage test. This is assumed to apply to a nominal drainage path of 1.3 m² (608 mm x 2133 mm) (23.9 inches x 83.9 inches) and for walls tested using a trickle wand, as described in this paper. This is to account for expected variation and test measurement uncertainty without essentially changing the implied performance, and especially when compared to the higher relative retentions found for other common cladding systems tested in a similar way.

CONCLUSIONS
The drainage test simulations conducted in this study are constructs for water penetration that may occur in the field. As such, while the findings only provide relative performance of systems, they have assisted in identifying key factors that will influence performance in the field. Of course, the real proof of performance lies in the large installed area of EIFS walls already constructed in the manner represented in this study that are believed to be trouble free.

By planning and sharing the results of this test program on their proprietary materials, the EIFS industry has provided CCMC, and by implication, the design profession, with the underlying basis for judging the potential relative quality of the majority of EIFS on the market. It also provides guidance for other current and future manufacturers of EIFS that were not represented in this consortium.

D.M. Onysko is a Principal at DMO Associates. John Edgar is Technical Manager- Building Science for Sto Corp and is Chairman of the EIFS Consortium that supported this work. Elie Alkhoury is the founder of CAN-BEST Building Sciences Corporation. Fadi Nabhan, is with the Canadian Construction Materials Centre, National Research Council Canada.

The authors wish to acknowledge the contribution made by the Consortium in agreeing to put all the data on the table. All representatives of the Consortium provided useful discussion on all issues in the development of the research program undertaken.

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Adhered Veneers and Inward Vapor Drives: Significance, Problems and Solutions

By Dr. John Straube, P.Eng., Chris Schumacher, Jonathan Smegal and Marcus Jablonka

ADHERED VENEERS, IN which masonry units are directly attached to a substrate via mortar and ties without a drainage or ventilation gap, have become a very popular finish in residential and light commercial construction. Typical applications apply thin masonry units over a bed of lath-reinforced mortar over a drainage plane (often a single layer of building paper, felt, or house wrap).

When used over wood- or steel-framed walls, numerous reports of moisture problems and failures have been reported (Rymell 2007). The lack of a well-defined drainage space, and warm-weather inward vapor drives have been implicated as the reasons for these moisture problems.

Drainage can easily be provided by installing a second layer of building paper, particularly if one layer is a creped house wrap, and ensuring that flashing and weep holes are included. However, controlling inward vapor drives is more problematic, as building papers and house wraps are highly vapor permeable, and both the mortar and the masonry unit can store a significant amount of rain water via capillary absorption. During sunny weather following rain, water vapor stored in the masonry can be driven into the sheathing and into the stud bay, resulting in wood decay and condensation on air-conditioned interior surfaces. Air-conditioned buildings with low-permeance vapor retarders (such as polyethylene, vinyl wall paper and aluminum foil) exacerbate this problem.

One proposed solution to avoiding the risk of these problems is the use of a vapor-impermeable air gap membrane behind the adhered veneer. A rigid plastic membrane will control inward vapor drives, but will not allow water vapor in the stud space or framing to dry to the exterior. Previous research suggests that a ventilated air space may allow the required drying (Karagiozis et al 2005, Straube et al 2004), but this has not been demonstrated in the field for an impermeable air gap membrane.

EXPERIMENTAL PROGRAM

An experimental program was developed to measure and compare the performance of adhered veneer cladding side-by-side with an alternative method that uses a vapor-impermeable, rigid, polymer-based air-gap membrane. The objective of the study was to compare adhered veneer walls using a rigid plastic dimple sheet in place of asphalt impregnated paper as the sheathing membrane. These walls were installed in a natural exposure field testing facility in Waterloo, Ontario, Canada.

We collected field measurements for over a year, monitoring two types of wood-framed walls; one with an air gap membrane and another installed following standard practice. No penetrations through the test assembly were installed to eliminate the potential of bulk rain penetration problems. Each type of wall was faced either north or south in a test hut located in Waterloo. Waterloo has an average of approximately 4300°C (7772°F) heating degree days (7800 HDD F). The hut is in an exposed location, free from obstruction by other buildings.

All of the test panels were 8 ft (2.4 m) in height, and 4 ft (1.2 m) in width and shared construction of 2x6 wood framing on approximately 16 inch (0.4 m) centers with OSB sheathing, a poly interior vapor barrier, drywall finish and air barrier, and R19 (RSI3.5) fiberglass batt insulation.

Instrumentation included a temperature and relative humidity sensor in the drain space, as well as the stud space, moisture content sensors in the sheathing and framing, and temperature sensors on the cladding and drywall. All of the monitored framing is clear eastern white pine (EWP), and the remaining framing is generic SPF framing. Details of the instrumentation, data conversion and other details can be found in Straube et al (2002). The data was measured at 5 minute intervals and the average recorded on an hourly basis. The sensor layout is shown in Figure 1.

The opening in the test facility was lined with a wood frame wrapped in a self-adhered flashing to help isolate the test panel from any other moisture sources. All of the instrumentation is located in the center third of the wall over the entire height. This helps minimize edge effects and simulates accurate field performance of the enclosure system.

Feature

Figure 1. Typical wall construction and sensor layout for full scale wall testing.
Moisture content behind the cladding was measured using a moisture content wafer. These sensors consist of a small piece of wood, of a known species, with moisture content pins installed into it (Ueno et al, 2008). The sensor equilibrates with the liquid or vapor around it, but because of its hygric mass, it does not react quickly. This sensor is generally used in locations where the moisture content is required, and the moisture content does not change quickly, such as masonry work.

Monitoring began on July 16, 2007 and is on-going.

**BOUNDARY CONDITIONS**

The exterior and interior conditions were both recorded during testing. The exterior temperatures and relative humidity are shown in **FIGURE 2**. The thirty-year average for monthly average temperatures in the Waterloo region are indicated by the black lines.

The interior temperature and relative humidity were controlled for most of the testing period, with relative humidity being kept between 40 percent and 50. As the test walls have sealed drywall air barriers and continuous polyethylene vapor barriers, interior moisture loads do not affect the test wall hygrothermal conditions.

One of the performance criteria for analysis and comparison of the two different wall design approaches is the drying potential, which was evaluated using a wetting apparatus to inject a specified volume of water into a known location in the test wall. The wetting apparatus is shown in **FIGURE 4**.

The wetting apparatus consists of a water storage and redistribution media (blue material), and an injection tube to inject water without opening the wall, and thereby disturbing the stud space conditions. This paper includes only the first intentional wetting event. The wetting event began on the morning of September 16. Each morning and evening 42.5 grams (1.5 ounces) of water was injected for 4 days for a total of 340 grams (12 ounces). This was intended to simulate a small but steady leak into the enclosure from, for example, a small leaky window, or a failed flashing, during a particularly severe storm.

The intentional wetting event is shown on some of the analysis graphs as a dashed red vertical line at the time of the first water injection. Following the analysis of performance under normal conditions, the intentional wetting event is analyzed in detail using the moisture content sensor located in the sheathing at the water storage media location (as can be seen in **FIGURE 4**).

### ANALYSIS RESULTS

To compare the performance of engineered stone veneer with and without an air gap membrane, the moisture content of the sheathing, moisture content of the framing and the relative humidity of the stud space were analyzed.

The first comparison, shown in **FIGURE 5**, are the sheathing moisture contents of the north orientation of both test walls. There are three moisture content measurement locations in the sheathing on each wall: 16 inches from the bottom, mid height, and 16 inches from the top. The data shows that the sheathing moisture content was higher in all three locations in the standard wall than in the wall with the air gap membrane. Generally, a moisture content of 16 to 20 percent correlates to a surrounding relative humidity of 80 to 90 percent (FPL 1999) and is considered the highest moisture content with no risk for moisture-related problems (Morris 1998). Relative humidities well above 80 percent, and wood moisture contents above 20 percent, may cause moisture-related problems, especially if sustained for long periods of time without drying. Wood rot and decay does not commence until at least 28 percent moisture content.

The sheathing moisture content at all three locations in the standard wall was greater than 16 percent, and approached 20 percent, from approximately October 2007 to May 2008. On the south orientation, the air gap test wall exhibited lower sheathing moisture contents than the standard construction wall (**FIGURE 6**). The performance difference is not as great as...
the north orientation, but there is still evidence of improved performance due to the air gap.

**FIGURE 7** shows a detailed analysis of the intentional wetting event that started on September 16, 2008. The only sensors included in this analysis are the moisture content sensors located in the lower sheathing, in the middle of the water storage media. The pins are electrically insulated along the shaft so that any moisture in the sheathing will affect the moisture content readings. The vertical scale in **FIGURE 7** has been changed from the other moisture content analysis to more clearly show the drying rates.

All of the sensors show a response to the increased moisture content within 24 hours of the first water injection. On the north orientation both of the test walls reach a maximum of 33 percent moisture content approximately one week following the first injection. On the south orientation both of the walls reach 25 percent moisture content approximately 3 days following the first injection.

The drying performance differences are evident from this analysis. On the north orientation the standard construction wall was still above 26 percent moisture content four weeks following the initial wetting. The air gap wall on the north orientation quickly dried down to 22 percent moisture content in approximately two weeks following the intentional wetting event, but the drying rate then changes and it dries more slowly.

On the south orientation the results are similar. The standard construction wall on the south orientation dries from 25 percent to 20 percent moisture content in one and a half weeks, but then fluctuates around 20 percent for approximately three weeks, until the end of the data collection. The air gap membrane wall on the south orientation dries to approximately 13 percent moisture content in the first week and a half very quickly. Similarly to the north orientation, the drying rate changes following the initial drying phase to a slower drying rate and reaches 9 percent four weeks following initial wetting.

The forgoing analysis convincingly demonstrates that the small gap produced by the air gap membrane provides sufficient ventilation to allow outward drying at a faster rate than traditional adhered veneers. Adhered veneers appear to have relatively little outward drying potential, and rain leaks or condensation within the stud-bay will dry at a slower rate than other types of walls previously measured (e.g., Straube et al 2004).

The moisture content of the framing lumber was measured at approximately 3/8” from the inside surface of the framing at mid-height. This testing location was specifically included to capture inward vapor-driven condensation on a vapor barrier. Vapor pressure is proportional (in a non-linear manner) to the temperature and moisture load. Generally, the south orientation has the greatest solar exposure and the highest cladding temperatures, which often result in the highest inward vapor drives in the summer months. Ventilation and vapor impermeable materials are both strategies to limit inward vapor drives.

**FIGURE 8** shows the framing moisture content for all four test walls. During the summer months of both 2007 and 2008, the standard wall on the south orientation had elevated
moisture content levels. The moisture content exceeded 16 percent on the south standard wall in the first week of June, and had not returned to 16 percent as of mid October. In 2007, the south standard wall did not return to 16 percent until the end of October. The moisture content of the standard wall on the north orientation is also elevated, but does not exceed 16 percent moisture content. The moisture content in the framing of the north standard construction wall is approximately 15 percent moisture content for the entire summer. These elevated moisture content levels indicate that the relative humidity is also likely elevated inside the test wall.

The air gap membrane walls on the north and south orientation show no significant increase in moisture content in the summer months caused by inward vapor drives.

In the winter months, no readings are plotted because the framing is too dry for the equipment to accurately measure (i.e., the moisture content is below 7 to 8 percent).

The relative humidities of the stud spaces are compared in Figure 9 for all four test walls. The south-facing standard wall has the highest relative humidity of all four walls, greater than 90 percent, which is expected, given the framing moisture content readings in Figure 8. The relative humidity in the south-facing standard wall began to exceed the other test walls as early as March and was still elevated in mid-October at the end of the testing period.

The recorded hourly temperatures of the stud space was measured in the order of 15 to over 30°C (59 to over 86°F) during warm and especially sunny weather. Given the daily average center-of-batt RH of 90 percent in the south standard wall and the 21 to 25°C (69 to 77°F) temperature of the polyethylene vapor barrier, condensation is predicted to occur on the polyethylene vapor barrier for hundreds, perhaps as much as a thousand hours, during the summer. The only source of the water vapor for this condensation is the exterior masonry, as the vapor impermeable and airtight interior polyethylene-drywall layer eliminates the interior as a source.

The standard wall on the north orientation also experiences elevated relative humidities in the summer month, but generally stays at approximately 80 percent. This corresponds to the previously analyzed 15 percent moisture content in the sheathing.

Both of the air gap membrane walls are generally between 60 percent and 70 percent relative humidity for the entire summer.

CONCLUSIONS

After monitoring the test walls for approximately one year, the following conclusions can be drawn:

- The air gap membrane walls experienced lower sheathing moisture...
content on both orientations at all times than the comparison standard construction walls.

- During normal operation (i.e., not during the intentional wetting event), the standard construction-practice walls on both the south and north orientation did cross the generally accepted moisture content threshold where moisture-related problems may occur, but the sheathing of the air gap membrane walls was significantly drier (below 12 percent) at all times under normal operating conditions.

- The air gap membrane walls exhibited faster outward drying following the intentional wetting of the OSB than the standard wall. The air gap, albeit small, allowed significant drying to occur.

- Warm weather inward vapor drives caused elevated moisture content levels in the framing of the standard construction walls. Summer condensation on the vapor barrier likely occurred. The vapor impermeable membrane appeared to decouple the wood framing and sheathing from the moisture in the masonry and transported by inward vapor drives.

- The relative humidities were elevated in both the standard construction walls in the summer months due to inward vapor drives. The elevated humidity levels were high enough (>80 percent) to cause some moisture-related durability problems over time. The air gap membrane walls did not experience relative humidities that would cause moisture-related durability problems.

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EDITOR’S NOTE: To obtain a full list of references for this article, email shannonl@matrixgroupinc.net or visit www.buildingscience.com.
BEC Corner

BOSTON
By Jonathan Baron, AIA

BEC-Boston continues to meet monthly (except for August and December) for one-and-a-half to two hours at the BSA headquarters in Boston’s Financial District. Recent presentations have included The CMA Approach for Rating Commercial Windows by James Benney and Jessica Ferris of NFRC; Field Testing of Fenestrations by Michael Velji and Edward Mannix of VP Consultants; and a Case Study of a new Residence Hall in Chicago by one of our members, Ted George of Goody Clancy. We typically have 20 to 30 attendees at our meetings, and there is always spirited discussion with the presenters.

BEC-Boston is preparing another High Performance Building award program. The call for entries will be released in November 2009, with the award to be announced in April of 2010, coinciding with the BEST 2 Conference in Portland, OR. The award will go to the building that best demonstrates innovation in design through the craft, science and engineering of high performance building enclosures in New England. The award will be open to completed projects in Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island and Vermont.

We are beginning a study of the impact of Massachusetts’ Energy Code on the energy efficiency of buildings. We hope to look at energy consumption within a group of sample buildings and to conduct airtightness testing.

Upcoming meetings will focus on spray polyurethane insulation, the results of DOE grant testing, daylighting research being performed at MIT, and a case study of a high performance residence. More information about our current initiatives as well as future and past meetings can be found at our website, www.bec-boston.org.

CHARLSTON
By Charles S. Muldrow, AIA, LEED AP

BEC-Charleston began the year on January 22nd with John Edgar of the STO Corp., who gave a presentation on new synthetic stucco systems and findings from the NET Facility, located in Hollywood, SC. This was followed by an excellent presentation on March 26th, from Theresa Westen of DuPont, on Air, Liquid & Vapor Permeability of Weather Resistant Barriers.

BEC-Charleston has forged an alliance with the East Cooper Breakfast Rotary Club and the East Cooper Habitat for Humanity to explore the possibility of building a Net Zero Energy House. To kick-start this, we hosted Jeff Christian from the Oak Ridge National Laboratory to speak on June 15th. The attendance was phenomenal and the energy to pull this off seems to be there.

On July 9th, we hosted William Rose, of the Building Research Council, to present Everything You Need to Know About Building Envelopes. On September 24th, our focus will be on windows, with a presentation by Christopher Mathis of MC Squared. We will complete our program year on October 23rd, with John Straube, PhD, of the Building Science Corporation, coming in for a full day seminar on Physics of Successful Green Design.

For information, contact Bryan Bolin at bryan@thomasanddenzinger.com.

MIAMI
By Karol Kazmierczak, AIA, ASHRAE, CDT, CSI, LEED-AP NCARB, BEC Miami Chairman

BEC-Miami entered into its third year with a stable formula: meetings are held every second Tuesday, location permitting, at the AIA office in Miami. Attendance is free-of-charge to everybody interested in building enclosures. Every meeting features a façade-related lecture followed by a discussion and attendants get AIA CES learning units.

Our membership consists of a mix of architects, building managers, architectural and engineering university faculty, building enclosure consultants, shell contractors, and technical salesmen, with registered architects forming the majority of attendants.

We seek sponsors among vendors and confer three levels of sponsorship in return: silver, gold and platinum.

BEC-Miami continues reaching out to the public. We try to attract an engineering staff of a local curtain wall manufacturer and architectural and engineering students from the Miami universities.

We also continue to look for knowledgeable speakers. We have asked building enclosure professionals attending curtain wall mockup testing at the Construction Research Laboratory in Miami to give us a lecture to coincide with their visits to Miami.

Recent speakers and topics have included Robert J. Connor, Esq. of Suncoast Insurance Associates, Inc. on Dynamics of Risk in the Design Industry; Jason Campbell of Carlisle SynTec Inc. on Single Ply Roofing; Mark Howell of Structural Preservation Systems on Building Envelope Technology; and Karol Kazmierczak of Morrison Hershfield Corporation on Principles of Façade Design.

Upcoming meetings will focus on mastering the basics of building enclosure physics.

We also just got our brand new website up. Check it out at www.B-E-C.info.

MINNESOTA
By Judd Peterson, Judd Allen Group

In February, we spent time exploring unplasticized PVC windows so we can speak with some authority about the types of window materials beyond aluminum and wood that clients may be asking about. Innotech Windows and Doors regional representative Henry Weins came in from Winnipeg, Canada to join local Innotech representative Paul Kellner for the presentation.

At our March meeting, Dow representative Kevin Slattery presented information on Dow’s new “Total Wall System”, where Dow undertook a testing program under NFPA 285 on a whole array of possible wall assembly combinations of insulations, membrane barriers, flashings, sheathings
and exterior claddings, including brick and stucco.

In April, we were interested in the unusual, exterior siding material that David Salmela employed in his most recent award-winning design for the Hawks Boots Manufacturing Facility. The material used on the Hawks Boots Facility is a material intended for use on exterior skateboard park surfaces and also for interior countertops, among other uses.

In May, Architectural Testing, Inc. presented a tremendous seminar at their facilities. It included renowned air barrier and energy enclosure experts Kevin Knight of ATI; Bruce Nelson of the Minnesota Department of Commerce, Office of Energy Security and key up-dater of the Minnesota State Energy Code; Scott Warner, Executive Vice President of ATI, discussing his involvement in developing the AAMA field testing methods we all rely on; and Paul Gary, an attorney that represents cases in window forensics and litigation.

In June, we reviewed masonry cleaners, sealers and coatings with Matt Henderson of ProSoCo and Kevin Gwinn of Tri-G Products. They lent their knowledge and recommendations for cleaning new construction masonry, restoration cleaning and for sealing various masonry materials from exterior environmental effects.

July’s meeting took place at the Orfield Laboratories in south Minneapolis. Steve Orfield and his world famed laboratory are located right here in the Twin Cities. He invited us to visit his lab and explained his position on performance based criteria for interior occupant-related phenomena, field testing and commissioning of buildings for these criteria, and how this relates to the building enclosure.

SEATTLE
By David K. Bates, AIA, Olympic Associates Company

After three years, I am handing over the reins as SeaBEC president to Peter Ryan of Wiss Janney Elstner Associates. As an organization we are doing well and have some great board members, but would be nowhere without the tireless efforts of our Treasurer, Roxanne Navrides of the Seattle Housing Authority.

We head into our new calendar year with a little reorganization: re-evaluating, reassigning board member responsibilities, and something very exciting—all our programs are planned out for the new year thanks to our education committee!

Our big meeting last year was a presentation by Dr. Joe Lstiburek, which we used as a successful membership drive. Our membership is diverse, but we intend on targeting contractors and architects in the future. Other meetings included discussions on BIM, building maintenance and sealant application.

SeaBEC goals for the future include an air barrier initiative with the State of Washington, helping the UW Architecture department with building science programs and closer cooperation with the local AIA chapter.

We are exploring opportunities for a one-day seminar, having a booth at the Buildx Conference and helping BEC Portland with their BEST 2 Conference. Continued on page 38
WASHINGTON

By Paul E. Totten, Simpson Gumpertz & Heger

This spring, Washington, DC-BEC reviewed the subject of energy efficiency and the building enclosure in a series of meetings coordinated and hosted by the BEC chairs. The monthly sessions were set up as round table discussions at the National Institute of Building Sciences.

The meetings covered general issues surrounding buildings and their energy use; methodologies to improve the building enclosure and energy performance; and a review and discussion of ASHRAE proposed standard 189.1P, Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings - Third Public Review (May 2009), which generated several comments. We submitted the issues discussed to ASHRAE through the public review program. In June, Michael Waite of Simpson Gumpertz & Heger New York office led a discussion on whole building energy modeling. DC-BEC adjourned for the summer months and will reconvene in September.

Continued from page 37

Buyer's Guide

Architects
The Marshall Group.............................. 18

Architectural Glass/Windows
Old Castle Glass .............................. 20, 21

Associations
Air Barrier Association of America .................. 10
The Glass Association .......................... 30

Below Grade Water and Containment Barrier
Polyguard ........................................ 4

Building Enclosure
Construction Consulting International ............. 18

Building Sciences and Restoration Consultants
Read Jones Christoffersen .......................... 37

Consulting Commissioning
Engineering Testing
Certification and Inspections Architectural Testing ........................................ OBC

Diagnostic Tools
The Energy Conservatory .......................... 19
Retrotec Energy Innovations Ltd ................. 3, 38

Engineered Curtain Wall and Window Wall
Old Castle Glass .................................. 20, 21

Entrance Systems
Spare Parts
Old Castle Glass .................................. 20, 21

JAG Architecture
Omegavue / Judd Allen Group .................. 8

Masonry
Morter Net USA Ltd ..................................... 35

Mineral Wool Insulation
Roxul Inc .................................................. 6

Rainscreen Stucco
Assembly
Stuc-O-Flex International .......................... IBC

Silicon Building Materials
Supplier
DOW Corning Inc ................................. 12

Structural Engineering Design and Consultants
WJE ....................................................... 18

Water Proofing
Sto Corp ............................................. IFC

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