DRAINAGE AND RETENTION OF WATER BY CLADDING SYSTEMS

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ABSTRACT

This laboratory study investigated the drainage, retention and isothermal drying of various wall cladding systems to determine behavioral characteristics and factors affecting their ability to dry.

The full scale laboratory wall tests included EIFS adhesively attached to the OSB sheathing with a liquid applied water penetration barrier (3 manufacturers), direct-applied vinyl siding (2 profiles), hardboard siding (2 profiles), wood siding (2 profiles), fibre cement board siding (one profile), some with and some without drainage mats (3 types) or batten strips.

Water was trickled into the space behind the cladding at a rate of 8 liters per hour for a one hour period. The weight of water added was monitored during this period and for at least 50 hours to study the drainage and drying rates under controlled laboratory conditions.

Wall cladding provided with intentional drainage cavities allowed most of the imposed water to drain quickly to the bottom of the walls where it was collected and drained. Wetting and retention of water in these cavities depended on the materials used in the construction of the wall. Drying rates were found to be dependent on the air flow characteristics of the drainage cavity and the flashing or drainage details at the bottom of the cladding.

Direct-applied cladding intercepted water from flowing down behind the siding for the full length of the wall. Water drained through joints and drainage holes near the upper portion of the wall where water was introduced. Drying rates were dependent on the vapor and air permeability of the joints in the siding (and drainage holes, in the case of vinyl).

The sooner that water entering behind cladding can escape, the better the wall manages moisture, no matter what quantity of water is imposed.

INTRODUCTION

Keeping rain out of a wall is the top priority of cladding for managing moisture intrusion and for assuring durability. Many premature building envelope failures across Canada and the United States have been directly related to inadequate provisions for controlling rain penetration. In response, some jurisdictions such as the city of Vancouver, and the Province of Nova Scotia have mandated the use of exterior claddings which incorporate “rainscreen” design principles, that is, the exterior walls contain both a first line and second line of defence. The latter constitutes a capillary break to permit drainage, and flashing to ensure that any water penetration through the cladding will be deflected to the outside and not adversely affect the remainder of the wall assembly.

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The test program described in this paper has focused on the ability of walls to manage water intrusion past the primary cladding. The question posed by this work was “how” water was managed once it got in, not “how” it got in to a wall in the first place. Since the retention of water, i.e., where it is held and how long it takes to dissipate, affects the durability of the main wall structure, these factors were the focus of this test program.

TEST PROGRAM

The selection of wall systems to test involved a series of compromises. To simplify the experimental task of maximizing the information gained, relatively non-absorbent finished cladding materials were selected. Consequently, stucco wall systems were excluded from this study. Systems were chosen that would represent some of the more common cladding systems currently used in residential construction. The ability of cladding with and without defined drainage cavities was studied. The materials and test walls fabricated for the test program are shown in Table 1.

Table 1 Matrix of Drainage Tests Planned

Cladding Type	Number of Walls	WRB	Location of Water Entry	Attachment	Number of Tests
EIFS	6	LA-WPB	F/B	Adhesive Ribbons	12
Vinyl Siding	3	2-SBPO	middle	2 direct attached	2
		1-BP	middle	1 direct attached	1
Hardboard Siding	3	3-SBPO	F/B	2 Mats	4
			middle	1 direct attached	1
Wood Siding	3	1 BP	F/B	1 Mat	2
		2 SBPO	middle	1 direct attached	1
			WRB	1 battens	1
Cement Siding	2	2 SBPO	middle	2 direct applied	2
TOTALS	**17**				**26**

F/B = walls tested twice, with water trickled down the **front** or **back** of the drainage cavity
SBPO = spun bonded polyolefin WRB
BP = building paper WRB
LA-WPB = liquid applied water penetration barrier

TEST WALL CONSTRUCTION

The basic wall specimens were all fabricated at the laboratory in Sainte-Foy (QC) by FPInnovations staff. All of the 1.22 by 2.44 m (4ft x 8ft) wood frames consisted of 38 x 89 mm (2 x 4-inch) SPF S-DRY studs at 400 mm (16-inch) spacing including a single bottom sill plate and double top plates (to facilitate handling and weighing). The structural sheathing consisted of 11.1mm (7/16-inch) OSB manufactured to the CSA O325 construction sheathing standard.

Liquid-applied water penetration barriers (LA-WPB) were used for the EIFS, while paper-based sheathing membrane (15 lbs) (WRB) and spun bonded polyolefin sheathing membrane (SBPO) were used for the other siding systems.

EIFS Wall Systems- 6 walls

A total of 10 walls were originally built by 3 members of an EIFS Consortium on drainage testing. From this group, 6 walls were selected for this study. These walls represent one class of EIFS. All EIFS walls used liquid-applied water penetration barriers (LA-WPB) applied to the wood-based sheathing. The 50 mm expanded polystyrene foam (EPS) was adhered to the cured LA-WPB with ribbons of a cement/adhesive mix formed with a notched trowel and spaced at about 64 mm (2.5 inches). When the foam was pressed against the beads of adhesive they were flattened to form ribbons about 2 to 3 mm thick. The joint pattern of the EPS foam in the central portion of the wall below the trickle trough was simulated to that which might be encountered in the field. The walls were finished with a trowelled on base coating together with glass fibre mesh reinforcement, and a final finish coat.

Two manufacturers used starter tracks for the bottom edge of the installation. They provided a starting edge for the installation and were designed to capture any water draining down the drainage plane and to redirect it. The third manufacturer used a narrow starter panel (150 mm) that relied on other flashing to direct drainage away from the wall.

Water penetrating the primary cladding may be retained on the back of the cladding in some way. This depends on the type of cladding used. In the case of EIFS walls, water may adhere to or be absorbed in the back of the EPS foam that has some residue of adhesive trowelled on it as well as the ribbons of adhesive that may or may not interfere with the flow of water. Also, bulk storage may occur in joints between the EPS panels. The starter track detail at the bottom of the wall may also be responsible for retaining some water.

EIFS walls were selected for this program on the basis of the water retentions during their initial tests. Thus, two walls were selected per manufacturer, representing the walls that retained the least and greatest amount of moisture when tested originally. The strategy was to retest these walls by directing the water for drainage to the back of the drainage cavity (against the LA-WPB) and later, after the walls dried, to the front of the drainage cavity (against the back of the EPS foam) to the extent that it was possible given the narrow space provided for drainage.

The walls for the three manufacturers were identified by letters (A, B, or C) while the numbers (1 through 6) represent the test wall number. In this report, discussion will be focussed on the Wall Number (1-3 and 4-6) and the group basis by which each wall was chosen.

Siding Systems

Two different profiles of vinyl siding were selected. Profile #1 was a double 4.5 inches horizontal siding (white colour) and Profile #2 was a double 4.5 inches dutchlap siding (brownstone colour). One wall specimen was fabricated using Profile #1 siding and two walls were built using Profile #2 siding.

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Two different hardboard siding profiles were selected. The first was a 9-inch fastening-spline system and the second was a 12-inch lap siding with an interlocking system. These siding profiles will be referred to as type H1 and H2 respectively. The profiles are shown in Figure 1.

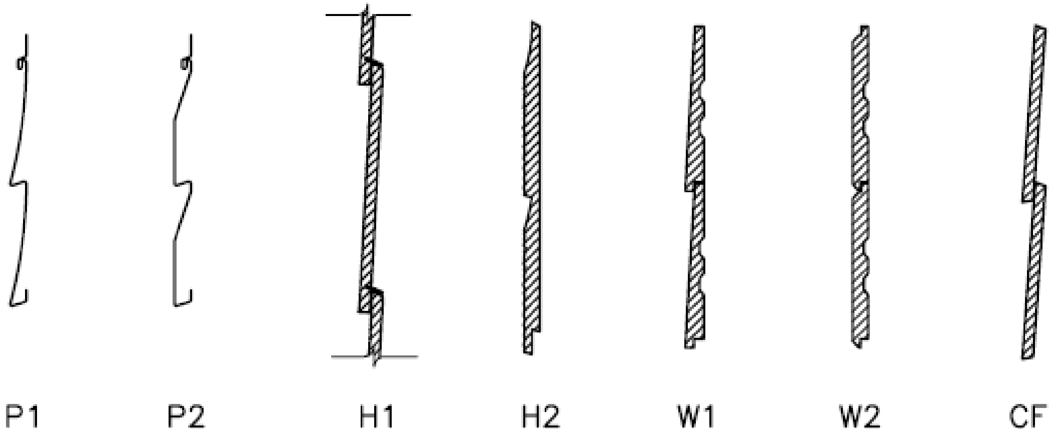

Figure 1   Cross section of Vinyl Siding Profiles, Hardboard Siding and Wood Siding

Two wood siding profiles were selected. The first was a 6-inch rabbetted bevel and the second was a 6-inch shiplap profile with "V" joint. Installation instructions recommended by the manufacturer were followed (with one exception to be described later). They are referred to as type W1 and W2. These profiles are also depicted in Figure 1.

Only one fibre cement profile was selected for this project. The profile in question was a 6¼-inch plank lap siding. This siding will be referred to as CF hereafter in this paper.

<u>Drainage Mats</u>
Three types of drainage mats were used in the fabrication of some of the wall systems. In all cases, installation instructions were provided by the manufacturers on their internet web sites. Those referred to for use as underlayment for wood shingles were also included because of their ability to act as a spacer yet allow ventilation and drainage on one side of the mat. They may also be suitable for use in exterior walls in some climates in combination with some siding materials.

The first mat (Mat 1) was a ventilating and self-draining rainscreen material intended for use in exterior walls that offers a thermal break besides moisture protection. The thickness of this mat was 6.7 mm (0.264 inches). The second mat (Mat 2) formed a three dimensional nylon matrix. It provided a mat thickness of 6.9 mm (0.27 inch). It was designed as an underlayment for wood shingles. The third "mat" (Mat 3) was formed from a solid sheet of polystyrene for its core with dimples that provide an overall spacing thickness of 6.3 mm (¼ inches).

The specific combinations of siding materials for each assembly are provided below.

<u>Hardboard Siding;</u>
Wall 1; Hardboard siding H1 direct-applied to the wall against SBPO.
Wall 2; Hardboard siding H2 applied on a drainage mat (Mat1) and SBPO.
Wall 3; Hardboard siding H2 applied on a drainage mat (Mat2) and SBPO

<u>Wood Siding;</u>
Wall 1; Wood siding W2 direct-applied on SBPO.
Wall 2; Wood siding W1 applied on a drainage mat (Mat3) and SBPO.

Wall 3; Wood siding W2 applied on wood furring strips and SBPO. The furring strips were 19 mm thick and trimmed to a width of 64 mm. The furring was attached to the wall directly opposite the stud lumber framing in the wall.

Fibre cement;
Wall 1; Fibre cement siding CF1 direct applied on SBPO
Wall 2; Fibre cement siding CF2 direct applied on WRB (building paper)

TESTING METHODS AND MEASUREMENTS

The drainage set-up was composed of three weight-balancing systems to accurately measure the weight of water added and retained in each test wall during the wetting/drying test. This allowed three 1.22 m x 2.44 m (4ft x 8ft) wall systems to be evaluated at essentially the same time.

Water was piped to each wall through a small plastic tube which drained into the trickle trough attached to the test wall at the top edge of the cladding. The water was metered using a pressure system.

The data acquisition system included sensitive load cells with Tracker Series 240 signal conditioners with 18 bit A/D to provide a high degree of resolution (0.2 g), and with RS 485 to RS 232 output to transfer the data to a notebook computer.

Figure 2 Overview of test set-up for weighing test walls during drainage/drying testing.

Water Flow Delivery

The water for drainage was piped to the trickle trough at each wall by an air pressure system. Water at room temperature was put in a glass carboy which was continuously weighed on a calibrated scale having a resolution level of 0.1g. Controlled air pressure was supplied to this container to expel water through tubing to the wall being wetted. The change in weight of the carboy was monitored every minute. In parallel to this monitoring, the flow rate was adjusted with a micro valve to ensure that a total of 8 kg of water was delivered to each wall within the 1-hour wetting period (133 g/min).

The test program required that flow be directed to either the front or back of the drainage cavity. The trickle trough allowed drops to flow down a thin serrated sheet of plastic to gather flow out of each drain hole. Tilting the trickle trough allowed the flow of droplets to be directed to specific vertical planes.

Test Protocols

The drained water was collected by a sloped galvanized gutter installed at the bottom of the wall cladding which directed it into a reservoir (bucket). For walls having direct-applied siding, with no specific provision for drainage, the water was delivered into the standardized opening width (4 mm) at the top edge of the siding. For all other tests, water was delivered to either the front or back of the drainage medium provided. When a wall was intended to be tested twice, at least 7 days of drying was allowed between tests. This was done to study if the amount of water retained was dependent on the drainage surface to which it was directed inside the cavity.

The change in weight of each wall was measured at a rate of 20 samples per second with the average stored for each second for the first two hours. For the remaining 48 hour monitoring period, 3 averages were recorded per minute.

Measurement of Environmental Conditions

The laboratory conditions were maintained at 20ºC and 50% RH on a year-round basis. Some variations in conditions occurred associated with the cycling of the air conditioning system.

The RH and temperature conditions surrounding the tested specimens were monitored constantly during testing. Four RH and temperature sensors were installed at the top part of each wall specimen to monitor the conditions of air exiting the top of the drainage cavity. These sensors were spaced uniformly (at about 300 mm) across the top of each wall. Two sensors were positioned below the trickle trough and the two others were at the same level but placed symmetrically away from both sides of the trough. All sensors were placed at about 25 to 50 mm from the top of the cladding. The aim was to compare these measurements with the ambient conditions in the lab that were also monitored in the vicinity of the test area.

Measurement of Moisture Distribution in the Drainage Cavities

It was recognized at the outset that significant moisture gradients would be found in both the siding and sheathing materials as a result of moisture retention, largely on surfaces. It was not considered prudent to rely on specific point determinations of moisture content in materials. Instead, a qualitative measurement approach was taken using a capacitance-based moisture meter.

The capacitance meter (Wagner L620) had sufficient internal data storage capacity to allow numerous readings to be taken from each wall. The measurements were made manually on the back of the OSB sheathing. A total of 90 moisture content readings were taken per wall both before and after each drainage test. The difference between the initial and final set of readings was imputed to be related to the moisture retained at that time. Contour maps were prepared to describe the inferred distribution of retained water. These maps may be examined by referring to the project reports [4, 5, and 6]

REVIEW OF TEST RESULTS

Due to the extensive detail involved in describing the behaviour of the wall cladding systems to manage water trickled behind them, each class of wall system will be summarized individually before providing an overview of the entire study.

Results for EIFS Wall Systems

Earlier drainage testing at FPInnovations found that the amount of water retained by EIFS walls was dependent on how water was delivered to the drainage cavity [ref]. Also, retention of water in joints could result in storage of significantly greater amounts of water than were held by wetted surfaces. The test protocols for the present investigation were designed to allow trickles to be delivered to specific surfaces at the point of entry into the drainage cavity. The composite drainage plots for Front and Back wetting are provided in Figures 3 and 4 for the 2-hr wetting/drainage period, and an example of combined 2-hr and 48-hr test duration is provided in Figure 5.

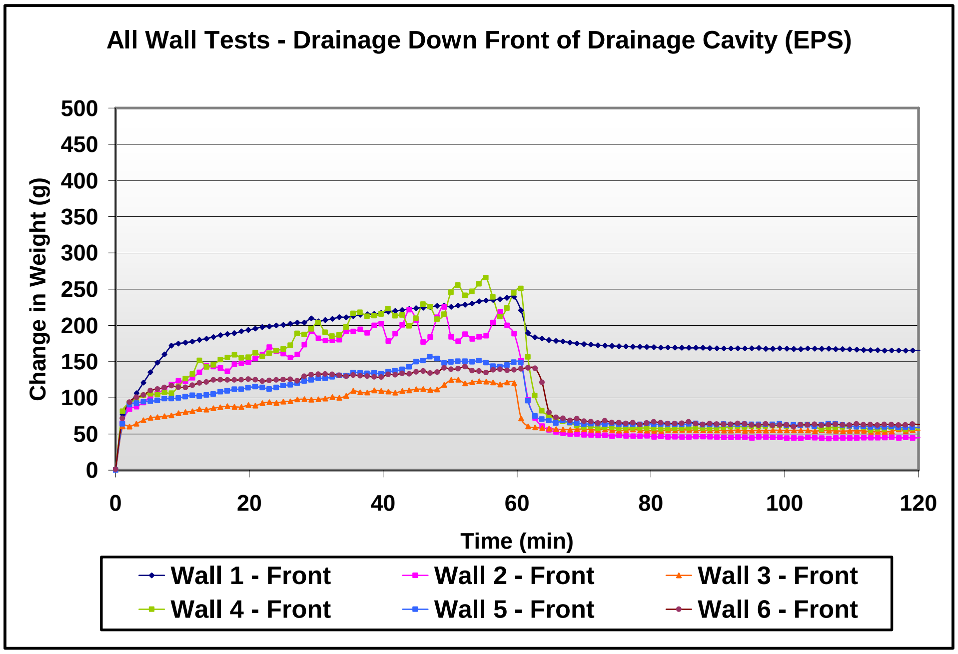

Figure 3   Composite plot of all EIFS drainage tests where water was trickled down the FRONT of the drainage cavity (down the back of the EPS).

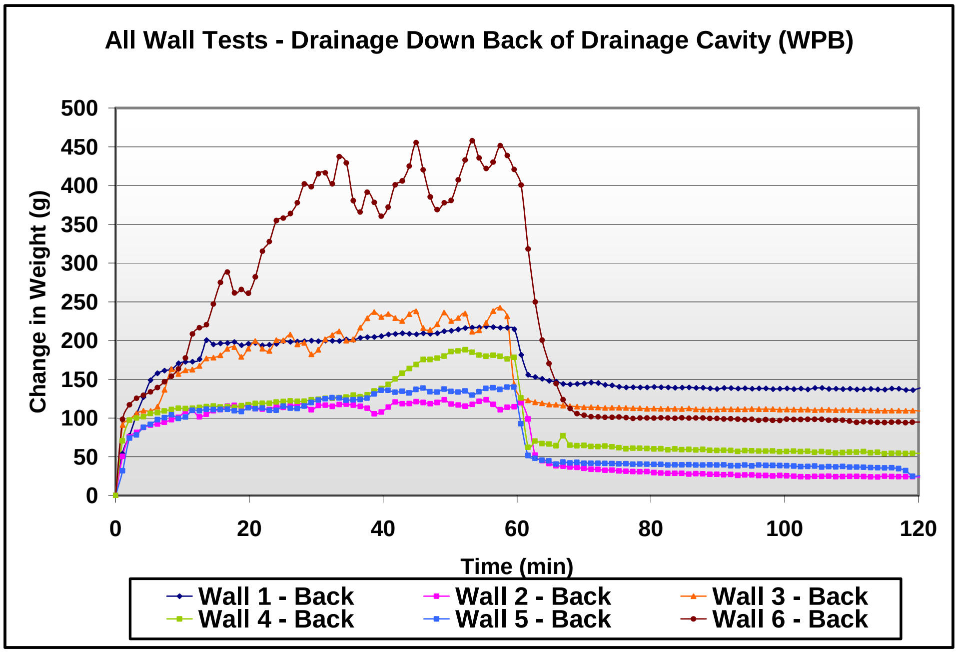

Figure 4   Composite plot of all EIFS drainage tests where water was trickled down the BACK of the drainage cavity (against the WPB)

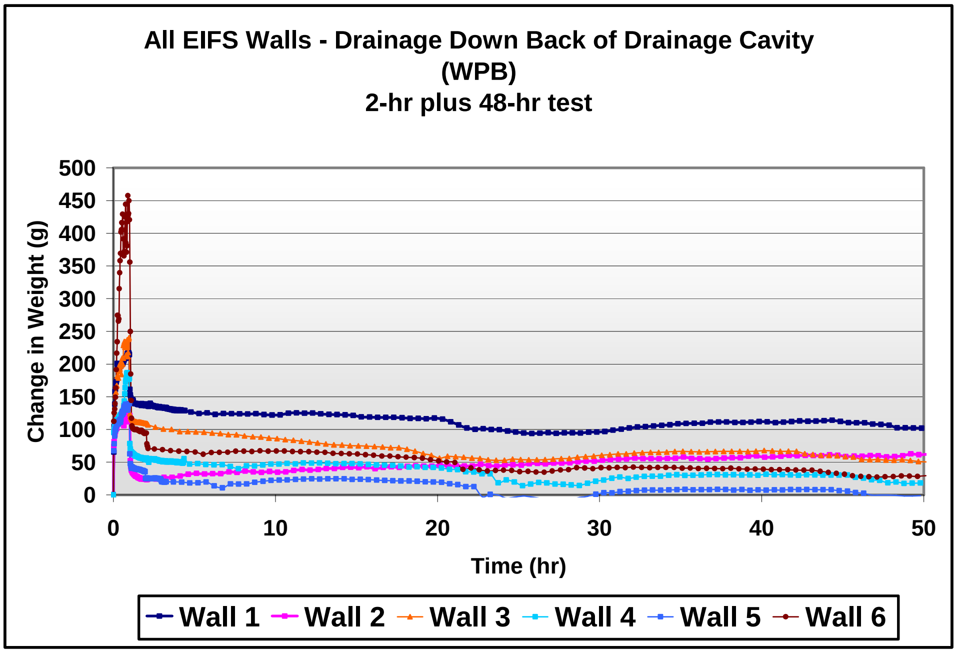

Figure 5 Composite plot of all EIFS drainage tests including 48-hr drying where water was trickled down the BACK of the drainage cavity (against the WPB).

From these profiles and from discussion in the previous section, it appears that test Wall 1-Front in Figure 5 experienced build-up of water in some of the EPS joints, based on the linear accumulation observed. Despite this, the subsequent drying rates were similar for all walls. Wall 2 and Wall 5, both having a relatively open starter panel at the bottom instead of a starter track, retained the least water. Additional comments and findings concerning these tests follow.

- The current water delivery system which provided trickles to an intended surface led to repeatable drainage/retention profiles compared with earlier tests that did not control where water was directed as well [3].
- All walls permitted the bulk of the supplied water to flow through and only 0.3 % to 1.4% of the water input was retained even though some EIFS walls had starter tracks that may also have retained some liquid water. Water held there would not be in contact with the base wall.
- Walls that originally retained the least water generally retained more when water trickled down the face of the LA-WPB coating than on the back of the EPS foam.
- Drying rates were not correlated with the spacing of ribbons or the level of retention of water at the conclusion of the 2-hr test period.
- For larger retentions, marginally higher drying rates resulted during the early drying period.
- During the 48-hr drying period, variation in environmental conditions did not result in monotonic drying curves.
- When EIFS walls were tested concurrently with some siding systems, it was found that other systems exposed to similar conditions were relatively unaffected by environmental fluctuations. This suggests that moisture pickup by the exposed wood framing and sheathing was minor for all walls.

A measure of the drying ability of walls built to comparable specification is the retention ratio, assuming all have been subjected to the same environmental conditions. Choosing the ratio of the 50-hr and 2-hr retention values is one form that might be examined. Table 2 summarizes those values for all 12 EIFS wall tests.

Table 2 Drying Rates and Retention Ratios for EIFS walls

Wall No.	Trickle Designation Re: Cavity	Surface Trickled On	Retention at 2-hr (g)	Initial Drying Rate (g/h)	Retention at 50-hr (g)	Drying Rate over 48 hr (g/h)**	50-hr / 2-hr Retention Ratio
1	Front	EPS	165	6.6	155	0.59	0.94
2	Front	EPS	45	2.8	42	0.42	0.93
3	Front	EPS	55	1.6	35	0.76	0.64
1	Back	WPB	137	6.9	102	0.64	0.74
2	Back	WPB	24	12.1	0*		0.00
3	Back	WPB	109	4.9	51	0.75	0.47
4	Front	EPS	56	0.8	45	0.05	0.80
5	Front	EPS	59	6.8	33	0.53	0.56
6	Front	EPS	63	4.0	45	0.95	0.71
4	Back	WPB	54	11.1	18	0.67	0.33
5	Back	WPB	26	7.8	0	0.86	0.00
6	Back	WPB	95	8.8	29	0.89	0.31
	Mean		74		46		0.54

* Wall 2-Back gained weight after fully drying the 48 hr drying out period

** Drying window chosen over most of the 48-drying period when possible

It was clear from the drying plots that considerable variation in weight (associated with the variation in environmental conditions) led to relatively unreliable end points particularly when so very little water is retained. The drying rates at 2-hr, i.e., soon after drainage stopped, were one order of magnitude higher than during the following drying period.

The EIFS systems were tested without knowing what surfaces would be most involved in absorption of water draining on them. The materials facing the drainage cavity and the starter tracks or starter panels at the base of the wall were all potential candidates for storing and absorbing or retaining moisture. Given the small space provided for drainage (from 2-3 mm) and the irregular width and spacing of adhesive ribbons - these tests showed that there was a lack of consistency in the difference between Front and Back water delivery for each wall. The narrow gap provided likely did not differentiate how moisture was managed. The variation found was considered to be small in relation to the total amount of water passing through each system.

Results for Vinyl Siding Systems

The three vinyl siding walls constructed had the siding applied directly to the WRB and base walls. Since they were direct applied, there was no intentional drainage cavity. They were however installed loosely as required in practice to avoid buckling related to temperature changes. The degree of tightness was assessed by sliding the siding laterally to ensure that no binding occurred. As with all of the direct-applied siding systems tested in this program, water was trickled into the middle of the top course without attempting to direct it to any particular surface.

The main distinction between direct-applied vinyl siding and the EIFS walls tested is that drainable EIFS formed a narrow but effective drainage space and did not permit moisture loss through the face of the system. Most siding systems, whether intentionally designed to do so or not, allow some water to exit through joints or drain holes. The intent of the test protocol was to have all water enter the 1200 mm wide wall and be available for drainage/retention. The edges of each vinyl test sample were sealed with caulking to prevent lateral flow of water out of the test walls. In practice, walls are not sealed that way and water entering behind the siding may flow laterally (if a head of water develops depending on the rate of water entry) and potentially find sufficient drainage holes for the majority of the water to pass through, or to find its way down to lower courses. Both profiles of vinyl siding represented here were designed to retain water entering behind the siding in the profile and to allow it to drain out through drain holes. During the wetting phase of Wall 1 (which involved Profile #1 and building paper) water on entering the first course of siding immediately started draining out of the small drainage holes provided in the profile for this purpose. Some head of water developed there and some leaked out through the imperfectly sealed edges. Most of the water drained out of the wall by passing through two or three drainage holes located in the bottom edge of the top course of siding.

Water that escaped drained down and wetted some of the wood framing that was not protected by the WRB. As a result, the total weight gained and its dissipation did not conform to the intended experimental design.

On the other hand, Walls 2 and 3 (utilizing vinyl siding having Profile #2 with SPBO and building paper WRB membranes) demonstrated less extensive moisture loss by edge leakage. The profile of this siding simulated a different type of wood siding as shown in Figure 1. Water draining from these drainage holes was retained along that surface and drained down for collection by the gutter. An example of drainage down this profile type is shown in Figure 6.

When these walls were dismounted from the test frames at the end of the test, some of the free water still held by the siding drained out on the floor. Water that was recovered by wiping the floor weighed about 10 and 40 grams was recovered this way. Wall 3 (Profile #2 with building paper) had the most water spill out (43 grams).

Figure 6 Example of face drainage from drain holes in vinyl siding (Profile #2)

Composite drainage plots of all three test walls are shown in Figure 7.

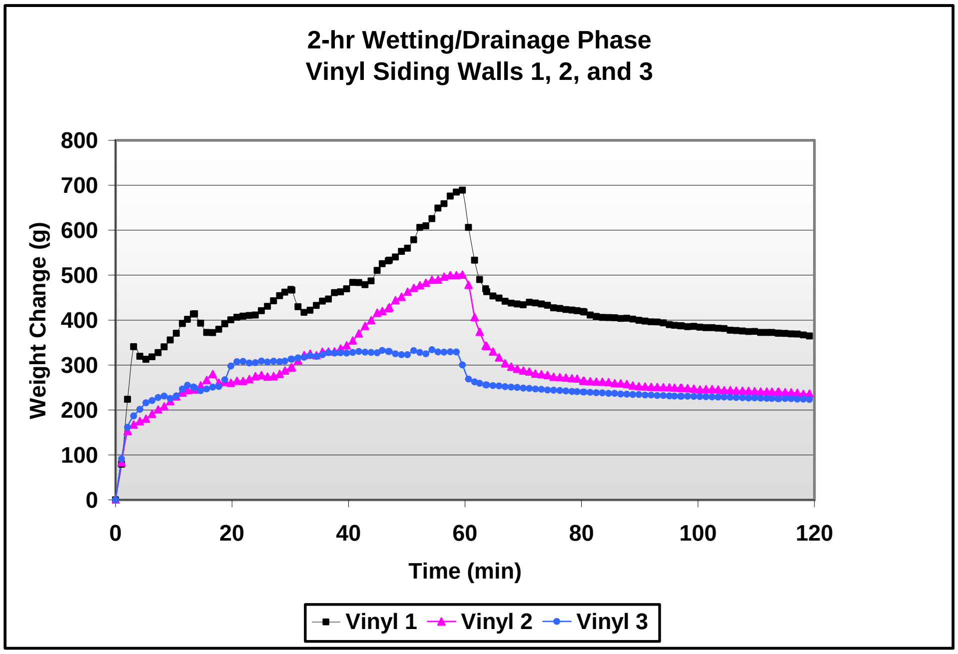

Figure 7 Composite plot of drainage tests on three vinyl clad walls for the 2-hr wetting/drainage period.

The three plots in Figure 7 are instructive in revealing how water was retained during wetting. This opinion is based on observations during the tests and the shape of the resulting plots. Wall V1 experienced the most retention and leakage, leakage that involved wetting of the wood framing and hence storage. The sharp increase in weight to the end of the wetting phase of the curve implies that more water would have been retained if the wetting had been allowed to continue, perhaps by more absorption into the wood framing.

To a lesser degree, this also happened for wall V2 which had a different profile. The retention at this stage seems largely dependent on the degree of failure to hold water within the siding space to be drained through the holes provided. Wall V3, on the other hand, experienced little extraneous leakage and reached a near plateau of retention in 20 minutes, so the head of water attained remained sufficient to allow the water to escape as rapidly as it was supplied to the wall.

The drying rates for walls V1, V2, and V3 (obtained by regression of the drying curves both when drainage stopped and for the longer drying period for each wall) are provided in Table 2. The total retentions for wall V1 reflected the larger amount of moisture that was absorbed into the wood framing from leakage during the test. The free water retained in the joint profile at the conclusion of the test was still sufficient to partially spill out when the walls were dismounted and turned over on their faces for measurement of moisture changes using the capacitance meter.

Table 2 Drying Rates and Retention Ratios for Vinyl Clad Walls

Wall No.	Surface Trickled On	Retention st 2-hr	Initial Drying Rate (g/h) *	Retention at 50-hr (g)	Drying Rate over 48 hr (g/h)**	50-h / 2-h Retention Ratio
V1	middle	364	73.8	283	0.40	0.78
V2	middle	236	41.6	130	1.34	0.55
V3	middle	224	22.4	134	1.01	0.60

* The initial drying rates are high because of evaporation from the wetted wood framing
** Drying window chosen over most of the 48-hr drying period

Several additional observations about the tests on walls with vinyl siding follow:

- The direct applied vinyl siding retained moisture largely within the top courses where the water was deposited.
- While the siding was installed loosely to allow expansion without buckling, the ability of the siding to allow drainage behind it did not appear to be facilitated. If it is intended that drainage be possible for “loosely installed” direct applied cladding systems, more explicit installation recommendations are needed.
- The vinyl siding walls exhibited drying, but some of that drying was from wood framing that had been wetted.
- Moisture retained in the vinyl siding joints as free water was not held in contact with the WRB and wood framing, but this moisture can contribute to establishing a local micro climate that in the long run may lead to problems in some areas of a building, particularly if the wetting is chronic.
- The absence of an effective drainage plane leaves the vinyl siding clad wall durability susceptible to blockage of the small drainage holes. Although not encountered here, partial clogging of these small holes by dirt would reduce the venting ability of vinyl siding in the future.

Results for Wood Based and Fibre Cement Siding Systems

The test walls reported on in this section included 2 types of hardboard siding, 2 types of wood siding, one type of cement fibre siding, 3 drainage mat systems and one wall with wooden battens (furring strips). The main distinguishing feature between these types of systems was their assembly as *direct-applied* or as *drained* systems. The performance of each group will be summarized separately in this section.

Results for Direct Applied Siding

Walls with direct-applied siding (1 hardboard, 1 wood and 2 fibre cement specimens), were tested only once. The water trickled into each wall was simply allowed to drip into the space behind the top siding course through the 4 mm space provided at the top edge. Urethane spray foam used to seal the ends (edges of the assemblies) proved to be successful in preventing lateral leakage than caulking used in tests of vinyl siding.

Composite drainage plots of all direct-applied sidings are provided in Figure 8. In all cases a SBPO weather resistant barrier was employed. Also included in this comparison is a retest of one wall.

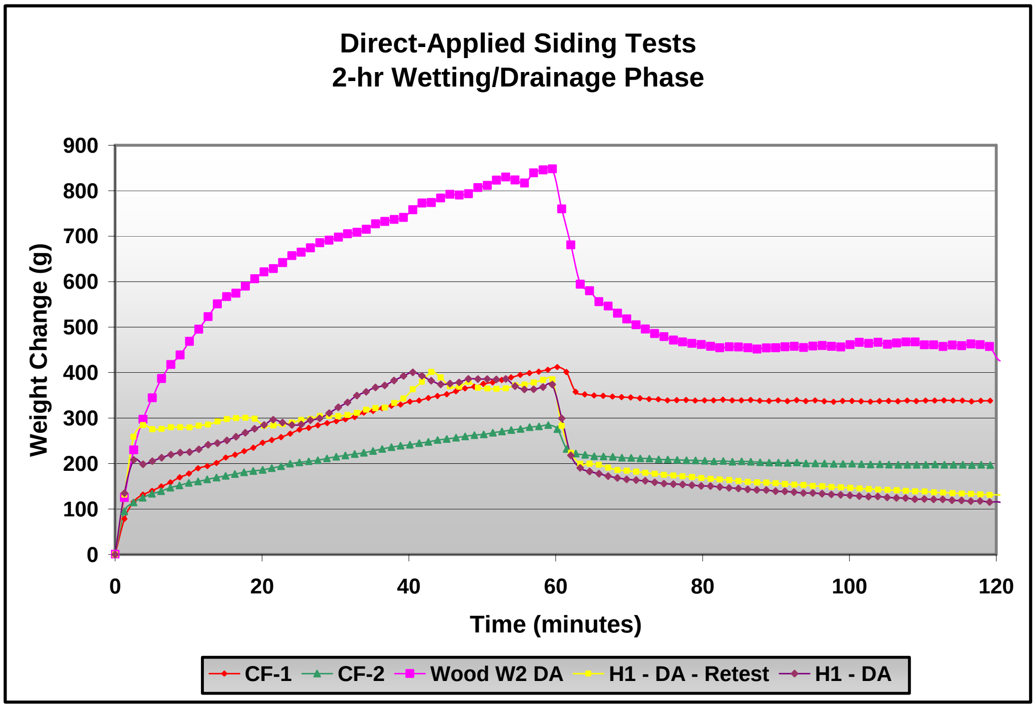

Figure 8 Composite plot of weight changes during the wetting/drainage phase for all walls with siding that was applied directly to the basic wall.

Quite apart from the magnitude and shape of the curves plotted, it was commonly observed that direct-applied siding did not appear to allow a significant amount of water to flow down behind to lower siding courses. Most of the water escaped through the first joint encountered by the water which then flowed over the face of the siding below. Some retention of water in the joint profiles occurred, but that level of detail could not be investigated in this study.

All siding employed was factory prefinished with at least a prime coat finish on the back of the siding. The following observations are based on the above plots:

- The H1 profile for initial and retest performance was very similar.
- The most water retained was by the W2 wood siding that had a shiplap profile and had nearly full contact with the base wall.
- The fibre-cement sidings continued to gain moisture at a steady rate to the end of the wetting period signifying a ready ability to absorb water. Drying of the fibre-cement siding was initially slow, but at the conclusion of the 48-hr drying period, both walls had dried to quite low levels and at the same rate.
- The water take-up rate for the first few minutes of the test appeared to be identical for all walls tested.
- The total amount of water retained in these tests is likely concentrated in relatively small areas associated with the contact between the siding and SBPO sheathing membrane. Siding profiles H1 and both fibre-cement siding wall samples were lapped and only the

top edge of each course was in direct contact with the SBPO. The back of the siding was otherwise exposed to air.

- The wood siding, on the other hand, was installed flat against the SBPO and was therefore capable of retaining more water. It must be stated that the manufacturer of this siding recommends this siding be installed on furring strips. That recommendation, using this profile, was also included for one wall in this study.

Several observations about distributions for direct-applied siding follow:

- One of the direct-applied fibre-cement siding walls retained more water than its matching wall. It also appears to have held that moisture in the upper portion where the water was introduced. The retention contours for the second wall peak lower down suggesting that some of the moisture found its way to a lower level, where the water was more distributed and from which it was able to dissipate more broadly. All siding systems that are direct-applied clamp the WRB tightly against the sheathing at the contact lines. However this ability must be highly dependant on installation factors and subsequent shrinkage effects at fastener locations.
- The direct-applied wood siding also retained more moisture at mid-height by the end of the drying period. The direct-applied lapped hardboard siding also retained more moisture at mid height. Exactly how that moisture was held cannot be determined from this crude level of detection. However, of all siding systems reported on here, this was the only direct-applied siding that was installed with the back face fully in contact with the WRB and it was expected to retain more moisture.
- In most of the above cases some moisture appears to have migrated downward even though the siding should have been tightly clamped to the wall. In typical walls, there are discontinuities in the contact between siding and the wall, as well as between adjacent courses of siding.

Results for Siding Applied on Drainage Mats and Furring Strips

For walls with drainage cavities, the trickle trough was deployed to direct the water down either the back of the drainage space against the WRB or to the back of the top edge of the siding as was done for the EIFS test walls (except for the specimen with 19mm wood-battens which was tested only once with water applied to the WRB surface).

All siding installed over drainage cavities performed as expected. Most of the water that trickled in at the top of the drainage space flowed within that space to the bottom where it was collected by the sloped gutters. The composite plots for these test walls are provided in Figures 9 for the first 2 hours of test.

- Contrary to expectations, the system with the largest initial retention was for the wood siding profile W2 installed on wood furring strips (19 mm x about 64 mm). The effect of the wood siding profile was immaterial in this case because the trickling of water was done to the back side of the drainage space. At least one trickle of water deposited directly on top of each furring strip and this water was absorbed quickly into the end grain. Despite the higher retention at these locations, this wall dried more quickly than other siding on drainage mats because of the larger drainage space and because the exposed ends of the furring strips were at the top of the drainage cavity.

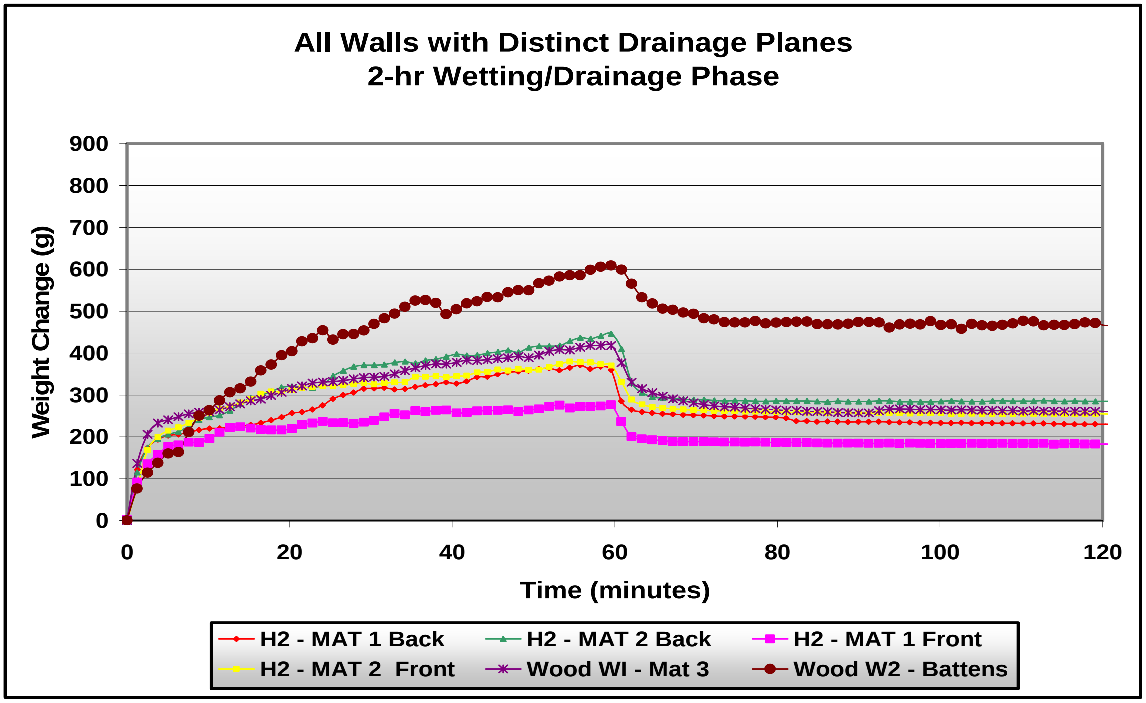

Figure 9 Composite plot of weight changes during the 2-hr wetting/drainage phase period for all walls with siding that was applied over some form of drainage matrix or batten strips.

- The wood siding installed on Mat 3 was wetted with the tips of the serrated plastic drip edge positioned in the middle of the space between the siding and the back of the dimpled plastic sheet. The positioning of so many dimples dispersed the incoming droplets as they fell and likely wetted all surfaces to some extent. This drainage medium did not allow any moisture to be transferred to the OSB and drying occurred only from the mat itself and the wood siding installed flat against it.
- Mat 1 and Mat 2 were wiry type products that were relatively open for the flow of water and vapour. Mat 3, intended for use on roofs under wood shingles, is a dimpled polyethylene sheet and is impermeable to vapour and liquid flow through it. The protruding dimples were directed outward towards the siding. The flat side of the dimpled sheet was placed against the WRB and acted as a vapour barrier for the inner wall. While this location for that function would not be suitable for Northern construction it would be permissible in hot humid climates. The use of Mat 3 in this project was primarily intended to illustrate the level of retention that might be attained by this class of product in combination with that cladding.

Relatively little can be surmised about the location of retained moisture from the weight measurements alone. The moisture maps (not shown) provided some additional insight despite the relatively crude measurement grid.

- The maps were very similar whether water was trickled down the front or back of the drainage cavity involving mat systems. This signifies that about the same degree of wetting occurred in both cases.
- The case involving wood siding applied to batten strips, with the water directed near the back of the drainage cavity and partly over the furring strips themselves, dried very well,

but there was some residual moisture about mid-height and in line with one of the vertical battens.

- The residual moisture in all cases appears to be concentrated more at mid-height of the test walls. It was surmised that fresh air from the laboratory entered the bottom of the drainage cavity and moisture evaporated more quickly there. As the moist buoyant air moved upward it was less able to take on additional moisture from the mid-height level and that moisture would be the last to dissipate to low levels. The upper portion of the wall was slightly warmer than the lower portion due to stack effect in the laboratory air and with a shorter distance to the upper end of the drainage cavity it was also able to dry more quickly in that direction.
- We have no knowledge about the air circulation taking place in the drainage cavity. However we do know, from the RH records, that air rising up directly from the top of the drainage path had a higher RH than ambient conditions. Sensors on either side of that path indicated results that were similar to ambient conditions. The temperature of the air rising from the path was usually warmer than on either side of the trickle trough. A possibility is that two possible symmetric local convective loops developed with air entering the wall at the top on either side of the trickle trough to pick up moisture and rise. If fresh air for drying was only available from the bottom of the wall, drying might only occur from the bottom to the top with the last residual moisture to be removed from the top of the drainage cavity.

Table 3 Summary of Retention Ratios and Drying Rates for Siding With and Without drainage cavities.

Surface Trickled On	Siding type	Mat type	2-hr Retention	Initial Drying Rate (g/h)	50-hr Retention	Drying Rate Over 48 hr (g/h)**	50-hr / 2-hr Retention Ratio
Siding With Drainage Cavities							
back	H2	M1	231	11.6	156	1.50	0.68
(WRB)	H2	M2	284	*	229	1.17	0.81
front	H2	M1	183	4.9	109	1.41	0.60
(siding)	H2	M2	254	7.0	221	0.82	0.87
back	W1	M3	260	39.9	123	2.78	0.47
(WRB)	W2	Battens	467	4.0*	0	12.60	0.00
Direct-Applied Siding							
mid	H1	DA	117	52.7	35	2.37	0.30
mid	H1(retest)	DA	130	34.9	0	1.40	0.00
mid	W2	DA	426	*	294	2.70	0.69
mid	FC-1	DA	340	3.1	50	5.59	0.15
mid	FC-2	DA	197	17.1	0	4.19	0.00

* Drying rates were very low in the period chosen, or slightly gaining in weight

** Drying window chosen over most of the 48-hr drying period

Finally, in comparing the drying rates and retention ratios shown in Table 3, it is apparent that the lower retention ratios tended to be associated with walls that dried more rapidly. Also, the provision of a relatively unobstructed drainage path tended to result in lower retention. The relationships are not clear cut, as each system had different factors at play influencing the water that was retained and drying that subsequently took place.

SUPPLEMENTARY INVESTIGATIONS OF TEST WALLS

Additional studies were undertaken to study the ability of wetted walls to dry. The air flow properties of all walls with drainage cavities were evaluated to obtain the air flow characteristics of the main cavity and of the restrictive starter tracks, if any. Walls with intentional drainage cavities (as tested) permitted ventilation of those surfaces under isothermal conditions. This was driven by buoyancy of moist air in the cavity without purposefully applied pressure differentials.

In a similar way, walls with direct-applied siding could dry in the short term primarily by vapor diffusion and air movement by moisture buoyancy through joints in the siding. Evaluating those properties could not be done conveniently on the walls as tested. Instead, large test samples were built to evaluate both the vapor permeance (wet-cup type test) and their air permeance. The results of both investigations are reported in project reports [6 and 7, and summarized in 8] and are not discussed in this paper except to note that there were correlations between the drying rates for walls with drainage cavities and their air flow characteristics. In a similar way, the drying rates of siding systems applied directly to walls without intentional drainage planes were related to the vapour permeance of siding joints which, in turn, were related to their air flow characteristics.

DISCUSSION AND CONCLUSIONS

It is clear that provision of drainage planes leads to a direct path for the water to flow to the bottom of a wall. In the process, a greater area of wetted surfaces becomes involved than when water is able to escape close to the point of entry. In this case a greater total weight of water can be retained depending on the design of the siding. However, since the moisture mapping showed that significantly larger areas of wall with drainage mats were affected, and the retained moisture was generally lower, it is likely that the concentration of moisture was higher where siding was directly applied. The moisture mapping done was not precise enough to locate high local concentrations of moisture where siding was clamped to the walls, or in joints between siding courses. Overlaps and other joints in the siding are designed to shed water that is on the outside surfaces of siding, and they are not particularly designed to easily shed water that may enter and flow down behind the siding.

It is not possible to claim on the basis of these results that moisture was held in the drainage mat for any length of time or that it was absorbed into other surfaces (the siding, WRB and the backup wall) defining the space. The dimpled drainage mat prevented moisture from being transmitted into the structural sheathing and dried more rapidly than did walls having matrix type mat systems. This suggests that at least one pathway was omitted and the result was better. For this test program only a limited variety of cases and siding systems could be included and the effect of the properties of the WRB was not included.

Even in walls with direct-applied siding that dried, ventilation loops through the upper open edge of siding contributed to that drying. When some water appeared to penetrate to lower reaches of a wall, drying by other means would take precedence, namely vapour diffusion and air exchange through the materials and the air gaps between courses of siding, small though they may be. The short time frame for the tests and knowledge about the reduced degree of vapour resistance of finished hardboard and OSB suggests that substantial loss of moisture directly through the siding materials was not a significant transfer mode out of the wall leading to the weight loss observed.

The experimental testing to determine the ability of walls with siding to manage water that enters the space behind the siding has taught us that despite the lack of provision of drainage cavities, siding joints can permit drainage close to the source of moisture. The ability to do so safely without risk of damage to either the siding or the formation of mould was beyond the scope of this study.

Provision of a drainage plane behind siding is the surest way to dissipate moisture despite the potential that a greater area (height) of wall might be exposed to water. The concentration of moisture and its location is likely a more important determinant affecting durability than the total quantity of moisture retained. The ability of the cladding construction to assist in dissipating moisture from behind it and the choice of materials inside the drainage cavity can provide a near fail-safe construction under real weather conditions. The current study was essentially limited to isothermal drying conditions. Drying under real weather conditions may be highly accelerated or slowed depending on the weather conditions at the time and building exposure. Testing of walls, as was done in this study, is a valuable means for assessing the influence of construction variables, something that computer modeling cannot provide.

RECOMMENDATIONS

The main recommendations for the application of drainage tests are:

- The test method as derived from ASTM E 2273-03 for EIFS walls is suitable for developing an understanding of how other types of wall systems manage water that penetrates the primary cladding. The test protocols employed enlarged upon the information developed that would otherwise have been provided by that standard.
- The test can be used to develop siding systems that perform better. Improved air permeance of joints for any particular system would likely improve the ability of the wall to drain water close to where it is introduced into a wall in the case of direct-applied siding. In the case of siding applied over drainage mats or battens, improved air permeance would also improve drying.

The main recommendations for further research are:

- The ability of walls with cladding on drainage cavities to dry depends on the air exchange that takes place both through siding joints (if there are any) and the moisture and thermal buoyancy of air in the column of air in the cavity. Control of both means of drying depends on the air flow properties of starter tracks, flashing and top closure details. Testing and computer modelling can be used to investigate these parameters to maximize drying without compromising other aspects of wall performance, i.e., thermal resistance of EIFS.
- Siding that is applied directly to the wall can retain water locally with sufficient concentration that, in chronic wetting situations, can lead to local degradation of the wall.

Study of the exact way that water is held at joints is needed to determine whether the properties of the WRB can influence the results, as might be the case on repeated wetting.

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