RESEARCH REPORT

Drainage and Retention of Water by Cladding Systems

Part 2 – Testing and Measurement Methodologies

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DRAINAGE AND RETENTION OF WATER BY CLADDING SYSTEMS

Part 2 – Testing and Measurement Methodologies

Presented to

Barry Craig
Senior Researcher
Housing Technology Group

Canada Mortgage and Housing Corporation
Policy and Research Division
700 Montreal Road
Ottawa Ontario
K1A 0P7

by

Donald M. Onysko and Constance Thivierge

Forintek Canada Corp.
Building Systems Department
319 rue Franquet
Québec, Québec
G1P 4R4

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Donald M. Onysko
DMO Associates

Richard Desjardins
Manager, Building Systems
Forintek Canada Corp.

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SUMMARY

A review of past testing methodologies involving drainage studies was undertaken and the decision was made to use relatively full scale test walls. The report describes the development of the test protocols and the basis for modifications that were made to the ASTM E 2273-03 test standard which was designed for EIFS systems. The test protocols were adapted for use on any cladding system. Wall construction details and the method and quantity of water delivered to the drainage cavity were modified. The intent of the test included study of how drying took place, so the opportunity for dissipation by natural ventilation was provided. As drainage cavities of different designs can affect the drainage paths taken by water entering the cavity, the method of water delivery developed allowed the water to be directed to the back or front of the drainage cavity. Monitoring of the weight of retained water was done throughout a 1-hr wetting period using an accurate weight balancing system that allowed three walls to be tested at the same time. The recording of weight changes was followed from the beginning of wetting through to when wetting was halted and during drying of the wall for a total time of at least 50 hours. An assessment of the monitoring of retained moisture was explored using a capacitance based moisture meter to measure the change in moisture before and after the drainage test at specific points on a grid of measurements. These measurements were used to provide contour plots of moisture differences to show where moisture was retained. The experiment was intended to be done under isothermal conditions in the laboratory at 20 deg C and 50% RH, but there were variations and these conditions were monitored in the vicinity of the test set-up, as well as at the top of each drainage cavity where the moist air was expected to exit as the walls dried.

RÉSUMÉ

Un examen des méthodologies déjà employées dans des essais de drainage a été fait et il a été décidé d'utiliser des murs de vraie grandeur relative pour les essais. Ce rapport décrit l'élaboration des protocoles d'essai et les principales modifications apportées à la norme d'essai ASTM E 2273-03 destinée à la mise à l'essai des systèmes d'isolation des façades avec enduit (SIFE). Ensuite, les protocoles d'essai ont été adaptés à la mise à l'essai de n'importe quel système de parement. Les détails de construction du mur ont été modifiés ainsi que le mode d'alimentation d'eau et son volume dans la cavité de drainage. L'essai cherchait aussi à étudier comment le séchage se produisait et à cette fin, il fallait permettre la dissipation par ventilation naturelle. Étant donné que les cavités de drainage des diverses conceptions peuvent influencer les voies de drainage empruntées par l'eau qui pénètre dans la cavité, le mode d'acheminement d'eau qui a été mis au point permettait de rediriger l'eau à l'arrière ou à l'avant de la cavité de drainage. Le contrôle du poids d'eau retenue a été effectué au cours d'une période de mouillage d'une heure, à l'aide d'un système d'équilibrage du poids précis qui permettait de mettre à l'essai trois murs à la fois. Les changements de poids ont été enregistrés du début à la fin de la période de mouillage et pendant la période de séchage du mur, soit une durée totale d'au moins 50 heures. L'évaluation du contrôle de l'humidité retenue s'est faite à l'aide d'un humidimètre à condensateur qui mesurait le changement d'humidité avant et après l'essai de drainage à des points précis sur une grille de mesures. Ces mesures ont permis d'exécuter un tracé des différences d'humidité afin de voir où l'humidité était retenue. L'expérience s'est déroulée dans les conditions isothermiques du laboratoire à 20°C et à une humidité relative de 50 %, mais il y a eu des variations et ces conditions ont été contrôlées à proximité du banc d'essai, ainsi que dans le haut des cavités de drainage où on s'attendait à ce que l'air humide s'échappe au cours de la période de séchage du mur.

CMHC SCHL

National Office

700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

Bureau national

700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

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The following constitute the research team that undertook the work reported here.

For DMO Associates:

Donald M. Onysko, PhD, DIC, C. Eng.	Principal Investigator
Marcin Pazera, B.Arch., M.Sc.	Materials Specialist, Syracuse University

For Forintek Canada Corp:

Richard Desjardins, P.Eng, M.Sc.	Manager, Building Systems, Forintek
Constance Thivierge, P.Eng.	Industry Advisor, Building Systems
Mohammad Mohammad, PhD	Group Leader, Building Systems
Anes Omeranovic	Technologist, Building Systems
Jean-Claude Garant	Technologist, Building Systems

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PREFACE

CMHC proposed that a series of drainage tests of exterior cladding assemblies be undertaken to produce data to quantify the ability of several types of cladding and methods of application on wall systems to manage and evacuate water that has intruded behind them. The test program has concentrated on the drainage characteristics of the tested systems, the amount of water that is retained and the drying ability of the cladding tested. The present report details the testing and methodologies employed.

The reports are organized by the different phases in the project and by the wall types tested for drainage with additional supplementary tests done in support of the work. In summary, the different “Parts” of reporting in this project are:

Part 1 - Experimental Approach and Plan
Part 2 - Testing and Measurement Methodologies.
Part 3 – Drainage Testing of EIFS Wall Systems
Part 4 - Drainage Testing of Walls with Vinyl Siding
Part 5 - Drainage Testing of Walls with Wood-based and Fibrous Cement Siding
Part 6 - Air Flow Characteristics of Wall Systems Having Drainage Cavities
Part 7 - Air Leakage and Vapour Permeance of Joints in Some Siding Systems
Part 8 - Summary Report

Reporting has been compartmentalized into this series of “Parts” because of the extensive detail involved in reporting on the many wall variants that have been included. Comparisons were considered more manageable for the reader to face by providing the details separately in each segment of the work.

DRAINAGE AND RETENTION OF WATER BY CLADDING SYSTEMS

Part 2 – Testing and Measurement Methodologies

1 INTRODUCTION

The reporting of work done in this project is organized by main topics. This Part of the report series is intended to provide background for the methodology of undertaking the drainage testing of walls. Also described is the development of some of the test protocols and the measurement of parameters that help explain how different systems perform.

2 OBJECTIVES

The objectives of this report are:

- To review some of the literature on testing walls for their drainage capability
- To describe the development of the test method details used in this study
- To describe the test measurements employed to characterize the drainage performance of the test walls

3 REVIEW OF DRAINAGE TEST METHODOLOGY

An overview of the phenomenological behaviour of outer-wall systems was described in the Introduction to the main report. Essentially, the intent of drainage testing involves depositing a known quantity of water behind the cladding over a fixed period of time, observing the manner that the water drains or is retained, and to monitor the rate at which subsequent drying takes place. This experiment was intended to take place under known isothermal conditions.

Earlier research in the literature concentrated on performance of exterior insulation and finish systems (EIFS) because of systemic failures in certain parts of North America involving their use. These studies, some of which will be examined here, led to the development of the current ASTM E 2273-03 "Standard Test Method for Determining the Drainage Efficiency of Exterior Insulation and Finish Systems (EIFS) Clad Wall Assemblies" [1]. The test method assesses drainage capability and a measure of the amount of water retained by a test wall. The criteria for judging suitability are found in ICC A235 requirements [6]. However, the basis for these requirements do not have obvious supporting evidence for their application in the many difference climatic conditions EIFS may be built. Consideration of criteria that some organizations have set will not be addressed in this report.

The Canadian Centre for Materials in Construction (CCMC) undertook a reassessment of the information needed to judge the suitability of the moisture handling of EIFS walls. This led to adoption of alternate preliminary criteria on drainage and retention and required changes in ASTM E 2273-03 to secure additional information. At the present time, the essentials of the CCMC test method [3] will be employed in this test program to assess other types of cladding systems besides EIFS. As such, the following review provides the basis for the test methods that will be employed, and to secure information beyond that required by either the ASTM test standard, or the CCMC variant of it.

3.1 Review of Studies on Drainage Testing

Early research into drainage capability of test assemblies by Tonyan et al [5] involved drainage tests on small test samples (12" wide x 48" long) representing EIFS and DEFS (direct applied EIFS). The water was supplied to the top of each assembly and a 4-inch water head (+/- 1/16") was maintained during the test. The drainage rate for each type of assembly was reported. The mass of water in the water supply tank was continuously weighed, as was the mass of water in the collection tank. The quantity of water drained was not constant throughout the test, generally slowing from the beginning of the test but achieving a steady state for part of the total test time. The main conclusion reached was that the drainage rates achieved were far higher than the drainage rates experienced on full scale test walls having water-managed DEFS and EIFS systems, and which included a window and other build-in defects. They concluded that there was more than sufficient drainage rate capacity to direct intruding water back to the outside in each case. This implies that even very slow flow rates were adequate to handle most of the water put in if the bottom of the drainage plane was not blocked off.

The second part of this paper reported on tests of 4' wide x 3' high wall test assemblies subjected to water spray followed by different degrees of exposure in a laboratory test chamber. The opposite interior conditions were maintained at one level of temperature and RH. All specimens had the same interior finish and a polyethylene vapour barrier that effectively decoupled the interior chamber RH from that in the wall cavities. Moisture contents in the OSB and the EIFS and DEFS were measured using moisture pins. It was concluded that since the measured moisture contents were small, that there was little moisture entry from the drainage plane through the wall sheathing materials and that all walls exhibited good performance. Moisture did climb within the materials, but the conditions were changed from one time to another, with the periods usually lasting only 72 hours, and at most 7 days. While the changes appeared to be low, there was condensation on the back of the vapour barrier under some conditions for many of the test walls. This implies that the retained moisture in the outer cladding and within the drainage plane was sufficient to create a sufficiently high RH condition in the wall cavities that led to condensation there even though the temperature at that plane was relatively warm at 20 °C.

A second study by Bronski and Roggiero [2] reported on a summary of field investigations in 5 States in the USA, and the results of a drying experiment involving 5 wall constructions (3 EIFS types, 1 stucco wall, and 1 wall with clapboard siding). The authors also made many recommendations on the construction of EIFS systems to improve their performance.

They reported that face sealed systems failed at many different types of joints, and that it was not realistic to expect them to perform well or for an indefinite length of time. The details that proved problematic are familiar to all and will not be repeated here. Needless to say, once moisture from outside entered the wall space behind, it could not be removed rapidly enough through drainage or dissipation as those walls were built at that time, and deterioration occurred for face sealed systems.

To determine the benefits of systems that allowed drainage, 5 test panels (1 x 2 m in size) were built to assess drying potential. Unlike the paper by Tonyan *et al* [5] these panels were constructed and the framing was dipped in water. In some cases the framing was wetted first followed by completion of the construction. In one case, the wall was completed with the EIFS installed and then dipped. Essentially, this was a drying experiment; just as the EDRA project conducted in Vancouver B.C. on stucco walls was a drying experiment (Hazleden [4]). In this case, the walls were not subject to a temperature gradient, but were held in unconditioned thermal conditions. In all cases, drying was poor and the EIFS systems, whether with or without drainage capability, were the slowest to dry. Without some ventilation behind the EIFS, drying of severely wetted framing in a cavity wall will be slow and may allow damage to take place. The test work did not simulate wetting from the outside, but assessed drying of walls that had already been wetted as could occur during construction. This project reinforced the concept that walls should work as rain control barriers. Wetting of the wall cavities from outdoor moisture indicated that the rain control function was not met adequately, and walls that were already wetted did not dry well in isothermal conditions. It is worth paraphrasing their conclusions

- Tests to measure drainage capacity of drainable systems are not meaningful on their own.
- Tests need to be established to assess the ability of water reaching the sheathing to escape to the exterior.
- Further research is needed on the amount of venting that is needed.
- Research on using a more permeable EIFS was recommended.

3.2 Review of ASTM E2273-03 [1]

Test details in the ASTM E2273-03 “Standard Test Method for Determining the Drainage Efficiency of Exterior Insulation and Finish Systems (EIFS) Clad Wall Assemblies” are quite different from the methods reviewed above. It also represents the most recent consensus by the committee participating in the development of that test standard. The test method was developed for testing of EIFS walls. However, the testing is limited to assessing drainage capability and assessing the amount of water retained after drainage has been completed, while the ability of a wall to dry water that has been retained is ignored. A diagrammatic representation of the test is shown in Figure 1.

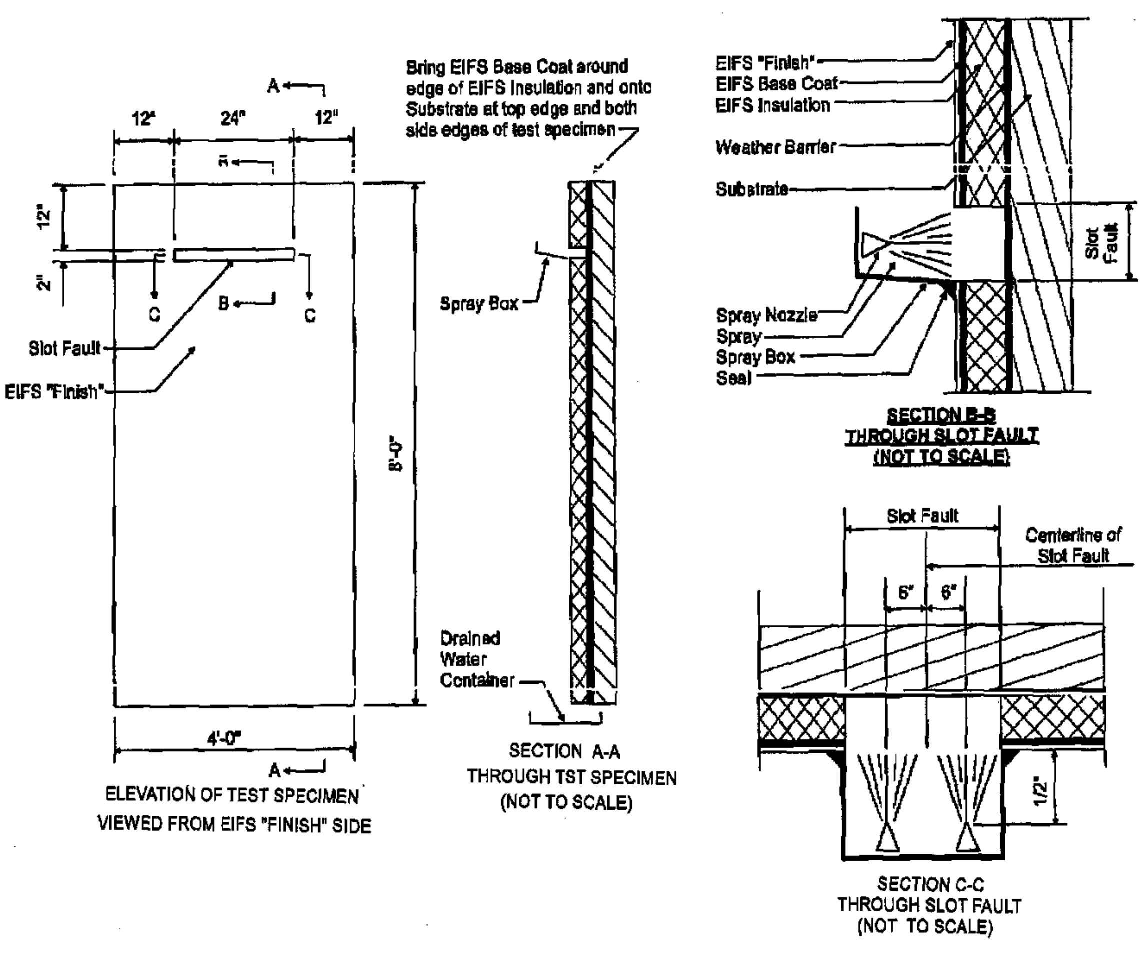


Figure 1 ASTM E2273-03 test set-up for EIFS walls

The test standard involves spraying water into a 24-inch wide slot of a 4 x 8 EIFS test wall 7 feet above the base. The spray rate is 106 g/min for 75 minutes (6.36 kg/h) for a total target mass of 7.950 kg. The water collected at the base of the wall is weighed at least 5 times during the test and one hour after spraying is halted. The difference between the mass of the assumed sprayed water and the water collected at the base permits calculation of the drainage efficiency. The difference between the two weights implies the amount of water retained by the wall. The water retained in the spray tray is counted as part of the retained water. Any water that may have impinged on the surface of the wall is also counted as retained.

The assumed sprayed water may not be accurately represented by the calibration procedure described in the test standard. One way to accurately determine the retained water is to continuously weigh the wall during the test and during the one-hour period that water may continue to drain out of the wall. Doing this presents some measurement difficulties but they are not insurmountable and several research laboratories have since done this in their research. Weighing of test walls throughout a test requires considerable care and may require changes in the method of delivery of the water to the wall.

The ASTM test method specifies that the test specimens be constructed in the same manner and materials as that used in actual construction. This wall size is large enough that simulation of a wall construction can be representative of construction delivered in the field. However, no specific mention is made of possible joint locations in the EPS relative to the spray tray.

Aside from reservations about the test method noted above, it is concluded that the approach is realistic. The test method does not specify any criteria for the drainage rate, drainage efficiency, retained water, or rate of dissipation of that retained water. However, the main approach can form the basis for establishing criteria for these parameters by others.

3.3 Additional Small Sample Tests

Recent unpublished results of drainage tests were provided here by M. Bomberg and M. Pazera based on exploratory tests done in 2002. These tests were performed on relatively small 610 x 610-mm EIFS wall samples. Tests on 36 wall samples of different constructions were done, both at a drainage rate of 1.0 L/h and 10 L/h. Half of the sample walls tested had no joints in the EPS, while half had a T-shaped joint representing a short vertical butt joint and a horizontal butt joint as shown in Figure 2. The average water retention for each set of three samples was provided for this review. All types except one involved mechanically attached EPS. None of the test samples had a final finish coating applied. The sample assemblies are described in Table 1. While the tests were exploratory, some conclusions can be drawn that are relevant to this review.

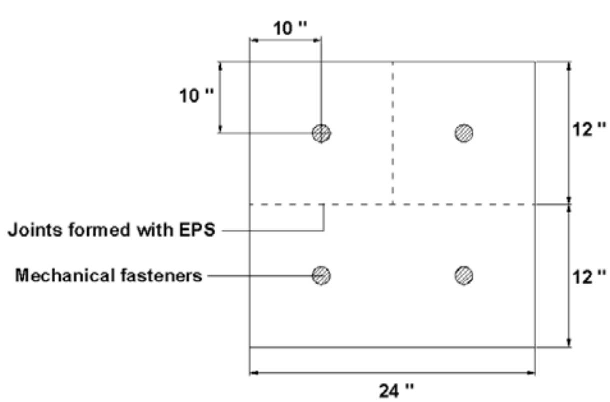


Figure 2 Construction of drainage test samples

Table 1 Materials used for test samples (description and codes)

	Substrate	WRB	Drainage/Attachment	Supplier	# of Specimens
9	OSB	Class P	None, M.F. EPS	C	6
10	OSB	Class P	M.F. EPS on Mat	C	6
11	OSB	Class P	None, M.F. EPS	A	6
13	OSB	Single Class C	M.F. EPS on Mat	B	6
14	OSB	Double Class C	None, M.F. EPS	B	6
15	Ext. gypsum	LA-WRB	Notch Adhesives 3/8”	A	6
				Total	36

* M.F. (Mechanically Fastened), P (Polyolefin house wrap), C (Cellulose based sheathing paper), LA-WPB (Liquid Applied Water Penetration Barrier) and OSB (Oriented Strand Board)

The 1.0 L/h test was done first, and the specimens were allowed to dry for 48 hours before the 10.0 L/h test was done. A trickle trough was used to input water into the drainage plane. According to a private communication, the walls returned to their original weight between tests. This implied that the majority of drying of retained water took place before the second test series was done. The summary of test results is provided in Tables 2 and 3 for the two rates of flow entry respectively.

Table 2 Moisture retention after the 1-L/h test for specimens with and without joints.

Specimen category no joints	Water Retention Mass (kg)	Specimen category with joints	Water Retention Mass (kg)	Increase in mass retained (%)
9	0.012	**9J**	0.028	133
10	0.012	**10J**	0.036	200
11	0.010	**11J**	0.044	340
13	0.010	**13J**	0.042	320
14	0.012	**14J**	0.044	267
15	0.013	**15J**	0.010	-

Table 3 Moisture retention after the 10-L/h test for specimens with and without joints.

Specimen category no joints	Water Retention Mass (kg)	Specimen category with joints	Water Retention Mass (kg)	Increase in mass retained (%)
9	0.012	**9J**	0.047	290
10	0.011	**10J**	0.028	155
11	0.019	**11J**	0.044	130
13	0.007	**13J**	0.040	470
14	0.012	**14J**	0.064	430
15	0.021	**15J**	0.040	90

The results provided in Tables 2 and 3 shows that the order of magnitude of water retained at both flow rates were similar. They also show that the specimens with joints retained more moisture. The retention of water by the specimens with LA-WPB (test 15) constructed for these tests was in the same order of magnitude as for tests involving membrane WRB between the EPS and the OSB or gypsum sheathing substrate. The higher rate of flow resulted in a slightly higher rate of retention, implying that a higher rate was more likely to deposit water into joints than would a smaller trickle of water. These results suggest the following:

- The difference between specimens with and without joints implies that water was retained in the spaces between EPS blocks. This is not a measure of the drainability of the space behind the EPS but is a measure of the possibility for water retention by joints in the system.
- The higher retention for some direct-applied specimens with joints may be a measure of the inability of the space provided to drain without backing up some hydraulic head which allowed more water to accumulate in the joints.
- The tests on samples without joints represent the drainage capability of the restricted space behind the EPS, not accounting for the effect of backing up of a hydraulic head on retention in joints.
- The LA-WPB samples (as constructed for these tests) did not necessarily possess better drainage than those having membrane WRBs.
- The data for dissipation rates of the retained moisture is not available for comment. It is however noted that the dissipation rate from the drainage space to the outside of the wall is a key factor to balance the rate of moisture transmission into the wall through the LA-WPB and the wood-based (or other) sheathing in cases where chronic wetting is likely.

Based on field experience, direct-applied EIFS using membrane WRBs have been shown to be more susceptible to damage in climates where there is considerable wind-driven rain despite the above noted drainability. While there is some advantage to use small test panels that can be constructed and tested economically, the major disadvantage is the difficulty of simulating the construction of the cladding system. Use of a 1200 x 2400-mm test panel can achieve this better than a smaller specimen.

3.4 Conclusions from the Above Reviews

These reviews led to decisions on test protocols and modifications introduced in the test method included in the CCMC Technical Guide for EIFS [3]. The main decisions affecting the test methods include:

- Weighing of the test wall to observe the weight change while wetting and drainage takes place including drying over an additional period of at least 48 hours.
- Use of a trickle trough based on that used for the small sample tests by Bomberg and Pazera for dispensing water into the drainage plane. This was further developed to allow the water droplets formed to be directed to specific layers at the top of the drainage cavity.
- Full-sized wall assemblies were built similar to those in the ASTM test standard to better simulate their as-built construction details.

Details for the development of the tests are discussed in the following section.

4 TEST PROTOCOLS

The test protocol employed was similar to that used in the ASTM E 2273-03 Test Standard [1] with the exceptions noted. Wall weight was continuously monitored throughout the test. Essentially, water was supplied to the drainage cavity for a 1-hr period. The completion of drainage of free water and the start of drying was monitored for the second hour and beyond for the following 48 hours.

4.1 Geometry of Test Wall Construction

The essential details describing the test wall construction are provided in Figures 3. The 4ft x 8ft (1.22 by 2.44 m) wood frames consisted of 38 x 89 mm (2 x 4) SPF S-DRY studs at about 400 mm (16 inches) spacing including a single bottom sill plate and double top plates. The latter were doubled to better take the handling stresses by hanging the wall from the top edge. The sheathing consisted of 11.1mm (7/16 inch) OSB manufactured to CSA O325. Two 1.22 by 1.22 m OSB sheathing panels were installed with a 3.2 mm gap between them as shown in Figure 3.

Nailing of the sheathing to the lumber framing was required at 150 mm around the perimeter of panels and 230 mm in the field of the panels. No blocking was employed at butt joints in the sheathing. The principal orientation (the primary orientation of the face strands) of the OSB panel was parallel to the studs. For this thickness of panel and stud spacing, this orientation is permitted to be parallel to or perpendicular to the stud direction. The panels were placed with the grade stamps facing the framing so the textured faces of the OSB to which the cladding was to be installed faced outward.

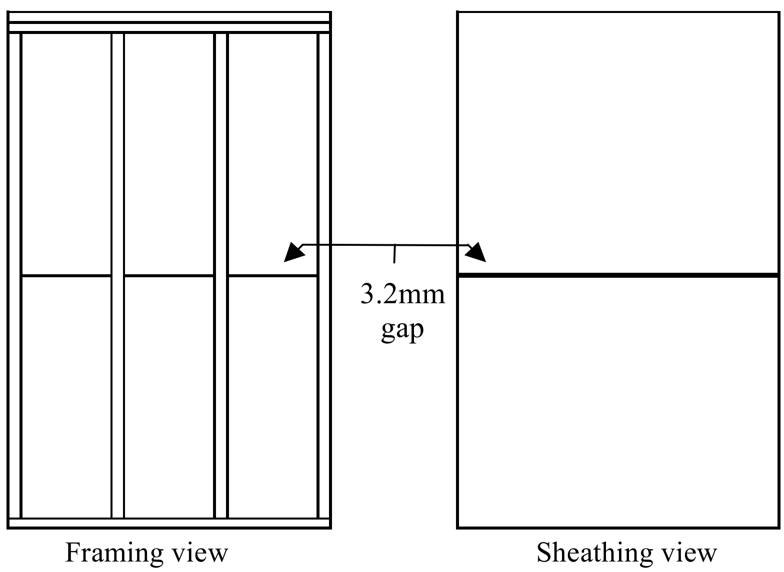


Figure 3 Framing and sheathing layout

The total height of cladding for most constructions was 2.134 m (7-feet). This dimension was based on the ASTM E 2273-03 test protocol. This permitted the top of the cladding, whatever its construction, to start about 152 mm (6-inches) down from the top of the wall for attachment of the trickle trough. The top of the cladding was straight for purposes of subsequent measurement of air flow characteristics. The boundary conditions for air flow out of the drainage cavity were thus simplified. Similarly, the bottom of the cladding was started about 152 mm from at the bottom of the framed wall to allow connection of a gutter to collect water draining from the wall. The height of cladding for drainage was thus maintained as for the ASTM E 2273-03 test protocol, without necessitating having to cut a slot into the cladding at that height. There were slight differences in total height of different siding products applied as a function of the lapped or locked siding dimensions.

4.2 Weight Measurement System

The test set-up built at Forintek is composed of three weight-balancing systems to allow up to three walls to be tested simultaneously. Weighing an entire test wall directly to the desired accuracy of 0.1 g or better is impractical. Consequently, the majority of the test wall weight is counterbalanced by other weights using a balance beam, and the weight of added water during the test was measured by an accurate load cell placed directly under each test wall. A diagrammatic representation of one balance system is shown in Figure 4. Photographs of the test set-up are shown in Appendix I.

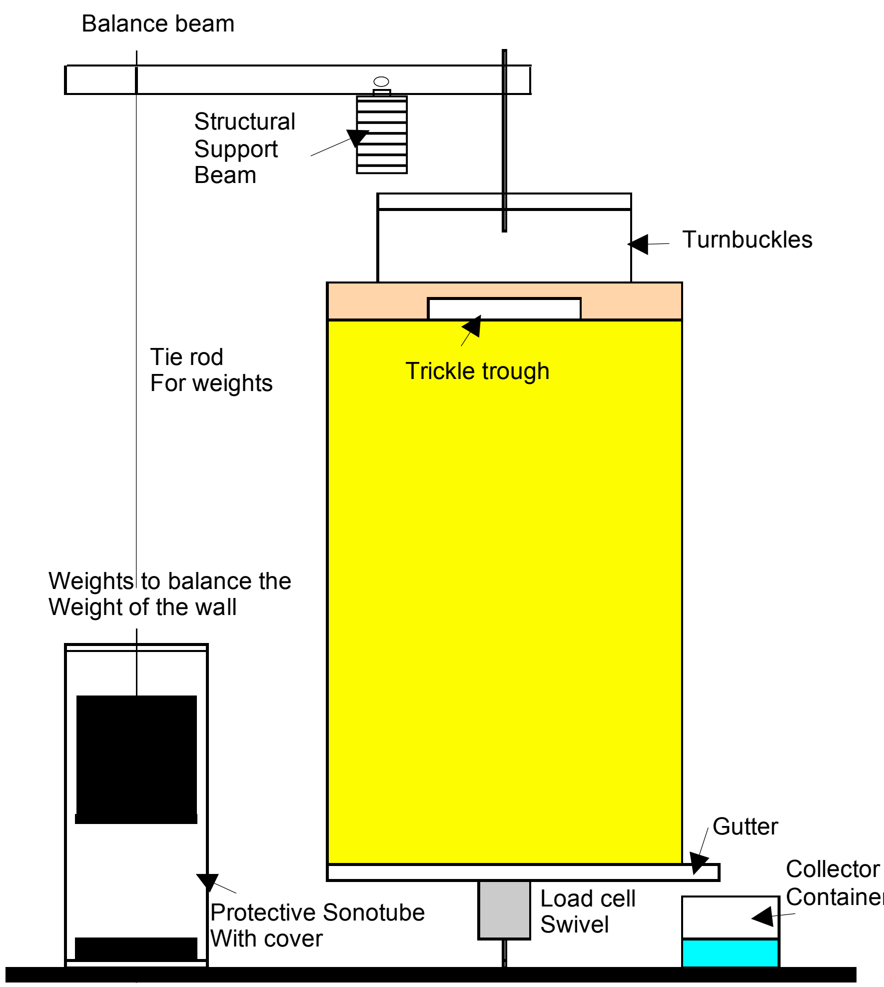


Figure 4 Balance beam set-up for monitoring wall weight

For test, each wall was hung from two metal plates positioned at the quarter-points of the wall width that were fastened to the top double wall plates. The position of these two suspension plates was adjustable to allow the test wall to hang perfectly plumb before allowing it to come in contact with the load cell. This was required to ensure that drainage would not be biased to flow more to one side of the wall than the other, and to have control of location of flow on the back or front of the drainage channel provided. Two adjustable vertical turnbuckles were mounted to a horizontal square tubing spreader bar that was hung from one end of a lever that supported the wall system (along with the metal plates) and provided for transverse levelling of the balance beam.

The pivot on the lever arm was provided by an axel rod supported by two (degreased) pillow blocks on top of a heavy glued laminated beam that was supported by heavy vertical steel columns anchored to the structural load floor. The axel rod passed through holes predrilled through the square tubing used as the lever arm. This provided a near frictionless pivot support for the balance beam.

On the other end of the balance beam, a round threaded rod was hung to support a platform on which weights are placed to counterbalance the weight of the wall. The suspended weights on this free-hanging rod were protected from disturbances caused by air movement or by accidental disturbance by enclosing that end of the counterbalance system within a 406 mm (16-inch) diameter Sonotube cylinder, the base of which was anchored to the floor. The load cells were positioned directly under the center of the bottom plate of the test wall. To make sure that the wall system sat uniformly on the load cell platen and to make up for lack of straightness of the bottom plate and the floor, a ball bearing roller was attached under the bottom plate of the wall which bore directly into a matching spherical dap in the transfer plate attached to the load cell. The load cell assembly rested on a steel H-section support on the floor of the test lab. The heights of materials and linkage lengths were adjusted so the balance beam was horizontal when the wall load was supported on the bearing. The weights used to balance the wall weight were adjusted so that sufficient preload was applied to the load cell to keep the wall in contact with the load cell during the test and to steady it against disturbances by persons walking past the set-up.

This arrangement allowed for non contact between the water delivery tubing and the test wall. The supporting frame bore the weight of the tubing and allowed the metered water to fall directly into the trickle trough attached to the test wall at the top edge of the cladding. The gravity drained trickle trough was maintained level throughout the test once it was set up.

Water passing though the drainage cavity or flowing down the face of the cladding in some instances was collected at the base of the wall by a sloped gutter. This water was directed into a pre-weighed container and the total quantity collected was weighed at the end of the test.

A typical change in weight measurement for a wall experiencing a 2-hr wetting/draining cycle is provided in Figure 5 below.

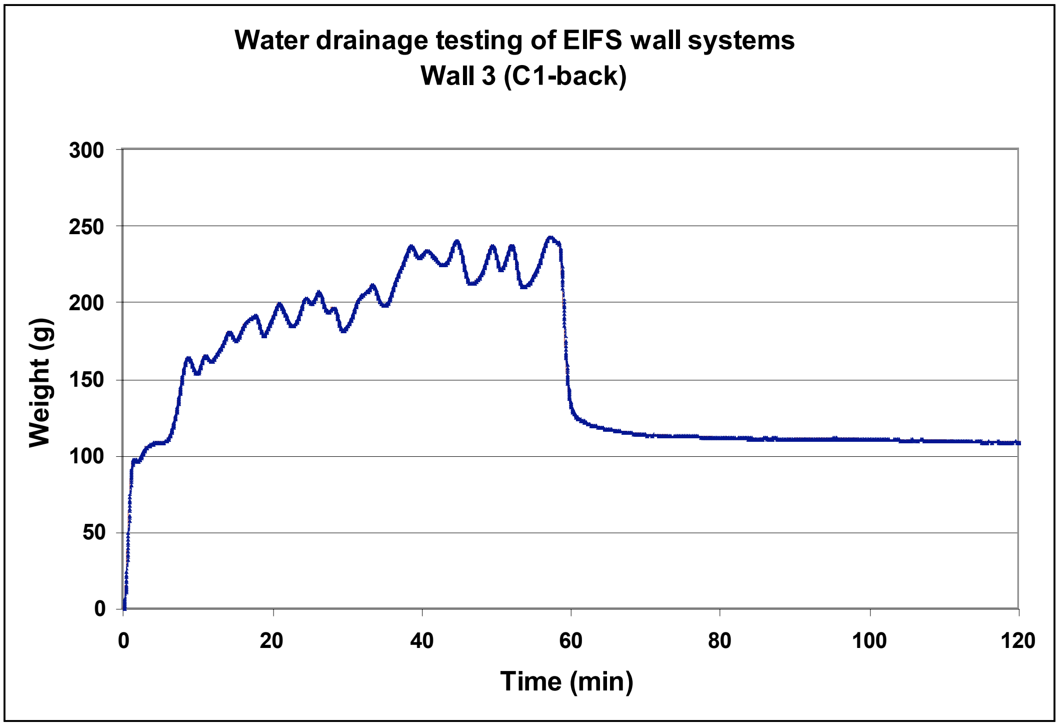


Figure 5 A typical load plot for a 2-hour wetting/draining cycle.

4.3 Rate of Water Intrusion

The rationale for direct intrusion of water behind the cladding is that the purpose of the work is to observe how much water is retained not how it got in. A well accepted justification for the amount of water to be used and its rate of entry to simulate some type of wetting event behind cladding does not exist. The main purpose of such an event is to observe relative performance, and potentially, retention relative to some arbitrary criterion for each class of construction that is considered to represent acceptable performance in practice.

While some previous tests established rates of flow based on maintaining a specific head of water, others established a specific rate of flow that might exist for water draining off a building during a storm. It may be rationally assumed that some of that water will find entry through a defect, such as a horizontal joint where caulking had been omitted or where it may have failed. The ASTM E 2237-03 test requirement is for water spray of 106 g/min for 75 minutes (6.36 kg/h) for a total target mass of 7.950 kg. Based on the small sample tests noted in Section 3.4 where water was trickled in at 1 L/hr and 10 L/hr, similar retention of water in EIFS walls was attained for both rates of wetting. The water pathways established in the space behind the cladding are unknown to begin with, but once established are likely to stay wetted and become the primary flow pathways for the duration of a test.

On the basis of the above information, the basis for the flow rate recommended for testing in the CCMC TG was 8 L/hr for one hour. This level is similar to that for the ASTM E 2237-03 test and is between the 1 L/h and 10 L/h rates examined by Bomberg and Pazera. On the basis of some preliminary testing it was concluded that the 8 L/h (133.33 g/min) represented an arbitrary yet defensible level of water entry for examining relative performance of test walls.

4.4 To Spray or to Trickle

The ASTM E 2237-03 test standard employed two spray heads in a spray tray 610 mm wide set into a slot in the EIFS construction one foot (305 mm) below the top of the 8 foot high sample wall (2438 mm). The spray is directed mainly at the back of the wall so that it would drain down into the space between the EPS foam and the WRB materials that provide backup to the EIFS installation. If there was insufficient ability to accept the prescribed flow rate, water would pond in the tray and establish a head to allow the supplied water to drain faster without spilling over the tray. The spray heads, piping and tubing were attached to the wall in a fixed position relative to the wall and spray tray. The ASTM E 2237-03 method does not involve weighing of the wall, so the weight of spray heads and water supply feed lines is not a matter for concern.

The trickle trough used by Bomberg and Pazera for the small sample tests was based on earlier experience at IRC where a similar approach was used. The trickle trough had small holes spaced at 20 mm and the water supply allowed water to pour from tubing into the trough where a lake formed to supply a sufficient gravity head over each hole to provide a uniform rate of dripping for every hole. Water not drained into the wall sample at the end of the test was mopped up and subtracted from the total amount provided. This approach did not impose additional load on the test wall sample and would have allowed the specimen weights to be monitored continuously. To supply a uniform trickle rate from all holes requires that the "lake" is uniform in depth. For that to occur, the trickle trough needs to be held in a horizontal position throughout the test.

It was concluded that trickle troughs used for this project would be similar to those used by Bomberg and Pazera but that the water delivered to the wall would not require the troughs to be sealed to the cladding. It was expected that a water head would not need to be developed to force the water into the space behind the cladding. The trough position was raised 25 mm above the top edge of the cladding so as to not restrict air movement out of the drainage space and hence to allow subsequent drying of the wall across the full width of the cladding.

4.5 Water flow delivery

Two systems of water flow delivery were tried and both are described in this section. The first system used was employed for the first phase of the first test series on EIFS wall systems. The second flow delivery system was an improvement which was used for all other tests done on all types of cladding in this test program including the retests of the EIFS walls.

The first system of controlling flow involved using a Watts pressure regulator Model 25AUB with a capacity of 25-75 psi and a Swagelok linear flow controller SS-4mg to control the water pressure and flow to the supply tubing from the mains. The mean flow rate was evaluated by continuous weighing of water outflow to a container on an electronic balance. The flow rate data was acquired and displayed on a computer monitor throughout a period preceding the wall test. The flow rate calibration monitoring varied from a half hour to a 2-hour period. This assured that the temperature of all components attained a constant temperature prior to conducting a test. The stability of mass of flow was high. Flow was directed to each wall in turn, and the time during which water was fed to each wall at the calibrated rate was used to calculate the total weight of water provided to it.

During this first testing phase, it was noted that the exact timing of flow entry could not be exactly assured and the continuous weight measurements using the load cells gave a better record of the exact timing. To provide for a more accurate delivery system that would act as an independent check on the load cell measurements, the following delivery system was then developed.

An air pressure control system was employed for control and the mass flow rate delivered to the wall under test was continuously monitored and cumulated. Twelve (12) kg of water tempered at room temperature was put in a glass carboy which was continuously weighted by a calibrated scale (Model Mettler PM 30000-k) having a precision level of 0.1g with the output stored in a computer file. Controlled air pressure was supplied to this container and water from within it was expelled through tubing to the wall being wetted. The change in weight of the carboy was monitored on a minute by minute basis and the weight increments were stored in a computer file. Just before starting the test, a tare offset was applied to the scale reading so the exact amount of water drained into a specific wall during a test was known precisely. The rate of flow provided was set so that 8 kg of water would be delivered to the test wall in 1 hour. When the total water input reached 8 kg a shut off valve in the tubing was closed and flow into the trickle trough stopped immediately.

The use of compressed air to force water to flow from the carboy to the test walls adds some weight to the carboy. As a check on the weight of compressed air that was added the carboy, the air pressure was measured and found to be 11 psi. At a maximum displacement of 8 L, the total weight of air added to the carboy, assuming it to be at ambient temperature, was calculated to be 18.1 g. This represents 0.23% of the total assumed flow during the 1-hour wetting phase of the test. If the actual total flow were to be used for calculations of water retention, this correction would have to be applied. However, continuous monitoring of the wall weight is the primary measure relied on to assess retention. In this case, the flow rate information is largely an independent check on the retained water being the difference between the weight of water delivered to a wall and the weight of water collected at the bottom of the wall. This correction is required for that calculation.

Twelve (12) kg of water were put in a glass carboy which was continuously weighed. This amount of water was sufficient for testing one wall. To make certain that the water used for each wall was at the same ambient temperature, another glass carboy was filled with 20 kg of water in sufficient time before test to reach those same conditions. This amount of water was sufficient for testing the remaining two walls when three test walls were assessed in the same test period.

4.6 Trickle Trough Design

The design of the trickle trough went through several iterations. The intent of the design was to allow flow to drip into the drainage plane in the wall and be relatively uniform across the width of the trough. For this, the finger flow from each drainage hole needed to be as uniform as possible. Because of the resistance to flow through small holes and wetting of surfaces on which water flowed, it was found that considerable care was required to achieve this desired goal. The installation of the trickle trough on the test wall had to be horizontal for the duration of the test. The weight measuring system adopted ensured that the plumbed position of the test wall would not change during the test and provided the necessary assurance for maintaining even gravity flow from this trickle trough design.

The initial trickle trough used to distribute water for drainage into the wall was 610 mm long (24 inches) and 95 mm wide (3.75 inches) with a bottom slope of 20%. Holes with a diameter of 2 mm (0.08 inch) were drilled every 38 mm (1.5 inch) c/c. Plexiglas material was used to fabricate the trickle trough.

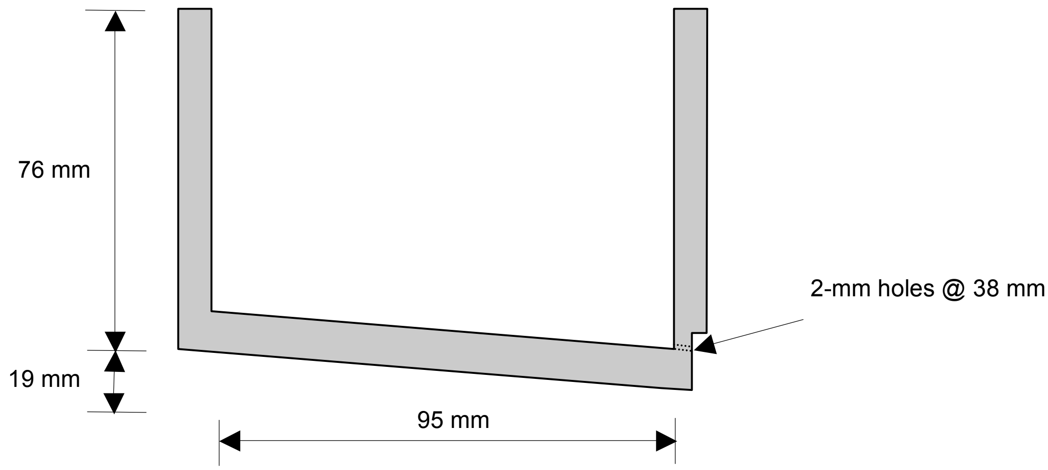


Figure 6   Cross-section through the trickle trough

As water exited the 2-mm holes and slid downward, surface tension held the water to the face of the machined notch in the backplane. The water drops then formed at the bottom drip edge. During initial development it was found that the water did not always move directly downward but was able to skew laterally, and sometimes join with flow from other holes. To assure minimum adhesion, the wetting angle of the Plexiglas surfaces over which water flowed was altered by lightly smearing the surface with vacuum grease. This tended to prevent the flow from wandering from the intended path. This design is shown in Figure 6. This design was used for the initial test series on EIFS walls.

Further improvements were then developed. To assure that the droplets formed at a leading edge in a more uniform way, a tapered drip edge was provided below the bottom of the trickle trough. Additionally, to assure that the head of water provided to the drip holes was greater than initially provided (based on the slope of the bottom of the trough) an insert was placed at the bottom of the trough. As water flowed into the trough, a deeper "lake" of water formed above the location of the drip holes. The size of droplets forming at the leading edge of the trough depends on surface tension. The sharper the tapered drip edge, the smaller and more precisely located those drops become. A narrow thin plastic sheet was then bonded to the drip edge which extended below the Plexiglas drip edge. Droplets forming on the leading edge were smaller and dripped off more precisely on the centerline of that sheet. This design is shown in Figure 7 and was the one used for all the repeat tests on EIFS walls and all other walls in the test program.

Figure 7 An improved trickle trough design.

The design of the trickle drainage box permitted liquid water to be delivered directly to the drainage cavity with some degree of control. It is possible to permit selective delivery of the water to the back face of the cladding or to the front face of the WRB, or to the front face of the base layer of WRB if desired (when there are two layers). This can be accomplished by tilting the trickle trough away from the backplane of the wall or towards it. The wall can also be tilted slightly, although this could bias the collection of water in certain geometric features and this is to be avoided. Directing the flow of water by tilting the trickle trough allows the water droplets to drain preferentially against the surface of interest.

The ASTM test is relatively indiscriminate on this point because it involves use of spray heads although that can be partially addressed in how the drainage trough is attached to the wall. Currently, that test favours deposition of the sprayed water against the WRB.

The width of the drainage trickle box is 610 mm which is about half the width of the test wall. This simulates an entry defect such as might occur under a window. Drainage within the central width of the wall does not engage edge effects to the same degree that was found important by others using relatively narrow drainage specimens.

From the point of view of computer modeling of the dissipation rates from a local leak, whether it is a point source, or a line source as described above, a full 3-D analysis capability is probably required. If however the trickle trough is as wide as the full width of the test wall, then a 2-D model can more easily be used for evaluating the theoretical behaviour of the wall when subjected to the kind of drainage test to be carried out in this test program, and potentially provide information that might be more useful for other computer simulations. It is not possible to say how different these results might be. For some systems, horizontal moisture gradients of retained moisture are expected to occur. Other, more open, systems are likely to provide a very direct vertical flow path. However, the distribution of moisture dissipation may have 3-D aspects to it, and it is expected that few if any computer models could handle that problem adequately. A full width trickle trough may provide information that would be less ambiguous to extrapolate to other circumstances however it would be more difficult to establish uniform flow across that width of wall in this manner.

In either case, even if liquid water tends to wet the wall uniformly without spreading laterally, the dissipation of moisture by evaporation and dissipation will occur in whatever direction it is possible. In reality, both depending on the system design and the complexity of air movement, both vertical and lateral dispersion of the moist air will take place.

4.7 Entry of Water

As a closing comment on the above test procedure, rather then cutting a slot in the EIFS wall for entry of water, it made more sense to provide entry at the top of whatever height of cladding is used. The reason for this is that measurement of other properties, such as air flow characteristics of the drainage cavity, is more easily accomplished for walls with a uniform top edge. The following sections describe the development of the test assemblies, the instrumentation, water flow delivery and test procedures.

4.8 Load Instrumentation and Data Acquisition

The load cells used initially (Tedea-Huntleigh model 1040) had a rated capacity of 7 kg. The acquisition system included a Tracker series 240 signal conditioner with an 18 bit A/D to provide a high degree of resolution, and a RS 485 to RS 232 output to transfer the data to a laptop computer. The software used to control sampling rate was designed by Intertechnology. Subsequently, after the initial test series carried out on EIFS walls provided for this investigation, the low capacity load cells were replaced with higher capacity load cells of the same design. These were Tedea-Huntleigh Model 9010 load cells having a rated capacity of 35 kg. The higher capacity load cells permitted applying a higher tare load to provide stability to the wall under test.

All load cells were sampled simultaneously at the rate of 20 samples per second, averaged over each second and, for the first 2 hours of test, were stored in a computer file at that rate for each load cell. The time at which the reading took place was also recorded. Each test wall was wetted in turn, so the data file ended up containing about 5 hours of data at this rate. Once the last of the three test walls had completed the second hour of its test, sampling was stopped and a new file was created in which the sampling continued at the rate of 20 samples a second, but was averaged over 20 seconds and stored at that rate for the remaining 48 hours of the test. The real time for beginning and end of each file was recorded and this allowed the two files to be merged for plotting and analysis. The data acquisition software used did not permit on-line alteration of the sampling rate.

4.9 Load Cell Calibration Validations

Initially, the validation of the output from the load cells was done prior to each test and for each wall with part of the wall weight acting as a tare load. As the system stabilised with the preload applied, load cell validation was done using calibrated reference weights. Each weight (50 g) was put on top of the bottom sill plate for a period of 1 minute and was then removed before placing the next higher weight (or weight combinations). Recordings were taken continuously throughout this process and the resulting information was analysed to determine whether any adjustments were required to the recorded data to account for differences in calibration from the preset values that had been initially input to the data acquisition system. The weights were applied in 50 g increments to a total of 500 g. In subsequent testing, a single weight of 500 g used for routine confirmation that there had been no change in the load cell calibrations.

Thin shims were also used between the free ends of the cantilever-design load cells and the base plate to prevent accidental over-compression of the load cells. The load cells are designed for the maximum safe load limit when the cantilever end touched the base plate to which it was mounted. However, it was desirable that load be limited to well below capacity. This also ensured that accidental overload during handling of the wall would not occur. In all cases, there was no need to make any adjustment to the calibration.

4.10 Moisture Distribution Measurements

Moisture dissipates from the region where it is retained, particularly if the cladding system tends to restrict the diffusion of moisture through it or through the drainage path. Attempting to obtain a large number of readings with a resistance-based moisture meter was not practical nor was it likely to be useful. Compounding the difficulty of getting reliable readings is that moisture gradients cannot be evaluated easily. The wood based sheathing and the cladding, if it is absorbent, were the most vulnerable to moisture pickup. The expectation was that very little moisture would be transmitted into the OSB sheathing for the short test periods planned.

Since there will be gradients and it will not be possible to accurately quantify the total amount of moisture in each layer (both the absorbed and adhered moisture) it is still of interest have some measure that can show the distribution of moisture from one drainage test to another. To this end, a capacitance based moisture meter was used to detect moisture in the drainage space and the materials bounding it by detecting it through the back of the OSB sheathing. This necessitated that the back of the test walls be accessible and not be covered by polyethylene sheeting as originally planned to prevent moisture gain of the wood framing and sheathing from the lab environment. The moisture meter used was designed for assessing the moisture content of lumber. The capacitance field generated by the instrument was estimated to extend beyond the 11.1 mm OSB sheathing thickness and would detect moisture in some of the materials in that space and beyond.

The Wagner L620 meter used had sufficient data storage capacity to allow numerous readings to be taken. The meter was employed to take readings on a spacing of 150 mm in each vertical scan. Two vertical scans per stud space were taken for a total of 6 scans resulting in collection of 90 moisture content readings per wall, both before and after the drainage test. The moisture readings were taken by laying each wall horizontally for ease of taking the readings. The axis of the meter was aligned parallel to the height of the wall while taking readings. For practical reasons, the readings after the drainage test were obtained only after the walls were dismounted at the end of the 48-hr drying period. Hence, the opportunity to see the distribution of retained water at its maximum level was lost for the wetting/drying protocol selected. The meter and its use are shown in Figure 8 (a) and (b).

(a) (b)

Figure 8 Photo of the Wagner meter and its use to measure the moisture in a test wall on a marked grid on the back of the OSB sheathing.

The spacing grid used for the test walls is shown in Figure 9.

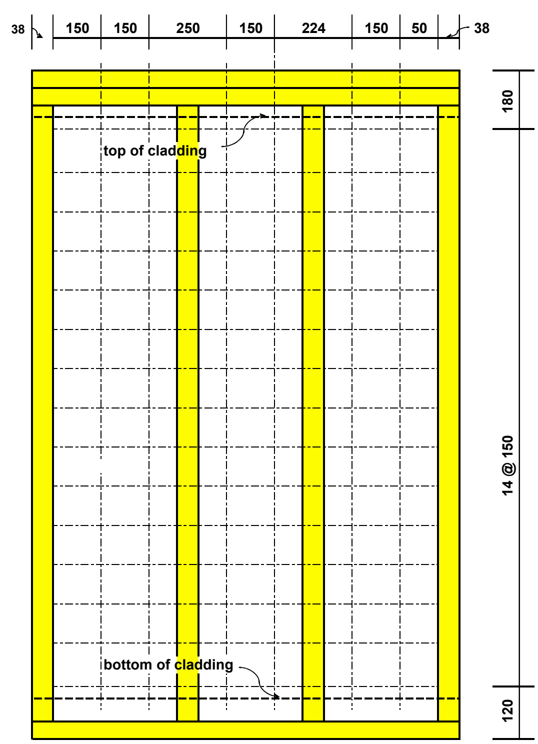


Figure 9 Typical measurement grid for moisture content measurements

The contour mapping was performed on the change in moisture content before and after drainage testing using Statistica software, Release 7.0. It was assumed that the edge moisture content was the same as the first line of measurements in from each vertical edge. The contour levels were fitted using a distance weighted least squares algorithm. An example of a typical resulting display is shown in Figure 10 without further comment at this time. These moisture readings provide a measure of the quantity of water present and are not a true measure of moisture content in any particular layer or material.

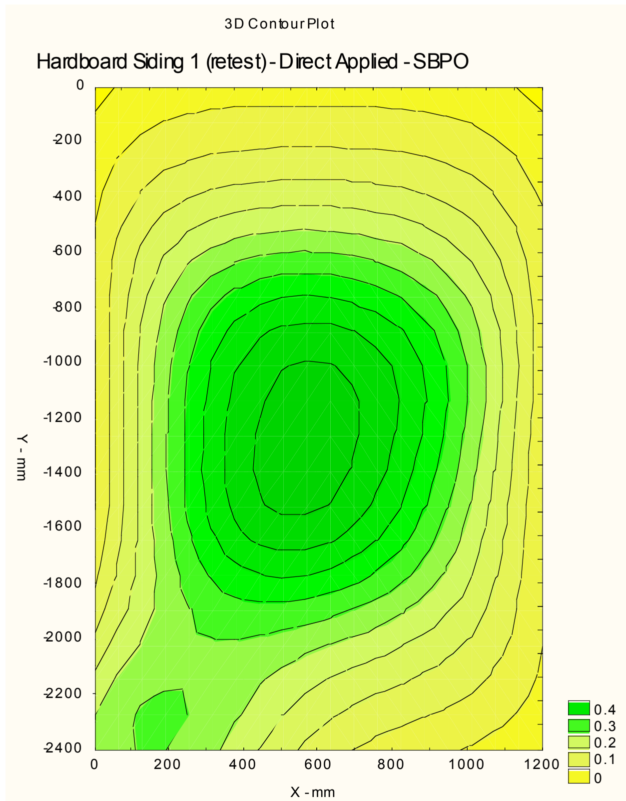


Figure 10 Typical moisture content contours

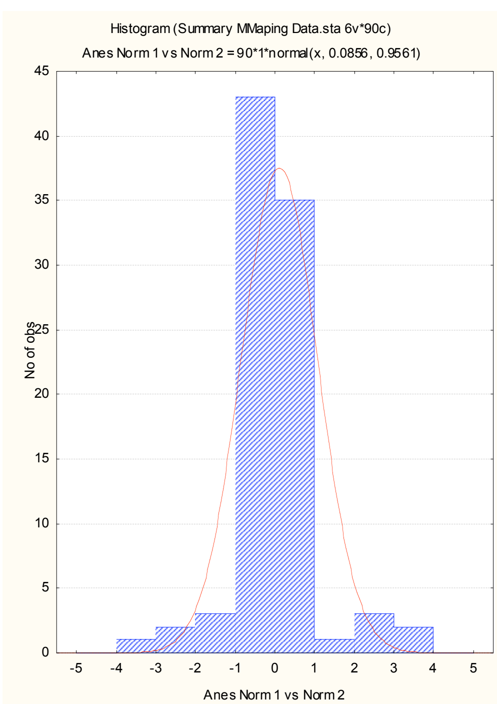
Since each moisture content difference depends on having the contact plate of the Wagner meter positioned at exactly the same location for before and after readings, the ability of the operator to do repeated measurements from one time to another was investigated. In all cases, the MC differences between each paired sets of 90 readings should all have been zero when repeated immediately after the first set of measurements on the same wall with no change in moisture content possible.

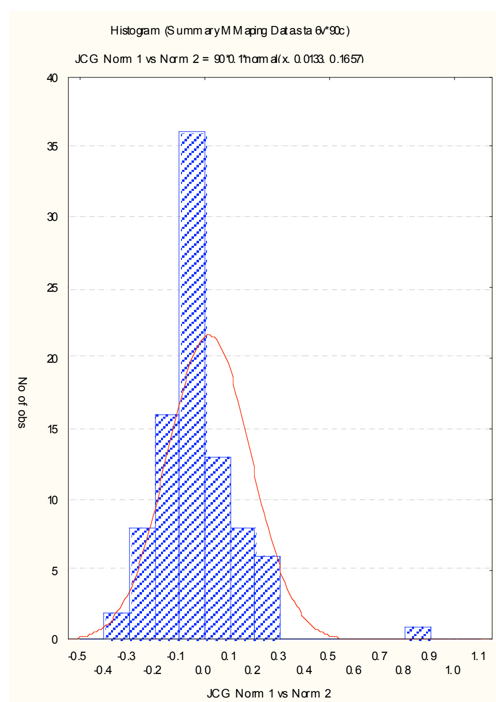
Two different operators were assessed by examining the moisture differentials from one time to another for a dry wall. The instructions given were that they proceed in a "normal" manner with respect to the speed of securing a complete set of readings. Two complete sets were obtaining in this way. This was followed by securing a set of readings where they took more time and a period of 4 seconds was allowed to elapse once they had moved the instrument to the next position. The time taken to set up and obtain 90 readings was a time consuming operation and there was a possibility that a rushed set of readings might be less reliable.

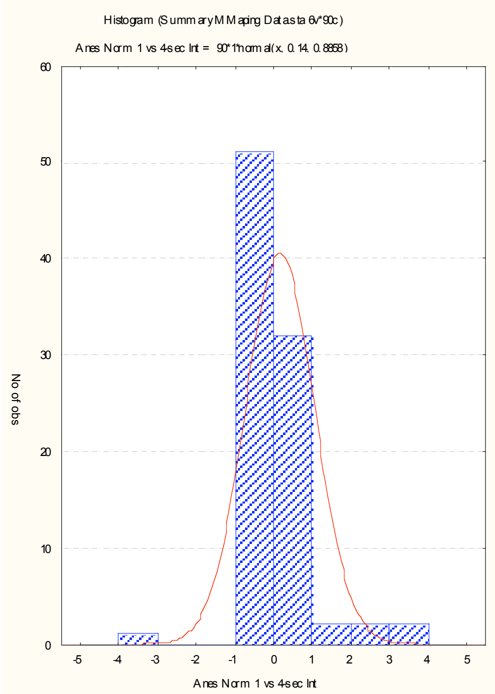
Distributions between repeated sets (Norm 1 vs. Norm 2) for both operators are shown in Figure 11. These show that the range for "Anes" was wider than for "JCG" in these particular data sets. The differences are both positive and negative implying that if each set were equally randomly in error from some true value, then their differences would be positive or negative. Many points were identically zero, but the range could be high. Also shown in Figure 11 are the differences between a "Norm" set of readings and a set with "4-sec" delays. The distributions for the operators are more similar but the ranges are just as broad. Additional data sets taken by these two operators revealed similar wide ranges. The conclusion reached was that differences between a "before wetting" set of readings and an "after wetting" set of readings should have all negative differences truncated at zero. A negative difference would imply that drying had taken place and this was highly unlikely in a wetting environment.

The second question examined was whether the position of the operator's body relative to the instrument would have an effect. When taking measurements using resistance-based meters on very dry material, the capacitance effect of the operator's presence can have a significant effect on the readings if the operator's body is not grounded. In this case, readings were taken with the operator's body close to the instrument, and then repeated with the body held at arms length away from it. There was no significant difference between the results for the two operators. Out of 20 comparisons, 11 sets were identical, 7 sets were 0.1 to 0.2 %MC different and one comparison was 1% MC different. Differences may have been caused by a shift in the position of the meter rather than being an effect related to the position of the operator's body. It was concluded that error in placement of the instrument had more effect than whether the operator's presence was close to the instrument or not. A maximum reading error of about 0.2% could be expected.

Finally, in reviewing the locations where high apparent moisture content differences were found, it was concluded that the large differences occurred at position #15 in each vertical scan. This was at the bottom of the wall where the upstanding leg of the metal gutter was close to those locations. Metal screws attaching the gutter penetrated the sheathing may also have affected the readings because they interfered with the positions of the grid points. It was concluded that it would be preferable to loose some information at that location than to have false data that would generate incorrect moisture content contours. To that end, all moisture readings at position 14 were duplicated into the position 15 location. In a similar way, given that the moisture content at the edges of the wall were likely similar to the MC at the first and last vertical grid line, these were duplicated at the 0 and 1200 mm positions respectively. The upper right hand corner of the cladding represented the zero coordinates as seem from the back of the wall. Finally, the data was inverted so that the moisture contours would appear as if observed by looking at the cladding on the front of the wall.







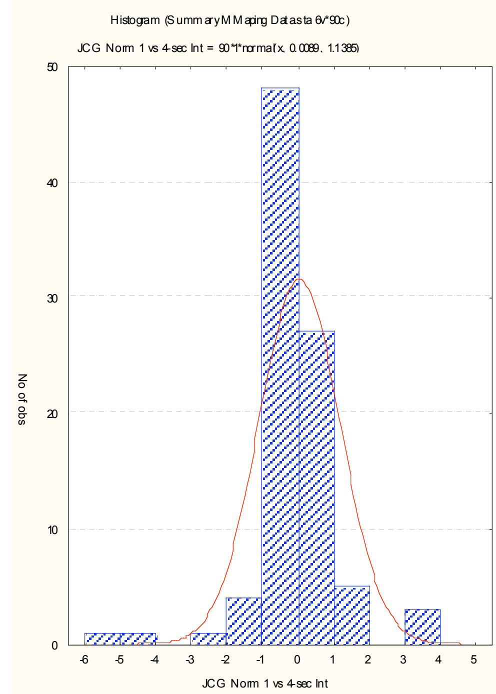


Figure 11 Histograms of differences between sets of measurements for two operators, both when a "Normal" rate of readings were taken, and when more time was allowed with 4-sec pauses.

4.11 Environmental Conditions and Measurements

The Forintek laboratory in which this study was performed is normally very well maintained at 20 ºC and 50% RH on a year-round basis, except temporarily when the large laboratory doors are opened for movement of materials into the lab from outside. At the above conditions, lumber attains a moisture content of 10% (dry weight basis) and OSB at about 8% on the same basis. Prior to test, walls were allowed to equilibrate to minimize pickup or loss of moisture from the air, particularly during the drying phase of the tests.

Experience from initial testing of EIFS walls had shown that maintenance of steady conditions depended on the time of the year, and the building dynamics. At certain times, and in certain locations when steady state conditions were desired (during the 48 hour drying period), there was variation in the weight of walls in one exposed test location. Cycling of the air conditioning system was higher in general during the colder periods of the year. The absorption of excess moisture from the laboratory air during the drying period was undesirable, given the stated goals of attempting to follow the dissipation of retained water to low levels at isothermal conditions.

Two actions were attempted to minimize this. The first action was to place a shroud between the walls most affected and the region of the laboratory where most of the air flow causing these changes was occurring. The second action was to divert the air flow from the large air supply ducts away from the test site within the large room in which this work was undertaken. Both of these attempts were only partly successful and were eventually dropped. Some EIFS wall tests during this initial phase of tests were found to have experienced excessive variation in weight that prevented steady state drying to be achieved. When this happened, these walls were scheduled for retest when conditions were steady.

EIFS walls were much more susceptible to these weight variations than other materials which suggested that the exposed wood-framed backs of the walls were not the primary moisture sinks.

The temperature (T) and relative humidity (RH) at each wall and in its vicinity was monitored. The RH sensors were Honeywell model HIH 3605 and the thermisters were from Analog Devices model AD592AN. Four T and RH sensors were installed at the top of each wall just above the top of the cladding, and four other sensor pairs were installed in the vicinity near the floor and above the test area. The sensor positions are shown in Figure 12(a) and 12(b) and a typical distribution of RH measured at the top of one wall during a test are shown in Figure 13. Sensor pair P15, while shown near one of the columns in Figure 12 (b) was actually located at that height on a table close to the set-up. Sensor pairs P12 and P13 are not in the plane of the frame, but are shown circled in Appendix I, Figure I-2.

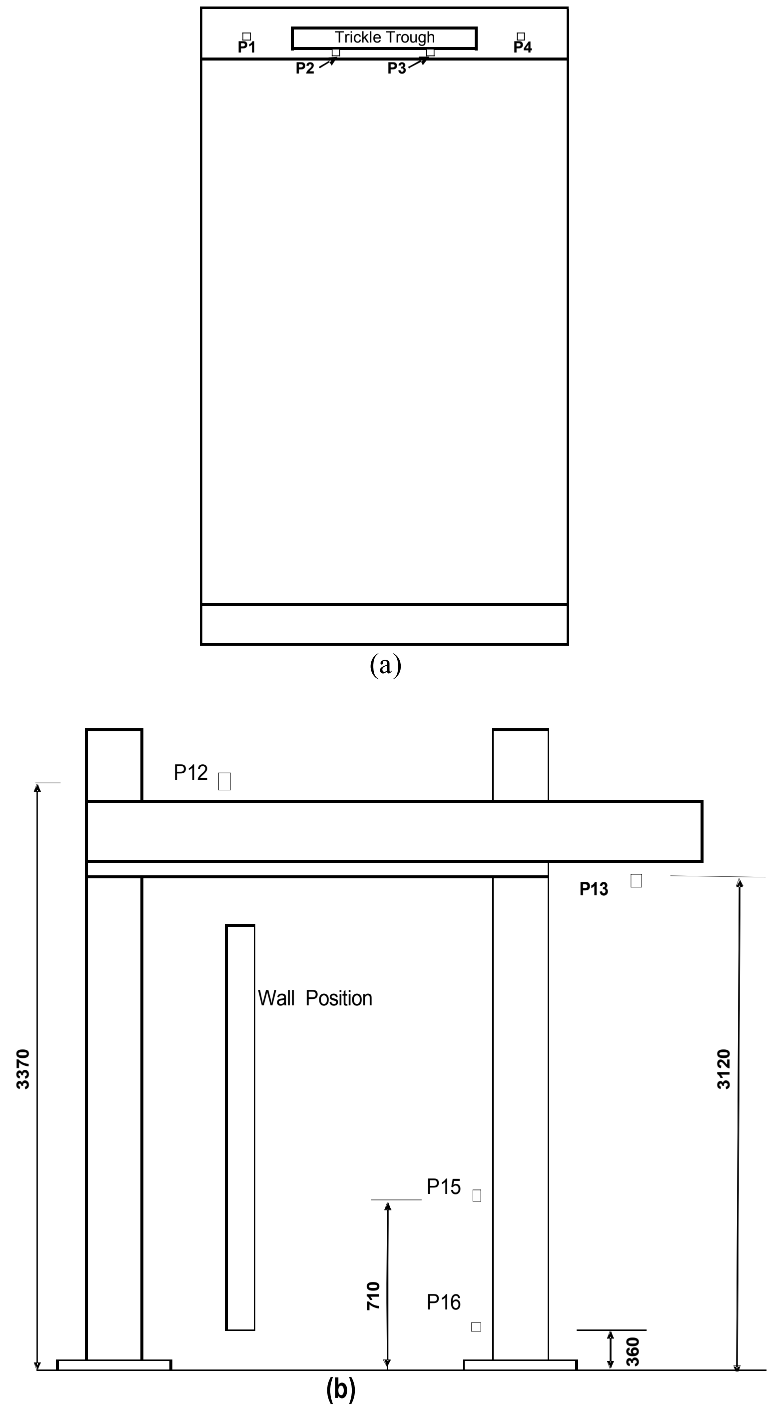


Figure 12 Location of temperature and relative humidity sensors shown located on a typical wall in (a), and the external sensors in the vicinity of the set-up in (b)

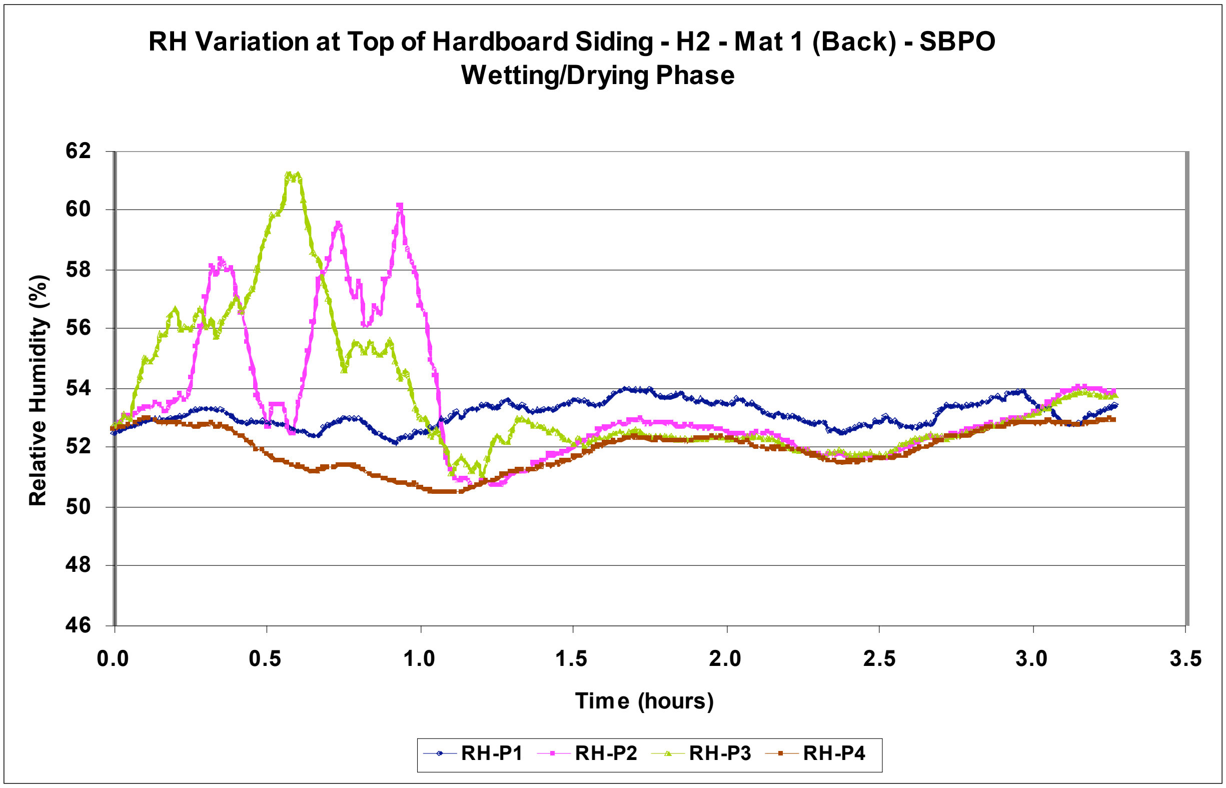


Figure 13 Typical relative humidity variation plots during the 2-hr test

5 FINAL TEST PROTOCOLS

5.1 Test Procedure

Prior to mounting the walls in the test frames, each wall was laid flat, and the initial moisture content of the wall was determined on the grid marked on the back of the OSB. The walls were then mounted in the test frame, plumbed, and the trickle troughs installed and levelled. The load cell calibration validation was then performed and the walls were ready for the wetting test.

The water was drained through the trickle trough into the top of the drainage plane of each wall in turn for a period of 1 hour. Approximately 8 litres of water were provided at a flow rate of 133g/min. The drained water was collected by the gutter installed at the bottom of the wall and drained into a pre-weighed container.

After 1 hour of supplying water at the calibrated rate, the water flow to that wall was turned off and the delivery of water was directed to the next wall to be tested. Each wall specimen was allowed to drain and monitoring at the high sampling rate was continued for at least an additional hour. The water remaining in the trickle trough at this time and in the collection gutter was mopped up with paper tissues. The water collected over this period was weighted with the container, as were the tissues used to mop up the gutter and trickle trough. This information, together with the load cell data, was used to determine the quantity of water that was retained within the wall at the end of the two-hour test period as a check on the weight measurements. The primary means for assessing the quantity of retained water, as defined at the end of the second hour of the test, and at the end of drying at 48 hours, were the weight measuring records.

At the conclusion of these tests, the walls were dismounted, laid flat, and the moisture contents were again determined at the same test points and in the same order, to allow the two data sets to be subtracted to determine if there had been any detectable change in observed moisture content as a percentage of dry mass for some arbitrary wood species (Aspen in this case). The walls were then set aside to complete their drying so that they would be available if a retest was required.

In the case of cladding systems that were not direct-applied, two tests were typically done. The initial drainage test in these cases involved directing the trickles to the surface of the WRB or LA-WPB whatever material was used in that situation. After at least 7 days of drying, the wall was retested by directing the trickles to run down the back of the cladding. In the case of the direct-applied siding the water was simply supplied into the middle of the space at the top of the cladding which was held open by 4 mm.

5.2 Air Flow Characterization on Drainage Cavities

As noted in the overall description of the project, there are additional important parameters that are needed to understand the behaviour of wall systems that experience wetting and drying, it is necessary that the air flow paths be characterized. Air flow measurements were made to characterize the flow paths for walls that had defined drainage cavities. These tests will be fully described in Part 6 of this report series. This data will enable these walls to be characterized for computer modeling. There is also little information about flow characteristics at flashing details, although theoretical measures can be found in the literature which can be incorporated into appropriate computer models. Where possible, depending on the degree of resistance to flow, these values were determined as well.

Air flow characteristics were only measured at the conclusion of the drainage tests. For some systems, especially those involving flexible WRB membranes, the air flow measurements may have been affected by wetting and drying if wrinkling of the material occurred. However, for this study only the final state of the drainage cavity has been measured.

5.3 Vapour Permeability and Air Flow Testing of Joints

To more fully understand the behaviour of walls to retain and dissipate moisture, some understanding of the vapour diffusivity of some of the materials is needed. Testing along these lines was performed on one-meter square samples of siding systems. While some information is available from existing databases of the air and permeability of materials, it is not available for gaps between components. For example, air permeability is very small for most materials and wood siding is no exception. The effect of permeability through joints has been largely ignored. Vinyl siding is not listed even though it is one of the most widely used materials. Its thermal resistance properties are insignificant; however, its air tightness and vapour permeability are restrictive to moisture exchange. Also, the vapour permeability of small joints between lapped siding and between locked vinyl siding are critical to moisture movement when the material is essentially impermeable.

The methodology used and the results for the vapour and air permeability tests on joints using these simulated wall specimens are provided in Part 7 of this report series.

6 CONCLUSIONS

The methodologies described in this report were addressed to provide information on the drainage, retention, and dissipation of moisture that was presumed to have been deposited in drainage cavities (or lack of them) from outside sources. The interest is not how the water got in, but how it can be removed. The following behavioural effects were considered:

$ characteristics of the drainage/ventilation cavity in retaining moisture
$ the rate at which moisture can dissipate as affected by various factors
$ air flow resistance within the drainage/ventilation channel, and at the entry and exits of flow
$ the air flow resistance through intermediate joints in the cladding
$ the vapour permeance of typical intermediate joints in certain cladding systems.

The number of variables and effects is large, and it is expected that behaviour will be different for different wall systems. The test program is aimed to seek understanding about the more important factors, and how different types of cladding systems perform under similar wetting loads.

While there is diversity in the construction methods and materials used it was hoped that much can be learned that will help guide how studies of this type might best be conducted in the future. It is unlikely that any one test can be considered representative of a particular class of cladding. However it was expected that at least some knowledge about typical performance of different systems would be obtained through this work.

7 REFERENCES

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3. CCMC. 2004. Technical Guide for External Insulation and Finish Systems, Masterformat No. 07240, Appendix A4 "Exterior Insulation and Finish Systems (EIFS), Class PB on Wood Substrates".

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5. Timothy D. Tonyan, Kevin W. Moyer, and William C. Brown “Water Management and Moisture Transport in Direct-Applied and EIFS Wall Assemblies”, Journal of Testing and Materials, Vol. 27, No. 3, May 1999, pp 219-230.

6. ICC Evaluation Service 2004. Acceptance Criteria for EIFS Clad Drainage Wall Assemblies. AC235.

APPENDIX I

Photos of Test Set-up

Figure I-1: Overview of test set-up for three test walls

Figure I-2: View of upper portion of three test walls showing the balance beams supported by the heavy laminated beam. Circled areas locate external RH and T sensors in the test area.

Figure I-3: Close up of the distribution bar supporting the upper edge of a test wall.

Figure I-4: Close-up of one pickup point designed to permit adjustment so that the wall is plumb before resting it on the load cell bearing.

Figure I-5: Weights on a platform suspended by a rod from the opposite end of a balance beam to counterbalance the weight of the test wall.

Figure I-6: The counterbalancing weights were enclosed in a Sonotube anchored to the floor to protect them from disturbance during testing.


Figure I-7: Trickle trough attached to deliver water to the drainage cavity


Figure I-8: Gutter and container for collection of drained water.

Figure I-9: Castor bearing used to attach to the underside of the sill plate of a test wall to accommodate for non plane conditions and to transfer the unbalanced load to one load cell.

Figure I-10: View of two load cells with bearing plates attached to the cantilever ends. Daps were machined into these plates directly over the centre of bearing to receive the castor bearings.

Figure I-11: Load cell assembly in place under a test wall. Also shown is a "keeper" to restrict rotation and swinging during mounting of the test wall. These did not contact the wall during test.

Figure I-11: Carboy with tempered water weighed continuously during delivery of water by forced air.

Figure I-12: Overview of instrumentation table near wall test setup.