RESEARCH REPORT

Drainage and Retention of Water by Cladding Systems

Part 8 – Summary Report

Canada

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DRAINAGE AND RETENTION OF WATER BY CLADDING SYSTEMS

Part 8 – Summary Report

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

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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EXECUTIVE SUMMARY

A series of drainage tests of exterior cladding assemblies were undertaken to quantify the ability of several types of cladding systems to manage and evacuate water that intruded behind them. The present report represents a summary and concluding analysis of testing and results that have been reported on separately for different wall systems.

Keeping rain out of a wall is the top priority of cladding for managing moisture intrusion and for assuring durability. Some jurisdictions mandate 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. This implies that some form of drainage medium is provided to allow water penetrating the primary cladding to escape with a minimum of retention.

The test program has focused on the ability of walls to manage water intrusion past the primary cladding. Both direct-applied and drained systems were included. No attempt was made to simulate either weather conditions or the way that water might get into the wall in practice. The question posed by this work was not "how" water got into a wall in the first place, but "how" water was managed once it got in. The test program included 6 EIFS walls, 3 walls each with vinyl siding, wood siding, hardboard siding, and 2 walls with fibre cement board siding. Both direct-applied and drained variants were included. Each wall panel was 1.22 m wide by 2.44 m high (4 ft by 8 ft).

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 test. Water was piped to each wall for one hour at a flow rate of 133 g/min (for a total of 8 litres) and allowed to drain into a trickle trough at the top edge of the cladding which distributed droplets behind the cladding over a 600 mm width of wall. This was followed by an hour for drainage and drying, and a further 48 hr drying period. The water that drained out of the wall was collected by a sloped galvanized gutter at the bottom of the wall.

For walls having direct-applied siding, with no specific provision for drainage, the water was directed into a standardized opening at the top course of siding. For all other walls, flow was directed to either the front or back of the drainage medium provided. When a particular wall was intended to be tested twice, this was done to study if more or less water could be retained by the cladding system depending on its construction.

Measurements of the environmental conditions (relative humidity and temperature) were made in the test area and at the top of each test wall. A capacitance based moisture meter was used to take the moisture readings on a grid before wetting and after the 48-hour drying period. The moisture content difference between the initial and final set of readings was imputed to be due to the retained moisture. Contour maps were prepared to describe the inferred distribution of retained water.

Drainage/Drying of EIFS Walls

- All EIFS 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 systems had starter tracks that may have retained some liquid water. Water held there was not in contact with the base wall.
- EIFS walls were more sensitive to variation in the environmental conditions in the controlled climate laboratory where the work was conducted than other cladding systems.
- Drying took place at essentially steady state room temperature and 50% RH in this period. However longer term drying for an additional 48-hrs resulted in essentially full drying for some walls.
- For walls where it was clear that water had collected in some joints in the 50-mm EPS insulation, drying was slow.

- The order of magnitude of the retention at the early stage of wetting was calculated to represent a moisture difference for a wood framed wall (including the OSB but not including the EIFS) of only 0.3% based on oven dry weight and substantially less for the majority of walls tested. This level of change, albeit taken over the entire wall, is very minor for wood structures.

Drainage/Drying of Vinyl Siding Walls

- The direct-applied vinyl siding retained moisture largely within the top siding courses where the water was deposited. Some water leaked out of the sealed ends and invalidated the intent of the test. The majority of water drained out of drainage holes provided by the siding profiles at the top course of siding.
- 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.
- Water retention by systems with drainage cavities allow the retention to be spread down over the full height of the wall, so the unit concentration is low. The moisture retained by a relatively impermeable direct-applied system, such as vinyl siding, retains the moisture in a more concentrated area.
- Moisture that was retained in the vinyl siding joints as free water did not appear to be held in contact with the WRB and wood framing but in the profile of the siding. This moisture can contribute to establishing a local micro climate that in the long run may lead to problems in some elevations of a building, particularly if the wetting is chronic.
- The absence of an effective drainage plane leaves the vinyl siding clad wall durability vulnerable to blockage of the small drainage holes. Clogging of these holes by dirt would reduce the ability of vinyl siding to handle intrusion of water in the future.

Drainage/Drying of Wood, Hardboard and Fibre Cement Siding Walls

- The water retained by the hardboard siding increased rapidly at the start of wetting and then tapered off. The fibre-cement sidings, on the other hand, 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.
- Drainage of direct-applied hardboard and fibre-cement siding occurred through the joints in the top of the wall close to where the water was input.
- The total amount of water retained in these tests is likely concentrated in relatively small areas associated with the contact between the siding and sheathing membrane. Only the top edges of each siding course was in direct contact with the wall. The back of siding was otherwise exposed to air and this facilitated drainage and drying.
- The wood siding that was installed flat against the wall retained the most water. It must be stated that the manufacturer of this siding recommends this siding be installed on batten strips and not be direct-applied.
- Comparing direct-applied siding with drained walls, it is important to appreciate that the area of wall wetted is quite different and the consequences of the magnitude of water retained is different. Concentration of retained water and its location has greater implications for durability than we could demonstrate by these tests.
- Contrary to expectations, the system with the largest initial retention was for wood siding installed on wood batten strips. This was because at least one trickle of water occurred directly on the top end of each batten strip. This water was absorbed quickly into the end grain. Despite retention at these locations, this wall dried more quickly than all others because it had a larger drainage space (19-mm).

- 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.
- All direct-applied siding systems clamp the WRB tightly against the sheathing at the contact lines. However the ability to dry must be highly dependant on installation factors and subsequent shrinkage effects at fastener locations.
- The direct-applied wood and lapped hardboard siding retained more moisture at mid-height by the end of the drying period based on the moisture mapping. Exactly how that moisture was held cannot be determined from this crude level of detection. However, of all siding systems reported on here, the wood siding 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.
- The residual moisture in many cases appears to be concentrated more at mid-height of the test walls. It was surmised that this was likely due to the way that drying took place. 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 also 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.

Air flow Measurements of Drainage Cavities
To investigate the influence of the size of the drainage cavities on drying, all walls with drainage cavities were tested to obtain their air flow characteristics. This data was used for correlation with drying rates. The following observations were made:

- The drainage cavities of all EIFS test walls exhibited somewhat similar air flow characteristics; for two manufacturers the pairs of test walls exhibited nearly identical performance.
- The flow characteristics of the bottom end of walls (involving starter tracks) were relatively restrictive compared with the main drainage cavity. The starter panels used by one EIFS manufacturer were relatively open as expected. Unexpectedly, the results for one companion wall were relatively restrictive yet appeared to be more open than those with specific starter tracks.
- The flow characteristics of EIFS walls fabricated with adhesive ribbons and all other walls with mesh-type drainage mats demonstrated laminar flow for the main drainage cavities.
- The drainage mat involving a dimpled plastic sheet offered multiple obstructions to flow and the air flow was characteristic of more turbulent flow.
- The mesh type mats were considerably more permissive than the drainage cavities of EIFS walls as they provided a drainage space of approximately 6 mm compared with the EIFS walls (2-3 mm).

Air Permeance and Vapour Permeance of Siding Wall Specimens
To investigate the influence of air flow and vapour diffusion through horizontal joints in the siding, a series of companion tests were undertaken on 876-mm square (34.5-inch square) wall samples built for these tests. The pans in which they were mounted served as chambers for both air pressure and the wet cup water vapour transmission tests. These supplemental tests were assumed to apply to their parent walls for correlation with drying rates.

- A reasonably good correlation was found between air flow and vapour flow characteristics of siding systems.
- Vinyl siding, with its manufactured interlocking joints and small drain holes, was the tightest for both vapour and air flow.
- This is followed by hardboard siding with a spline system. Contact mismatch between the spline and the top of the siding below leads to some air and vapour transmission.

- Greater transmission resulted for the second hardboard product that had an in-line interlocking shiplap joint, which had moderately higher leakiness than the first product.
- The leakiest siding was the fibre-cement product (as constructed) because of the greater mismatch provided between the adjacent courses of siding.
- Each system, by design and by assembly, results in a unique range of tightness that may be translated to equivalent vapour permeance, but only in a somewhat general way given all of the factors influencing air tightness and vapour exchange.
- Given the correlation between air flow and vapour diffusion through joints, it is more economical to test the air flow characteristics of joints because of the short time needed. Vapour transmission tests took a very long time to complete because of the limited number of specimens that could be tested simultaneously and because of their size.

Factors Correlated with Drying of Retained Water:
Multiple regressions were undertaken on the drying rates, retentions at 2-hr, ambient vapour pressures and air and vapour flow characteristics of the drainage cavities and siding joints. The following findings were arrived at:

- Drying of walls with drainage cavities was dominated by the air flow characteristics of the cavities. The variable used to represent the flow characteristics was the coefficient of the fitted power flow equation, i.e., air flow at a pressure differential of 1 Pa.
- Drying of walls that had direct-applied siding was dominated by one of the siding characteristics, namely air flow characteristic, also at 1 Pa pressure differential.
- Both vapour flow and air flow had near equal correlation coefficients but they are collinear variables. One cannot say which is the most important except that both can act independently and individually to different degrees depending on the environmental conditions.
- Ambient vapour pressure conditions did not have a statistically significant effect on drying which gives testimony to the adequacy of control provided, except at very low water retentions. Also not statistically important was the absolute level of retained water. More important were the system related effects and how retained water was held.
- Vapour diffusion directly through the siding or through the wall is a relatively slow process compared with diffusion through joints. In any case, it is advisable to avoid depending on vapour diffusion through siding for removal of moisture behind it.
- Since air flow permeance and vapour permeance of joints are highly correlated, one cannot confidently attribute the drying of direct-applied siding that was actually achieved to one or other degree of permeance. Under laboratory conditions with no wind, very likely vapour permeance dominated. The fact that air permeance exhibited a higher correlation may only mean that the actual vapour permeance of the walls was better than that found for the smaller siding samples tested.
- Ensuring that air and vapour flow capability at joints is maximized either through design of the siding or by its installation is a worthy design goal. Installation of siding by means of nails having thick heads that assure a gap at laps is an inexpensive solution and also facilitates drainage of water from behind siding close to where it may enter behind it.
- From the above observations it is clear that provision of drainage planes leads to a more direct path for the water to flow to the bottom. But, in the process, a greater area of wetted surfaces becomes involved. Also, a greater total weight of water can be retained depending on the design of the siding.
- 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 from behind the siding.

- Clearly, since even the walls with direct-applied siding 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/or air exchange through the materials and the air gaps between courses of siding, small though they may be.

The experimental testing of the ability of walls with siding to manage water that enters the space behind the siding has taught us that despite lack of provision of drainage cavities, siding joints can permit drainage close to the source of moisture. The ability to do so safely has not been assessed in this study because knowledge about the detailed concentration of moisture resulting from that form of entry and escape was not available. In any case, a study directed at that subject would require additional detailed measurements that could not be undertaken in this study. The variability in retention from one wall to another of the same construction could only be observed for apparently similar walls with fibre-cement siding. Their relative performance suggests that installation variables of all such walls may have much to do with the reliability of their drainage and retention performance.

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 of durability. 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 limited to essentially 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. Researching the performance of siding experimentally must be limited to examining relative conditions. However, if the mechanics of all the air, moisture and thermal paths are understood and properly characterized, it may be possible to employ computer modelling to parametrically assess relative performance of siding systems in widely differing climates. 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 with Regard to Testing Methods:

- The drying period, currently 48 hours long, could be reduced and still achieve the information about drying rates. The total test time for any wall could be reduced to a total of 24 hours with a 2-hr wetting/draining period and a 22 hour drying period.
- While the trickle trough developed performed suitably, it depends on gravity flow and even distribution of water across its full width. A pumped trickle wand would achieve the desired result more easily providing that it was supported independently from the wall.
- The balance beam system employed proved to be satisfactory and required only minor checking of calibration for each test. The original detailed calibrations held throughout the entire period; however more direct suspension would reduce the effect of disturbances at linkage connections.

Recommendations on the Application of Drainage Tests:

- 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 significantly enlarged upon the information developed and understanding achieved than would otherwise have been attained by testing to that standard.
- The drainage test can be used to develop siding systems that perform better. Knowing that air permeance of siding joints was most responsible for drying and that vapour permeance is strongly related, only the air permeance needs to be measured. Improved air permeance of joints for any particular system would likely improve the ability of a 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.

Recommendations for Further Research:

- The current test protocols permitted air and vapour flow out of the top of the siding. Introducing water to the top of the wall and then sealing off the entry creates the worst case scenario for drying. Different systems may perform substantially differently than found here and should be investigated.
- 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.
- The current test program was limited to several combinations of materials and profiles. If testing were done to arrive at representative performance, likely three test walls of each system would be sufficient. If testing were done to investigate how a particular system achieved its performance, much more detailed work is required, and for that one test wall is sufficient.

RÉSUMÉ

Une série d'essais de drainage sur des parements extérieurs a été menée afin d'évaluer la capacité de plusieurs types de parements à gérer et à évacuer l'eau qui pénètre derrière la façade. Ce rapport présente le résumé, ainsi que l'analyse des essais et des résultats concernant les différents systèmes muraux, qui ont tous fait l'objet d'un rapport distinct.

La priorité absolue du parement est de repousser l'eau de manière à gérer les infiltrations d'eau et à assurer la durabilité du mur. Certaines administrations autorisent l'utilisation de parements extérieurs qui incorporent les principes de conception de « l'écran pare-pluie », c'est-à-dire que les murs extérieurs sont dotés d'une première et d'une seconde ligne de défense. Cela suppose qu'on a prévu une certaine forme de drainage afin de permettre à l'eau qui traverse le parement de s'évacuer avec le moins de rétention possible.

Les essais étaient axés sur la capacité des murs à gérer l'eau qui traverse le parement. Les parements appliqués directement sur le support et les murs drainés ont fait partie du programme d'essais. Les conditions d'exposition naturelles n'ont pas été simulées de quelque façon. L'idée de départ n'était pas de déterminer « comment » l'eau s'infiltrait dans le mur, mais plutôt d'établir « comment » l'eau était gérée une fois qu'elle y était entrée. Six murs à système d'isolation des façades avec enduit (SIFE), trois murs parés chacun d'un bardage de vinyle, de bois et de panneau dur, et deux murs à bardage de fibrociment ont été mis à l'essai. Des variantes du parement appliqué directement sur un support et sur un mur drainé ont été étudiées. Les échantillons de mur mesuraient 1,22 m de largeur sur 2,44 m de hauteur (4 pi sur 8 pi).

L'installation d'essai de drainage était constituée de trois systèmes d'équilibrage du poids qui mesuraient le poids exact de l'eau ajoutée et retenue dans chaque mur au cours de l'essai de mouillage. L'eau était canalisée à chaque mur pendant une heure à un débit de 133 g/min (pour un total de 8 L) et se versait dans un bac goutte à goutte assis sur le haut du parement et qui répartissait les gouttelettes d'eau derrière le parement sur une largeur de mur de 600 mm. Après une heure de drainage et de séchage, on a laissé sécher l'échantillon pendant 48 heures de plus. L'eau qui s'évacuait du mur s'écoulait dans une gouttière galvanisée inclinée qu'on avait installée au bas du mur.

Dans le cas des murs où le bardage est appliqué directement sur le support, sans disposition particulière pour le drainage, l'eau était canalisée dans une ouverture normalisée au sommet du rang supérieur de bardage. Quant aux autres murs, l'écoulement était dirigé soit sur le devant ou l'arrière de l'élément servant au drainage du mur. Lorsqu'on décidait de mettre à l'essai un mur particulier une deuxième fois, on voulait déterminer si plus ou moins d'eau pouvait être retenue par le système de bardage selon sa construction.

Les mesures des conditions d'essai (humidité relative et température) ont été prises dans la zone d'essai et dans la partie supérieure de chaque mur à l'étude. Un humidimètre à condensateur a été utilisé pour enregistrer les lectures d'humidité relative sur une grille, avant le mouillage et après la période d'assèchement de 48 heures. On a posé comme hypothèse que l'humidité retenue était à la base de la différence de teneur en eau entre les premières et les dernières mesures. Des tracés ont été préparés pour décrire la distribution présumée de l'eau retenue.

Drainage-séchage des murs SIFE

- Tous les murs revêtus d'un SIFE ont permis à presque toute l'eau de s'écouler et seulement entre 0,3 % et 1,4 % de l'eau introduite a été emprisonnée, même si certains systèmes étaient munis de rails de départ qui pourraient avoir retenu une partie de cette eau. L'eau emprisonnée à cet endroit n'entrait pas en contact avec le revêtement intermédiaire.
- Les murs revêtus d'un SIFE étaient plus sensibles aux variations des conditions ambiantes de laboratoire à environnement contrôlé, où les travaux ont été effectués, que les autres revêtements extérieurs.
- Au cours de cette période, l'assèchement s'effectuait essentiellement à une température de la pièce constante et à une humidité relative de 50 %. Cependant, une période de séchage plus longue de 48 heures a permis l'assèchement presque complet de certains murs.
- Dans les murs où il était évident que l'eau s'était accumulée dans les joints d'isolant de mousse de polystyrène expansé de 50 mm, il fallait plus de temps pour le séchage.
- L'ordre de grandeur de la rétention d'eau au stade initial du mouillage a été calculé à partir du poids anhydre de manière à représenter une différence d'humidité d'un mur à ossature de bois (comprenant le panneau OSB, mais pas le SIFE) de seulement 0,3 % et de beaucoup inférieur à cette valeur pour la majorité des autres murs mis à l'essai. Ce niveau de changement, bien que calculé pour le mur en entier, n'a que très peu d'effet sur une ossature en bois.

Drainage/séchage des murs à bardage en vinyle

- Le bardage en vinyle appliqué directement sur un support emprisonnait l'humidité surtout dans les rangs supérieurs du bardage où l'eau a été introduite. Des fuites d'eau dans les extrémités scellées ont invalidé l'objectif poursuivi. L'eau s'est surtout écoulée par les orifices de drainage dans les profils de bardage du rang supérieur.
- Même si le bardage a été installé lâchement afin d'en permettre la dilatation sans gondolage, la capacité de drainage à l'arrière ne semblait pas meilleure. Pour qu'un bardage « installé lâchement » sur un support permette le drainage, le fabricant devrait fournir des recommandations d'installation plus explicites.
- La rétention d'eau dans les murs dotés de cavités de drainage se fait sur toute la surface de mur, de sorte que la mesure de concentration d'eau est faible. L'humidité retenue par un système appliqué directement sur un support relativement imperméable, comme un bardage en vinyle, retient l'humidité sur une surface plus restreinte.
- L'humidité sous forme d'eau libre emprisonnée dans les joints de bardage en vinyle ne semblait pas rester en contact avec la membrane de revêtement intermédiaire (MRI) et l'ossature en bois, mais semblait plutôt s'accumuler dans le profilé. Cette humidité peut contribuer à l'établissement d'un microclimat local qui, à long terme, peut entraîner des problèmes dans certaines élévations d'un bâtiment, particulièrement aux endroits où le mouillage est chronique.
- En raison de l'absence de plan de drainage efficace, le colmatage des petits orifices de drainage met en péril la durabilité d'un mur à bardage de vinyle. L'encrassement de ces orifices par la saleté peut à la longue nuire à la capacité du bardage de vinyle à gérer les infiltrations d'eau.

Drainage/séchage des murs à bardage de bois, de panneau dur et de fibrociment

- Le volume d'eau retenue par le bardage de panneau dur a augmenté rapidement au début du mouillage puis a diminué. En revanche, les bardages de fibrociment ont continué à retenir l'humidité à un taux constant à la fin de la période de mouillage, marquant leur grande capacité à retenir l'eau. L'assèchement du bardage de fibrociment a été lent au début, mais à la fin de la période de séchage de 48 heures, les deux murs s'étaient considérablement asséchés.
- Le drainage du bardage en panneau dur et celui en fibrociment posé directement sur le support s'est fait par les joints dans la partie supérieure du mur, à proximité de l'endroit où l'eau a été introduite.

- Le volume total d’eau retenue dans ces essais est vraisemblablement concentré sur une surface relativement petite en raison du contact entre le bardage et la membrane de revêtement. Seules les rives supérieures de chaque rang de bardage entraient directement en contact avec le mur. Par ailleurs, la paroi arrière du bardage était autrement exposée à l’air, facilitant ainsi le drainage et le séchage.
- Le bardage de bois installé à plat sur le mur absorbait une plus grande quantité d’eau. Il faut mentionner que le fabricant de ce bardage recommande de le poser sur des fourrures et non pas directement sur le support.
- En comparant le bardage posé directement sur le support à celui des murs drainés, il importe de comprendre que la superficie de mur mouillée diffère considérablement et que les conséquences du volume d’eau retenue sont aussi différentes. La concentration d’eau retenue et son emplacement ont des conséquences plus grandes sur la durabilité que l’on a pu le démontrer dans le cadre des essais.
- Contrairement aux attentes, le bardage de bois posé sur des fourrures a connu la plus grande rétention d’eau initiale parce qu’au moins un filet d’eau s’est écoulé directement sur l’extrémité supérieure de chaque fourrure en bois. L’eau a rapidement été absorbée dans le bois d’extrémité. Malgré la rétention à ces endroits, ce mur s’est asséché plus rapidement que tous les autres parce qu’il était doté d’une cavité de drainage (19 mm) plus large.
- L’un des murs en bardage de fibrociment posé directement sur le support retenait plus d’eau que son jumeau. Il semblait aussi avoir retenu cette humidité dans la partie supérieure à l’endroit où l’eau avait été introduite.
- Tous les bardages posés directement sur le support assujettissent fortement la membrane de revêtement intermédiaire (MRI) aux points de contact. Cependant, la capacité d’assèchement est largement tributaire des facteurs liés à l’exécution des travaux et des effets de rétrécissement subséquents à l’endroit des fixations.
- Les relevés d’humidité ont permis de constater que les bardages de panneau dur et de bois à chevauchement posés directement sur le support retenaient plus d’humidité à mi-hauteur du mur à la fin de la période d’assèchement. Il était cependant impossible de déterminer comment l’humidité restait emprisonnée à cause de la méthode de détection sommaire employée. Cependant, de tous les bardages étudiés, le bardage de bois a été le seul posé directement sur le support où la paroi arrière entrait entièrement en contact avec la MRI et on s’attendait à ce que la rétention d’humidité y soit plus grande.
- Dans de nombreux cas, l’humidité résiduelle semblait se concentrer davantage à la mi-hauteur des murs d’essai. On a supposé que c’était sans doute à cause de la manière dont l’assèchement se produisait. L’air frais du laboratoire pénétrait par la partie inférieure de la cavité de drainage et l’humidité s’y évaporait plus rapidement. À mesure que l’air humide se déplaçait vers le haut, sa capacité d’absorption d’humidité additionnelle diminuait à mi-hauteur, et ce n’est qu’en dernier que cette humidité parvenait à se dissiper par le bas du mur. Le haut du mur était aussi un peu plus chaud que le bas en raison de l’effet de tirage induit dans l’air et, compte tenu de la proximité de la partie supérieure de la cavité de drainage, le mur était en mesure de s’assécher plus rapidement dans cette direction.

Mesures de l'écoulement de l'air dans les cavités de drainage
Afin d'étudier l'incidence de la dimension des cavités de drainage sur l'assèchement, tous les murs dotés de cavités de drainage ont été mis à l'essai afin de déterminer leurs caractéristiques d'écoulement d'air. Ces données ont servi à établir des corrélations avec les vitesses d'assèchement. On a relevé les observations suivantes :

- Les caractéristiques d'écoulement de l'air dans les cavités de drainage de tous les murs d'essai revêtus d'un SIFE se sont révélées semblables; dans le cas de deux fabricants, la performance de leurs paires de murs d'essai était à peu près identique.
- L'écoulement dans le bas des murs (munis d'un rail de départ) était relativement limité comparativement à ce que permettait la cavité de drainage principale. Les panneaux de départ utilisés par le fabricant du SIFE créaient un espace relativement ouvert comme prévu. Contre toute attente, un des deux murs du même fabricant présentait un espace relativement limité, mais qui semblait être plus ouvert que celui des murs dotés de rails de départ.
- Les caractéristiques d'écoulement des murs revêtus d'un SIFE fabriqués à l'aide de cordons d'adhésif et tous les autres murs munis d'une membrane de drainage du type à treillis affichaient un écoulement laminaire dans les principales cavités de drainage.
- La membrane de drainage en plastique alvéolaire opposait de nombreux obstacles à la circulation de l'air, et l'écoulement de l'air était caractérisé par une plus grande turbulence.
- Les membranes de drainage de type à treillis étaient considérablement moins restrictives que les cavités de drainage des murs revêtus d'un SIFE étant donné qu'elles produisaient un vide de drainage d'environ 6 mm comparativement à 2 ou 3 mm dans les murs dotés d'un SIFE.

Perméance à l'air et à la vapeur d'eau des échantillons de mur de bardage
Dans le but d'étudier l'incidence de l'écoulement de l'air et de la diffusion de la vapeur d'eau par les joints horizontaux dans le bardage, des essais connexes ont été entrepris sur des échantillons de mur de 876 mm² (34,5 po²) construits pour ces essais. Les plateaux dans lesquels ils ont été montés servaient de « chambre » pour l'essai de pression d'air et de transmission de la vapeur d'eau par le procédé de mouillage. On a supposé que ces essais supplémentaires permettraient d'établir une corrélation acceptable des vitesses d'assèchement avec les murs d'origine.

- Une assez bonne corrélation a été établie entre les caractéristiques d'écoulement de l'air et d'écoulement de vapeur d'eau dans les systèmes de bardage.
- Le bardage de vinyle à joints à emboîtement et à petits orifices de drainage usinés était le plus étanche à l'écoulement de l'air et de la vapeur d'eau.
- Le bardage de panneau dur doté d'un système à languette arrive au deuxième rang. Un mauvais raccord entre la languette et le haut du rang de bardage sous-jacent autorisait une certaine transmission d'air et de vapeur d'eau.
- Une plus importante transmission se produisait dans le deuxième produit de panneau dur doté d'un joint continu à feuillure en chicane, lequel affichait des fuites moyennement plus élevées que le premier produit.
- Le bardage le moins étanche était le produit en fibrociment (tel que construit) en raison d'un appariement moins réussi entre les rangs voisins de bardage.
- Chaque système, de par sa conception et son assemblage, produisait une plage unique d'étanchéité qui pouvait se traduire en une perméance à la vapeur d'eau équivalente, mais seulement de manière assez générale, compte tenu de tous les facteurs qui influent sur l'étanchéité à l'air et l'échange de vapeur d'eau.
- Étant donné la corrélation entre l'écoulement de l'air et la diffusion de la vapeur d'eau par les joints, il est plus économique de mettre à l'essai les caractéristiques d'écoulement de l'air des joints parce qu'il faut moins de temps pour le faire. Les essais de transmission de la vapeur d'eau ont demandé beaucoup de temps à cause de leur taille et du nombre limité de spécimens qui pouvaient être mis à l'essai simultanément.

Facteurs entrant en corrélation avec le séchage de l'eau retenue
De multiples analyses de régression ont été entreprises sur les vitesses d'assèchement, les rétentions à deux heures, les pressions de vapeur d'eau ambiante et les caractéristiques d'écoulement de l'air et de la vapeur d'eau des cavités de drainage et des joints de bardage. Voici les conclusions formulées par les chercheurs :

- L'assèchement des murs à cavité de drainage est tributaire des caractéristiques de circulation de l'air dans les cavités. Les variables utilisées pour caractériser l'écoulement étaient le coefficient de l'équation de puissance du débit adaptée, c.-à-d. l'écoulement de l'air à un différentiel de pression de 1 Pa.
- L'assèchement des murs dotés d'un bardage posé directement sur le support est tributaire d'une des caractéristiques du bardage, soit l'écoulement de l'air, également calculé à un différentiel de pression de 1 Pa.
- L'écoulement de la vapeur d'eau et l'écoulement de l'air présentent des coefficients de corrélation presque égaux, mais ces variables sont colinéaires. Il a été impossible de déterminer quel était le plus important, sauf que les deux pouvaient agir indépendamment et individuellement dans une certaine mesure, selon les conditions du milieu ambiant.
- Les conditions de pression de la vapeur d'eau ambiante n'ont pas eu d'effet significatif d'un point de vue statistique sur l'assèchement, ce qui témoigne de la justesse des contrôles exercés, sauf dans les cas où la rétention d'eau était très faible. Le niveau absolu d'eau retenue n'était pas non plus important d'un point de vue statistique. Les effets liés au système et la façon pour le mur de retenir l'eau avaient davantage d'importance.
- La diffusion de vapeur d'eau directement à travers le parement ou à travers le mur est un processus relativement lent comparativement aux autres moyens d'évacuation de l'eau derrière le parement. Il faut éviter de compter sur la diffusion de la vapeur d'eau à travers le parement pour évacuer l'humidité qui se loge derrière.
- Étant donné que la perméance à l'écoulement de l'air et la perméance à la vapeur d'eau par les joints étaient en forte corrélation, on ne peut attribuer en toute certitude l'assèchement du bardage posé directement sur le support à un ou à l'autre niveau de perméance. Dans des conditions en laboratoire, sans l'effet du vent, toute porte à croire que la perméance à la vapeur d'eau dominerait. Le fait que la perméance à l'air présente une corrélation plus élevée peut simplement signifier que la perméance à la vapeur d'eau réelle des murs était meilleure que celle trouvée pour les autres échantillons de bardage de moins grandes dimensions.
- Il convient de vouloir maximiser la capacité à l'écoulement de l'air et de la vapeur d'eau aux joints soit par la conception du bardage ou par son installation. L'installation du bardage au moyen de clous à tête épaisse qui produisent un léger écart dans les joints à recouvrement constitue une solution peu coûteuse et facilite le drainage de l'eau derrière le bardage à proximité de l'endroit où elle peut s'infiltrer.
- À partir des observations précédentes, il est évident que l'aménagement de plans de drainage a pour effet de créer une voie plus directe pour l'écoulement de l'eau. Mais, dans le processus, de plus grandes superficies mouillées entrent en jeu. Aussi, un poids d'eau total plus élevé peut être retenu selon la conception du parement.
- Les joints à chevauchement et autres types de joints dans le parement sont conçus pour repousser l'eau qui se trouve sur la paroi extérieure du parement et ne sont pas particulièrement destinés à faciliter l'égouttement de l'eau qui peut s'infiltrer à l'arrière du parement.
- De toute évidence, même si les murs dotés d'un bardage appliqué directement sur le support se sont asséchés, les boucles de ventilation qui se créent dans la partie supérieure ouverte du mur ont contribué au séchage. Lorsque l'eau semblait pénétrer dans la partie inférieure d'un mur, ce sont d'autres phénomènes de séchage qui prédominaient, notamment la diffusion de la vapeur d'eau ou l'échange d'air par les matériaux et les vides d'air entre les rangs de bardage, si petits soient-ils.

La mise à l’essai expérimentale de la capacité des murs à parement à gérer l’eau qui pénètre dans le vide à l’arrière du bardage révèle qu’à défaut de prévoir une cavité de drainage, les joints dans le bardage peuvent néanmoins permettre le drainage près de la source d’humidité. La capacité à le faire en toute sécurité n’a pas été évaluée dans cette étude parce que des données détaillées sur la concentration d’humidité produite par cette forme d’infiltration et d’évacuation n’étaient pas disponibles. Quoi qu’il en soit, une étude portant sur ce sujet ferait appel à des mesures détaillées additionnelles qui ne pouvaient pas être prises dans la présente étude. La variabilité de la rétention d’un mur à un autre de même construction n’a pu être observée que pour des murs apparemment semblables, dotés d’un parement de fibrociment. Leur performance relative suggère que les variables d’installation de tous ces murs peuvent jouer beaucoup sur la fiabilité de la performance en drainage et en rétention de l’eau.

L’aménagement d’un plan de drainage derrière le bardage est la façon la plus sûre de dissiper l’humidité, même si une plus grande superficie (hauteur) de mur peut être exposée à l’eau. La concentration et l’emplacement de l’humidité sont vraisemblablement un déterminant plus important de la durabilité. La capacité de la construction à permettre à l’humidité de se dissiper à l’arrière du parement et le choix des matériaux qui composent la cavité de drainage peuvent assurer une construction quasi infaillible dans des conditions climatiques réelles. L’étude actuelle s’est bornée essentiellement aux conditions d’assèchement isothermiques. Le séchage dans des conditions climatiques réelles peut être grandement accéléré ou ralenti selon les conditions climatiques du moment et l’exposition du bâtiment. La recherche expérimentale sur la performance des bardages doit se limiter à l’examen des conditions relatives. Cependant, si le fonctionnement de toutes les voies qu’empruntent l’air, l’humidité et la chaleur est compris et caractérisé correctement, une modélisation informatique pourrait servir à évaluer de façon paramétrique la performance relative des systèmes de bardage dans une grande gamme de conditions climatiques différentes. La mise à l’essai des murs, comme elle a été faite dans la présente étude, constitue un moyen précieux d’évaluer l’influence des variables de construction, chose que la modélisation informatique ne peut faire.

Recommandations à l’égard des méthodes d’essai

- La période d’assèchement, d’une durée actuelle de 48 heures, pourrait être réduite tout en permettant de produire l’information au sujet des vitesses de séchage. La durée totale de l’essai pourrait être réduite à 24 heures, dont une période de mouillage-drainage de 2 heures et une période d’assèchement de 22 heures.
- Même si le bac goutte-à-goutte au-dessus du mur a fonctionné adéquatement, il dépend de l’écoulement par gravité et de la distribution uniforme de l’eau sur toute sa largeur. Un tube branché à une pompe pourrait réaliser le résultat voulu plus facilement, pourvu que l’ensemble ne soit pas fixé au mur.
- Le système de poutre équilibrée employé a fonctionné convenablement et n’a exigé que des réglages mineurs de calibrage à chaque essai. Le calibrage détaillé d’origine s’est maintenu pendant toute la durée des essais; cependant, une suspension plus directe réduirait l’effet des perturbations dans les raccords de liaison.

Recommandations relatives à l'application des essais de drainage

- La méthode d'essai inspirée de la norme ASTM E 2273-03 pour les murs revêtus d'un SIFE permet de mieux comprendre comment d'autres types de systèmes muraux gèrent l'eau qui traverse le bardage. Les protocoles d'essai utilisés ont enrichi de façon significative l'information et la base de connaissances, ce qui n'aurait pas été possible si on s'en était tenu à l'essai de l'ASTM.
- L'essai de drainage peut servir à élaborer des systèmes de bardage qui donnent une meilleure performance. En sachant que la perméance à l'air des joints du bardage est en grande partie responsable du séchage et que la perméance à la vapeur d'eau y est fortement liée, on n'a qu'à mesurer la perméance à l'air. La perméance à l'air des joints de tout système particulier améliorerait vraisemblablement la capacité d'un mur à évacuer l'eau à proximité de son point d'infiltration dans le mur, dans le cas d'un bardage posé directement sur le support. Dans le cas d'un bardage posé sur une membrane de drainage ou des fourrures, une meilleure perméance à l'air améliorerait aussi l'assèchement.

Recommandations concernant des recherches plus poussées

- Les protocoles d'essai courants autorisent l'écoulement de l'air et de vapeur d'eau dans la partie supérieure du bardage. En introduisant l'eau dans la partie supérieure du mur, puis en scellant l'entrée, on a pu créer le pire scénario d'assèchement. D'autres systèmes peuvent fonctionner bien différemment que ceux trouvés ici et devraient être étudiés.
- La capacité d'assèchement des murs à bardage sur cavités de drainage est fonction de l'échange d'air dans les joints du bardage (le cas échéant) et de la densité de la colonne d'air que forme la cavité. La gestion de ces deux moyens d'assèchement signifie que l'assèchement dépend des caractéristiques d'écoulement de l'air, des détails des rails de départ, des solins et des obturateurs dans le haut. La mise à l'essai et la modélisation informatique peuvent servir à étudier ces paramètres afin de maximiser le séchage sans compromettre les autres aspects de la performance du mur, p. ex. la résistance thermique des SIFE.
- Le bardage posé directement sur le revêtement intermédiaire peut retenir l'eau localement en concentration suffisante qui, dans des situations de mouillage chronique, peut mener à une dégradation locale du mur. Il faut une étude sur la façon précise dont l'eau est retenue dans les joints pour déterminer si les propriétés de la MRI peuvent influer sur les résultats, comme dans le cas d'un mouillage répété.
- Le programme d'essai actuel a été limité à plusieurs combinaisons de matériaux et de profils. Si l'essai était effectué en vue d'arriver à une performance représentative, il suffirait vraisemblablement de trois murs d'essai de chaque système. Si l'essai était effectué pour étudier comment un système particulier fonctionne, des travaux plus poussés sont requis et, à cette fin, un seul mur d'essai suffit.

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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For DMO Associates:

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

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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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 original request was that the study focus on the drainage characteristics of the tested systems. However, it was clear that that the primary focus should be the amount of water that is retained and how it might dissipate. The present report represents a summary and concluding analysis of testing and results that have been reported on separately for different wall systems.

The reports are organized by the wall types tested and 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. This final report in the series is an overview of the findings of the entire project.

DRAINAGE AND RETENSION OF WATER BY CLADDING SYSTEMS

1 INTRODUCTION

Keeping rain out of a wall is the top priority of cladding for managing moisture intrusion and for assuring durability. Premature building envelope failures across Canada and the United States directly related to the use of exterior claddings that represent the “face seal” approach to prevent rain penetration have led to mandated improvements in design. Some jurisdictions, such as the City of Vancouver, have mandated in their building by-laws 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 has constituted a capillary break to permit drainage, and flashing to ensure that any water penetration through the cladding will not adversely affect the remainder of the wall assembly.

As a condition for the Canadian Construction Materials Centre (CCMC) Products Evaluation Service, exterior wall systems must incorporate a second line of defence (unless proven to be unnecessary). This requirement is to ensure that any water penetration through the cladding will not adversely affect the remainder of the wall assembly. CCMC has identified two types of second line of defence which are considered suitable for use in conjunction with rainscreen claddings, 1) an adequate drainage cavity of at least 10 mm together with appropriate details to remove water from the wall assembly, or 2) a water proof barrier to be used in conjunction with insulating cladding systems. Evaluation of exterior claddings without one of these two types of second line of defence will require the development of testing and/or modeling and/or field study protocols. The National Building Code of Canada (NBCC) has incorporated similar requirements into the latest edition of the NBCC (2005).

Wall systems are expected, as their prime function, to perform durably to protect the interior living spaces from the outside climate. Successful building systems do this while at the same time acting to manage heat, air, and moisture from all sources involving the building enclosure, whatever the occupancy.

Once a wall is wetted in some way and drainage of liquid water stops, the further removal of moisture from each test wall involves a complex set of physical mechanisms. The means by which moisture removal takes place from those wetted materials in a wall, without considering the order of magnitude effects, are by vapour diffusion and by ventilation in some cases. As a consequence of the complexity of behaviour and the various systems in use, it is logical to conduct experiments under limited boundary conditions to understand how different systems will behave. With this basic understanding, it may then be possible to more confidently undertake more detailed investigations and parametric analysis of total wall performance involving real weather conditions.

The test program described in this series of reports has focused on the ability of walls to manage water intrusion past the primary cladding. No attempt was made to attempt to simulate conditions that might be encountered in practice. 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. Furthermore, given that the retention of water, where it is held and how long it takes to dissipate, affects the durability of the main wall structure, these are the factors this test program attempts to address within the limits of the experiment.

2 EXPERIMENTAL DESIGN

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. Out of the many other possible choices available, systems were chosen that would represent some of the more important cladding systems currently used in residential construction. It was planned that, given limitations in budget, these tests would provide a glimpse as to the ability of broad classes of cladding, with and without defined drainage cavities, to manage moisture that penetrates them. Supplementary tests to help explain the mechanics of moisture removal were also included.

To simply make and test individual walls of each type is probably appropriate for exploratory work. At this stage, aside from previous drainage tests on EIFS walls, there was insufficient experience to suggest what number of walls of each type would be most useful to test. Given the limit imposed by costs, and in consultation with CMHC staff, it was decided that as broad a selection as possible of different wall types should be made at this stage.

Further, some system choices were dictated by the availability of some materials. The materials and test walls that were eventually 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 1-BP	middle middle	2 direct attached 1 direct attached	2 1
Hardboard Siding	3	3-SBPO	F/B middle	2 Mats 1 direct attached	4 1
Wood Siding	3	1 BP 2 SBPO	F/B middle WRB	1 Mat 1 direct attached 1 battens	2 1 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 olefin WRB
BP = building paper WRB
LA-WPB = liquid applied water penetration barrier

3 TEST WALL CONSTRUCTION

The individual test reports on EIFS walls, vinyl siding, wood-based siding and fibre cement board siding (Part 3, 4 and 5) fully describe both the materials used and fabrication details used. It will suffice here to only briefly review some of that information as a preface to summarizing the results and undertaking further analysis.

The wall specimens were all fabricated at the laboratory in Sainte-Foy by Forintek 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), paper-based sheathing membrane (15 lbs) (WRB) and spun bonded polyolefin sheathing membrane (SBPO) were used in the project. Although all can be referred to as WRB materials, the above abbreviations will be used to distinguish them in this report.

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 used liquid-applied water penetration barriers (LA-WPB) applied to the wood-based sheathing. After sufficient cure time, the 50 mm expanded polystyrene foam (EPS) was adhered to the LA-WPB with ribbons of a cement/adhesive mix. The ribbons were formed with a notched trowel that spaced beads of adhesive mix about 64 mm (2.5 inches) apart. When the foam was pressed against the beads of adhesive they were flattened to form ribbons. The thickness of the ribbons, and hence the thickness of the drainage space provided, was between 2 and 3 mm. 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.

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

The base coating applied to the outside of the EPS foam, specific to the individual manufacturer, was towelled on together with glass fibre mesh reinforcement. The edges of the panels were similarly dealt with to seal the edges to the wood framing. The final finish coating was applied after curing of the base coating for one day. Drainage testing of walls under the CMHC program was done at least 6 months after their initial construction.

The test walls were originally tested by trickling water into the drainage space built into each wall in a way that allowed drops to form at the edge of the trickle trough and to drop into that narrow space. As noted in the introductory report to this test program “Part 1 –Experimental Approach and Test Plan”, some 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.

To understand how moisture was retained in drainage cavities, besides moisture that may be adhered to the surfaces or absorbed into the materials that the water has come in contact with, it was decided that EIFS walls be 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 using the test protocols on which the current protocols are based. 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 (the back of the EPS foam) to the extent that that was possible given the narrow space provided for drainage. The current test program was not designed to examine the exact factors that are responsible for retention of water in each system except in a general way by system type.

The EIFS walls that retained the least water in initial tests were:

Wall 1; A-4
Wall 2; B-1
Wall 3; C-1

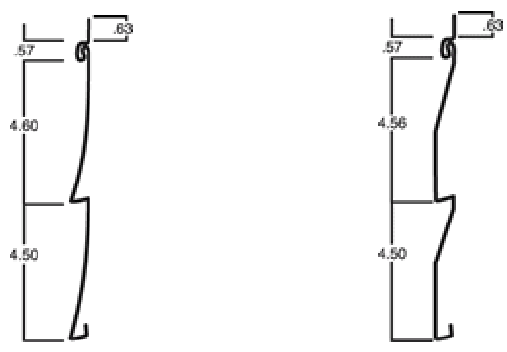
The EIFS walls that retained the most water in initial tests were:

Wall 4; A-1
Wall 5; B-4
Wall 6: C-3

The above designations identify the manufacturer (A, B, or C) and the numbers (1 to 4) represent the test number used in the original test program. 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.

Vinyl Siding – 3 walls

Two different profiles of vinyl siding were used for the purpose of this project. They were both manufactured by Mitten Company. 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). The specifications for both profiles and for the starter strip used are presented in Part 4, Appendix I. One wall specimen was fabricated using Profile #1 siding and two walls were built using Profile #2 siding. These profiles are shown in Figure 1.

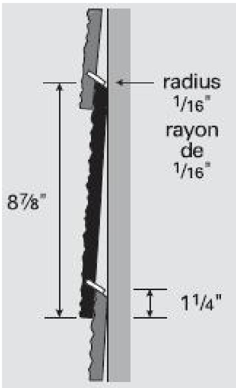


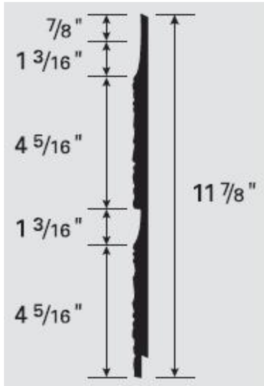
Profile #1 Profile #2

Figure 1 Cross section of Profiles #1 and #2

Hardboard siding – Profiles details – 3 walls

Hardboard siding used for this study was manufactured by Canexel. Two (2) profiles were selected. The first was a 9-inch fastening-spline system (Ced'R-Vue^{TM}) and the second was a 12-inch lap siding with an interlocking system (Ridgewood D-5^{TM}). Installation instructions recommended by the manufacturer were followed and are provided on the manufacturer's internet web site. The link to that site is provided in Part 5 - Appendix I. These siding profiles will be referred to as H1 and H2 respectively hereafter in this report. The profiles shown in Figure 2 were taken from the manufacturer's web page where the dimensions are shown in Imperial units.





H1 H2

Figure 2 Hardboard siding profiles

Wood siding – Profiles details- 3 walls

Wood siding used for this study was manufactured by Maibec. Two (2) 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) and are provided on the manufacturer's internet web site. The link to that site is provided in Part 5-Appendix I. They will be referred to as W1 and W2 respectively hereafter in this report. These profiles are depicted in Figure 3.

W1 W2

Figure 3 Wood siding profiles tested

Fibre cement siding – Profiles details – 2 walls

Fibre cement siding used for this study was manufactured by James Hardie North America. Only one profile was selected for this project. The profile in question was a 6¼-inch Hardiplank® lap siding (Colorplus Select Cedarmill©). Installation instructions recommended by the manufacturer are provided on the manufacturer's internet web site. The link to that site is provided in Part 5-Appendix I. This siding will be referred to as CF hereafter in this report. A photo of this siding applied to a test wall is shown in Figure 4.

Figure 4 Fibre cement siding applied to a test wall

Drainage Mats

Three types of drainage mats were used in the fabrication of some of the wall systems. In all cases, installation instructions are 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. Photos of the fabrication of test walls, including use of these mats, are included in Part 5-Appendix II.

The first mat, referred to hereafter as Mat 1 in this report, was manufactured by Benjamin Obdyke and it is called Home Slicker®. The Home Slicker® product is a ventilating and self-draining rainscreen material intended for use in exterior walls that offers a thermal break besides moisture protection. The manufacturer's literature states that one version of the product meets the CCMC requirement for performance equivalent to a 10 mm rainscreen. However, that distinction could not be determined from the supply firm from which the material used was purchased. The thickness of this mat is reported to be 6.7 mm (0.264 inches).

The second mat, referred to hereafter as Mat 2 in this report, was also manufactured by Benjamin Obdyke. The Cedar Breather® underlayment is a mat forming a three dimensional matrix made of nylon. It has a mat thickness of 6.9 mm (0.27 inch). The Cedar Breather® is used as an underpayment for wood shingles. It provides a continuous air space which allows shingles and shakes to dry more readily.

The third "mat", referred to hereafter as Mat 3 in this report, was provided by American Wick Drain Corporation and is called CedarSaver™. CedarSaver™ is a formed solid sheet underlayment which uses polystyrene for its core and has dimples that provide an overall spacing thickness of 6.3 mm (¼ inches).

Given the description of all the materials used, three hardboard, three wood and two fibre cement siding wall systems were built for this phase of the test program. The specific combinations of materials for each assembly are provided below.

Hardboard Siding;
Wall 1; Hardboard siding H1 direct-applied to the wall against SBPO.
Wall 2; Hardboard siding H2 applied on a drainage mat (Mat1: Home Slicker®) and SBPO.
Wall 3; Hardboard siding H2 applied on a drainage mat (Mat2: Cedar Breather®) and SBPO

Wood Siding;
Wall 1; Wood siding W2 direct-applied on SBPO.
Wall 2; Wood siding W1 applied on a drainage mat (Mat3: CedarSaver™) and SBPO.
Wall 3; Wood siding W2 applied on wood batten strips and SBPO. The batten strips were nominal 1 x 4 wood straps that were trimmed to a width of 64 mm and had a thickness of 19 mm. These battens were attached to the wall directly opposite the stud lumber framing in the wall.

Fibre cement;
Wall 1; Fibre cement siding CF1 applied on SBPO
Wall 2; Fibre cement siding CF2 applied on WRB

4 TESTING 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 test. Full details are provided in the Part 2 report on testing methodology. This allowed three 1.22 m x 2.44 m (4ft x 8ft) wall systems to be evaluated at essentially the same time.

The water was piped to each wall through a small plastic tube which allowed the metered water to drain into the trickle trough attached to the test wall at the top edge of the cladding. The water was metered using a pressure system described more completely in the above noted report on testing methodologies.

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. The software used to control the sampling rate of signals from each load cell was designed by Intertechnology.

Figure 5 Overview of test set-up for weighing of test walls during drainage/drying testing.

4.1 Water Flow Delivery

The water for drainage was piped to the trickle trough at each wall by an air pressure system. Room tempered water 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 on a minute by minute basis and the weight increments were automatically stored in a computer file. In parallel to this monitoring, the flow rate was calculated and the flow 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.

As explained in the report on testing methodologies [2], the water was delivered to each wall in turn to a Plexiglas distribution trough which allowed the water to dribble or trickle into the drainage cavity. The test program required that flow could be directed to either the front or back of the drainage cavity. The trickle trough allowed drops to flow down a thin sheet of plastic bonded to the back from holes drilled in the bottom of the trough. The bottom edge of the sheet was serrated to gather the flow out of each hole to single locations. Tilting the trickle trough allowed the flow of droplets to be directed to specific planes.

4.2 Test Protocols

The flow of water was delivered into the top of the drainage cavity of each wall for a period of approximately 1 hour (until 8 kg of water had been delivered to the trickle trough). The flow rate was 133g/min. The water that drained through the drainage cavity was collected by a sloped galvanized gutter installed at the bottom of the wall cladding which directed the drained water into a pre-weighed container.

For walls having direct-applied siding, with no specific provision for drainage, the water was directed into the standardized opening at the top course of siding. For all other tests, an attempt was made to direct the flow either to the front or back of the drainage medium provided. When a particular wall was intended to be tested twice, sufficient time was allowed for the initial retained water to dissipate (for a minimum of 7 days) before the second test was performed. This was done to study if more or less water could be retained by the cladding system depending on its construction.

After supplying water for one hour at the calibrated rate, the water flow to the wall was turned off. The glass carboy was replaced by another container with tempered fresh water (20 kg) to be used for the next two specimens to be tested. Each wall specimen was allowed to drain for one additional hour after flow to it was halted. The water remaining in the trickle trough at the end of this 2-hour test time and water adhered to the collection gutter and the specimen surface (if any) was mopped up delicately with paper tissues. The water collected over this period was weighed with the container, as were the tissues used to mop up water droplets in the gutter, the specimen surface and the 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. This test period has been referred to in the reports and plots as the wetting/drainage phase.

The change in weight for each wall was sampled at the rate of 20 samples per second. They were averaged and stored at the rate of one record per second for all walls. When the drainage test on the third wall was completed, load monitoring was temporarily halted and the storage rate was changed to 3 samples per minute to avoid creating an excessively large data file during the next stage of the test protocol. This data, at the slower sampling rate, was stored in a separate file and monitoring was continued for a period of at least an additional 48 hours.

The laboratory conditions were set to be maintained at 20ºC and 50% RH on a year-round basis, except temporarily when the large laboratory doors are opened for movement of materials into the laboratory. The conditions at each wall were monitored using temperature and RH sensors and recorded as specified in the next section. Within the large laboratory space in which this work took place, there were some variations in the conditions associated with the cycling of the air conditioning system. Some additional discussion about variations in conditions that occurred during the test period for each set of tests is provided in the discussion section of this report.

Plots for each wall system for both the wetting/drainage phase and the combined wetting/drying period of 50 hours are provided in Appendices assigned to reports for each class of siding.

4.3 Measurement of Environmental Conditions

As noted in the previous section, the RH and temperature conditions surrounding the tested specimens were monitored constantly during the testing period (in all, for almost 50 hours duration). 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 other two 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. To monitor these ambient conditions, four additional monitoring stations were installed. Two stations were positioned above the top of the test frame area, one station was on a table top in the vicinity of the test area, and one station was near the floor and attached to one of the test frame columns at approximately the same height as the gutters at the base of each test wall.

4.4 Measurement of Moisture 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. It was not considered prudent to rely on specific point determinations of moisture content in materials. Instead, based on earlier attempts to map the retained moisture distribution in materials contacted by water in drainage cavities, a qualitative measurement approach was taken using a capacitance-based moisture meter.

The meter used was a Wagner L620 meter that had sufficient data storage capacity to allow numerous readings to be taken from each wall. The measurements were made manually at a spacing of 150 mm on each vertical scan on the back of the OSB sheathing. 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 after the wall was laid horizontally exposing the back of the OSB sheathing. For practical reasons, the measurements after the drainage/drying test were obtained after the walls were dismounted from the balance beam setup. The difference between the initial and final set of readings was imputed to be due to the retained moisture at that time. Contour maps were prepared to describe the inferred distribution of retained water.

5 REVIEW OF TEST RESULTS

The extensive detail involved in describing the behaviour of each class of wall cladding systems to manage water trickled behind them will be summarized individually before attempting to undertake any further analysis of the data.

5.1 Interpretation of Drainage Test Results

From the numerous drainage tests conducted, certain characteristic weight gain ‘profiles” were observed that are related to the manner that wall systems manage water put behind cladding. These “profiles” are influenced by how water is stored by absorption by wetted materials and by direct storage as liquid water.

Current drainage tests, specifically those following the methods in ASTM E2273-03 concentrate only on determining the retention of water at the conclusion of a drainage test and following a specific period for drainage of free water from a wall [1]. But, how one gets to that point is also instructive, and in this section, we will try to describe what we have learned from this project in this regard. This will be explored using a series of “profiles” derived from tests in this test program that are shown in Figure 6.

Figure 6(a) shows a typical weight change plot in which several portions of the water retention history are highlighted. Since water is fed into the drainage space at a uniform rate during the 1-hr wetting stage, the actual weight measured includes both the mass of moving films and trickles of water that have some momentum within the wall, as well as the force of the water deposited into the trickle trough because this is a dynamic event. Losses include drainage and some evaporation but the latter is assumed to be a minor amount. Different legs of the profiles are labelled from ***a*** to ***d*** and are described below

(***a***) The rapid rise in initial weight gain is primarily related to the wetting of surfaces in the drainage cavity wall, and build up of water in the trickle trough (because it is gravity fed system). Typically, drainage down either the drainage cavity or water flowing out through joints in the cladding on the outside of the wall occurs very soon after water is introduced into the wall.

(***b***) Once surface wetting is achieved, the weight gain rate slows down as less water is absorbed into the materials surfacing the drainage cavity. Normally this proceeds at a reducing rate as less and less water can be absorbed into the wetted surfaces. Once a wetting pattern has been established, trickles tend to follow the initial paths and not all of the surfaces inside the cavity over the width of the trickle trough are wetted. This figure shows that accumulation of water is not completed at the end of the wetting period because the wall is still gaining weight at the end of the wetting period. If the weight gain curve was asymptotic with a horizontal line before or at that time, this would indicate the wall had gained about as much water as it could using that method of wetting.

(***c***) Immediately after the water feed is stopped, drainage continues and the measured weight change drops rapidly. That flow gradually slows and stops when the last drop of free water able to escape leaves the wall and sloped gutter. Any free water remaining in the trickle trough or in the collection gutter is still part of the total wall weight. The collection gutter was shaped to a “V” so that drainage from it would be rapid and less surface area would be wetted there.

(***d***) From this point onward, the loss in weight is due to evaporation from the wall proper, the trickle trough and the gutter. Examination of the outside wetted surfaces revealed that there was little weight associated with retention in the trickle trough and gutter. Mopping that moisture up with tissues and determining the weight of water absorbed by them confirmed this. The drying rate, particularly after about 15 minutes at the conclusion of wetting period was generally linear, unless the walls were disturbed in some way or if the environmental conditions were not relatively stable.

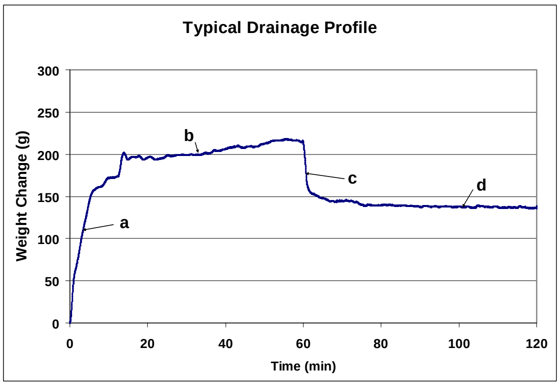


Figure 6 (a)

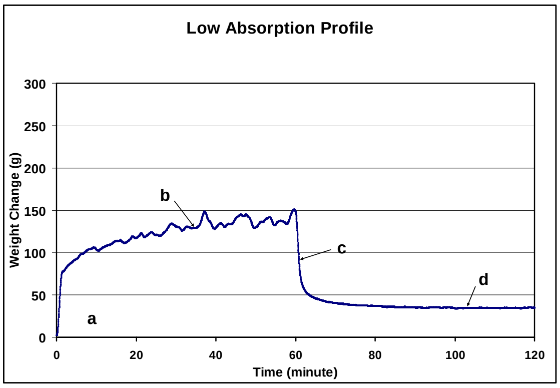


Figure 6 (d)

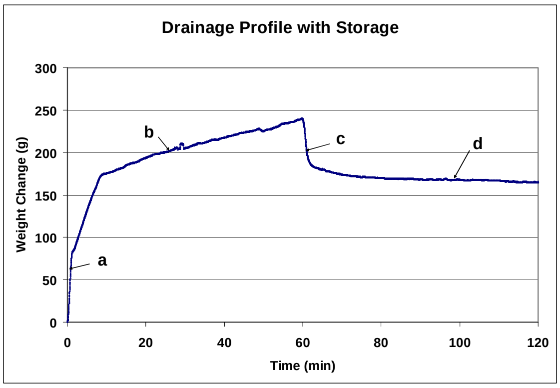


Figure 6 (b)

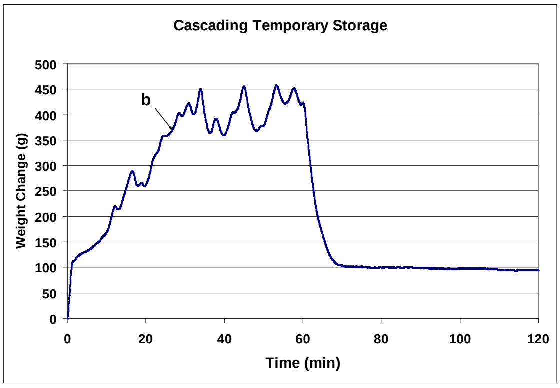


Figure 6 (e)

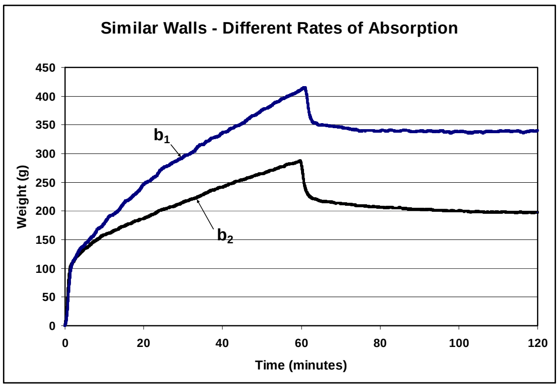


Figure 6 (c)

Figure 6 (a) to (e) demonstrate different characteristics of weight gain and loss during drainage/retention testing of cladding systems.

Figure 6 (b) shows a deviation from the typical pattern. The (***b***) leg of curve shows the wall gaining weight fairly rapidly and in an almost linear manner. This is typical of a situation where water is being stored as free water in joints in the cladding or by adsorption on the drainage medium. Usually, the drop in weight after wetting is halted is still in the same order of magnitude as for walls where storage did not take place, but the retained moisture is quite a bit higher.

Figure 6 (c) shows two typical plots for two apparently identical walls, both showing an absorptive phase but with one absorbing water at a higher rate because of a difference in the ability of materials within the cavity to do so.

Figure 6 (d) shows the result for a drainage cavity in which the wetted surfaces absorb relatively little water and a weight plateau is reached before the wetting period is terminated.

Figure 6 (e) shows a case where cascading of water in the drainage cavity takes place and water gushes out of the wall at the bottom in a pulsed manner during wetting. This is typical of a wall in which some entrapment takes place where water films can build up and be held to some point before being released. In cases such as this, the uncertainty in the amount of retained water held at any point after wetting is completed is partly affected by exactly when wetting was terminated.

Finally, drying in the period after the 2-hr wetting/drainage period is critically dependent on the environmental conditions (in this supposed isothermal drying phase); it is also dependent on how the water is stored. Uniform distributions of water on exposed surfaces can be expected to dry at a relatively uniform manner. However, where there are concentrations of liquid water, such as at joints, these will be slow to dry under these same conditions because of the lack of similar exposure.

One measure for describing the drying during this stage, again assuming steady state conditions, is the retention ratio. That is defined as the ratio between the retained weight at the conclusion of some extended drying period (say 48 hours) and the retained weight at some earlier period, such as at the end of the 2-hour wetting/drainage period. The smaller the retention ratio the more effectively drying has taken place. If the value approaches unity, little or no drying has occurred over that “drying” period.

5.2 Summary of Results for EIFS Wall Systems

Earlier drainage testing at Forintek found that the amount of water retained was dependent on how water was delivered to the drainage cavity. Water might have wetted the top of the EPS and might not be wetted identically in repeat tests. Also, retention of water in joints resulted in significantly greater amounts of water stored. The test protocols for the present investigation were designed to allow trickles to be delivered to specific surfaces at the point of entry to the drainage cavity. Also, to test this delivery issue for these narrow drainage cavities, the basis for selection of EIFS walls was their initial retained water levels - the most retained (Walls 1, 2 and 3) versus the least water retained (Walls 4,5 and 6).

The composite drainage plots for Front and Back wetting are provided in Figures 7 and 8 for the 2-hr wetting/drainage period, and in Figure 9 and 10 for the combined 2-hr and 48-hr drying period. For purposes of identification of multiple plots in this report, the data has been decimated to the extent that individual symbols can be distinguished in each plot.

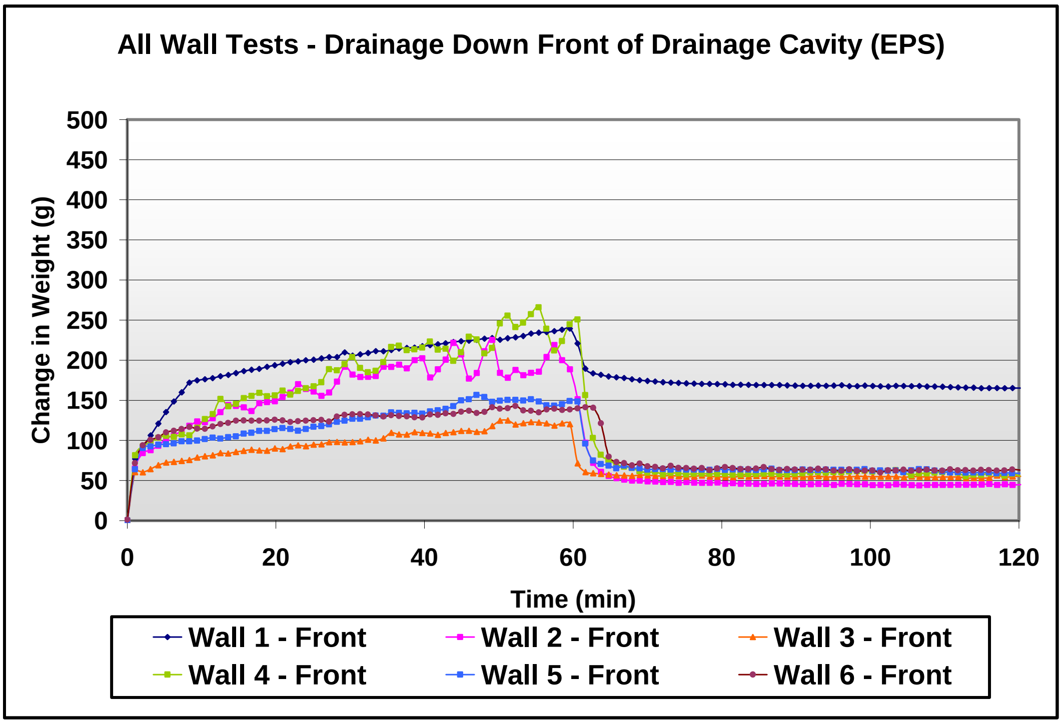


Figure 7 Composite plot of all EIFS drainage tests where water was trickled down the FRONT of the drainage cavity (down the back of the EPS).

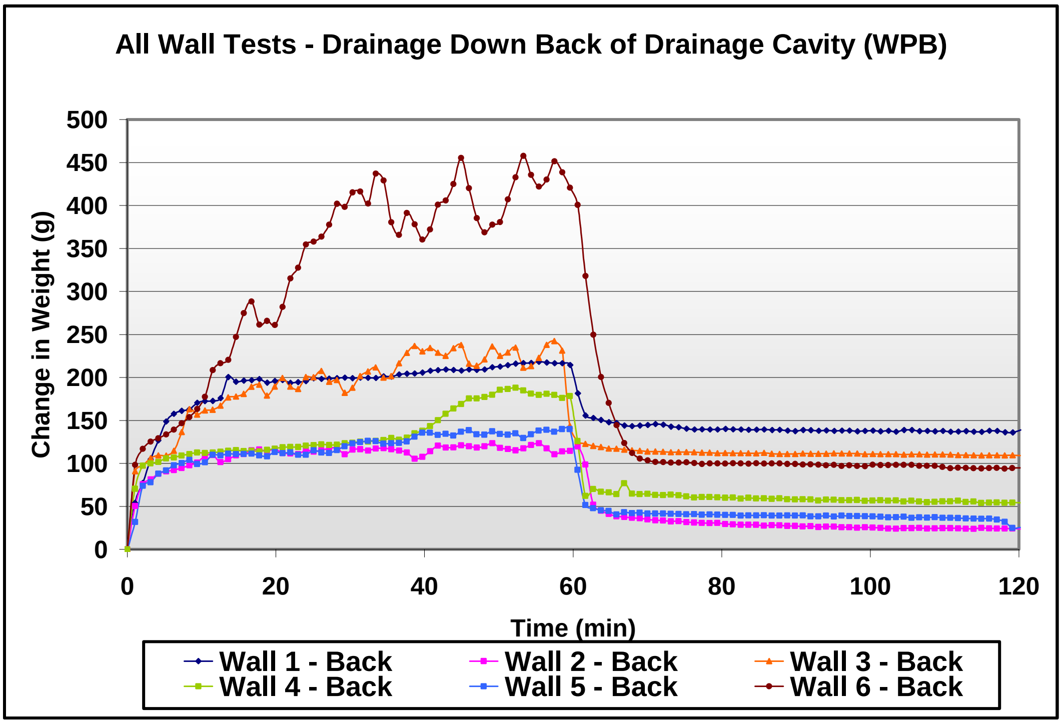


Figure 8 Composite plot of all EIFS drainage tests where water was trickled down the BACK of the drainage cavity (against the WPB).

From these profiles and from discussion in the previous section, it appears that test Wall 1-front in Figure 7 experienced build-up of water in some of the EPS joints, based on the appearance of the "***b"*** leg of the profile compared with all the other profiles. In a similar vein, tests Wall3-back and Wall 6-back in Figure 8, both by Manufacturer C experienced some cascading in the "***b***" leg of the profile relative to all the walls tested. Despite this, the drying rates were similar for all walls. Wall tests Wall 2 and Wall 5, both having a 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 significantly lowered and repeatable drainage/retention profiles compared with initial tests performed in 2004 which depended on the formation of larger droplet sizes to form prior to entering the drainage cavities..
- 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 systems had starter tracks that may have retained some liquid water. Water held there would not be in contact with the base wall.
- The walls that originally retained the least water generally retained more when water trickled down the face of the coated sheathing than on the back of the EPS foam although not all walls did so.
- Adhesive ribbon spacing at the top of the wall was variable from one wall to another and between systems. The fixed pattern for trickling at 38 mm spacing likely was responsible for some of the variability. Other means of delivery, such as spraying would likely also have similar variability as trickles would not necessarily form in a predicable way from one time to another.
- Drying rates in the first hour after wetting were not found to be 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. There was good evidence that the change in the weight gain by the wood framing was miniscule compared with that gained by the finish system itself as a result of environmental changes.

The drying phase for both Front and Back tests are shown in Figures 9 and 10 following at the same vertical scale as the former plots in order that any resulting variations not be exaggerated. Both show a daily cycle introduced by the conditioning and lab occupancy.

- The longer 48-hr drying period required much higher control on environmental conditions than could be provided to obtain monotonic drying curves. To be able to detect the dissipation rate of the small levels of retained moisture required very good control for EIFS walls.
- When EIFS walls were tested concurrently with some of the other systems, it was found that other systems exposed to similar conditions were relatively unaffected compared with the EIFS walls. This suggests that moisture pickup by the wood framing and sheathing was minor for all walls compared with that by the EIFS finish systems.
- Drying took place at essentially steady state room temperature and 50% RH in this period. However longer term drying for an additional 48-hrs resulted in essentially full drying for some walls. For other walls there was a gain in weight even though they were in an air conditioned environment. These conditions were effectively steady from the point of view of persons working in that environment and from the point of view of wood properties and structures testing. For the drainage tests on EIFS walls, they responded more rapidly to those changes compared with wood structures. In practice, the normal variation in exterior weather conditions would dominate these small retention levels.
- The order of magnitude of the retention at that early stage of wetting was calculated to represent a moisture content change for a wood framed wall including the OSB but not including the EIFS of only 0.3% based on oven dry weight and substantially less for the majority of walls tested. This level of change, albeit taken over the entire wall, is very minor for wood structures

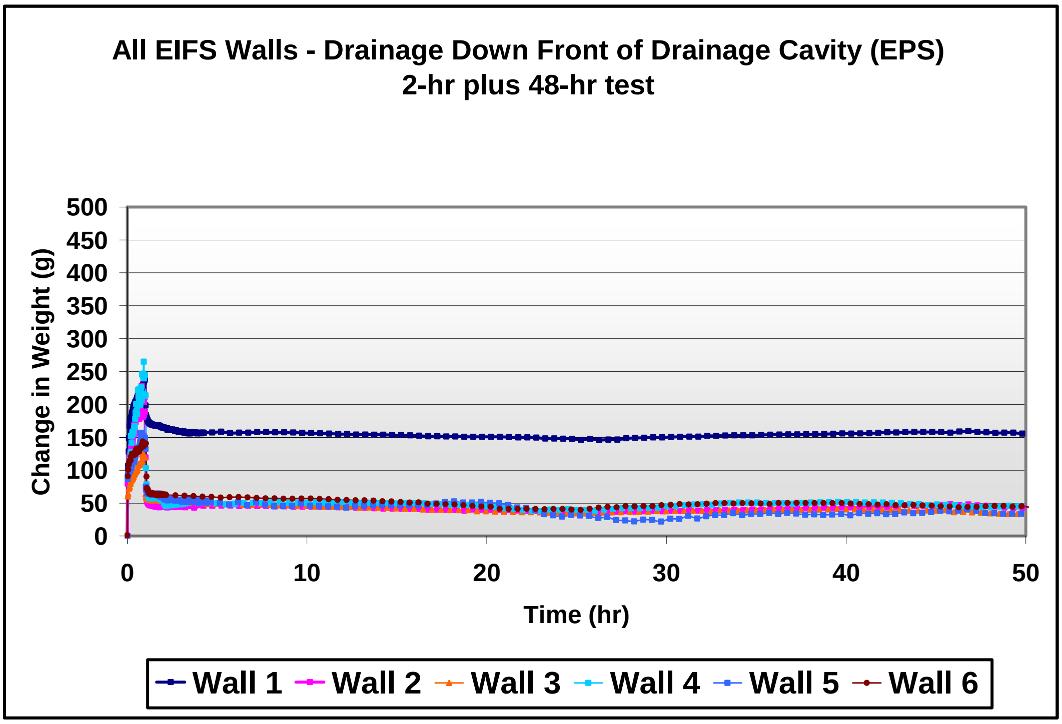


Figure 9 Composite plot of all EIFS drainage tests including 48-hr drying where water was trickled down the FRONT of the drainage cavity (down the back of the EPS).

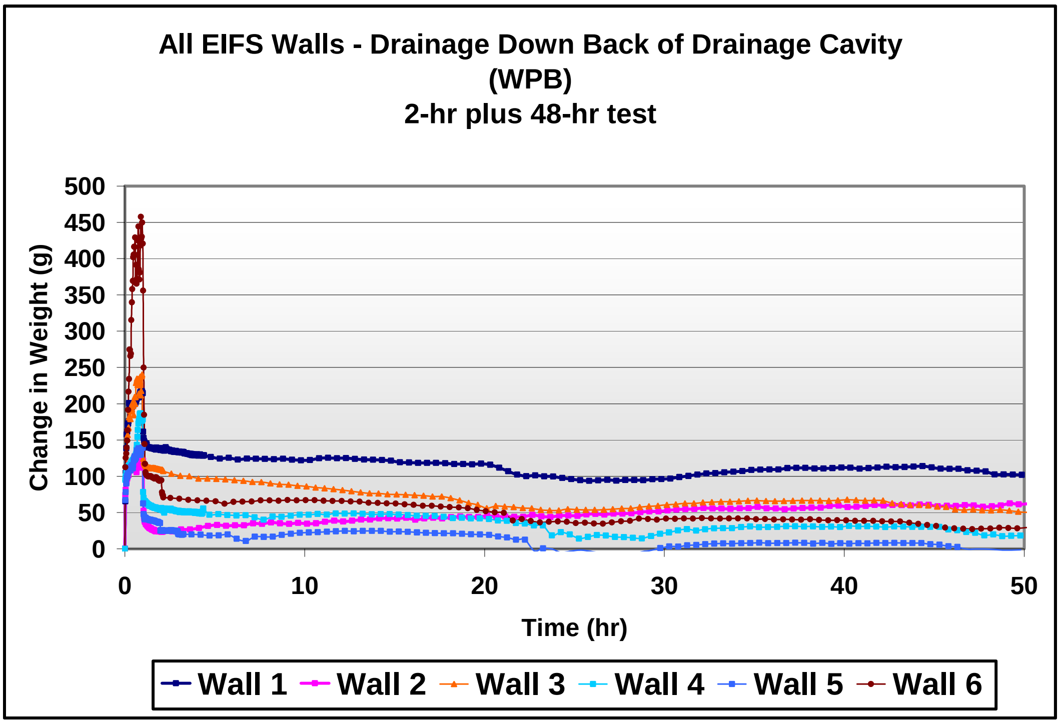


Figure 10 Composite plot of all EIFS drainage tests including 48-hr drying where water was trickled down the BACK of the drainage cavity (against the WPB).

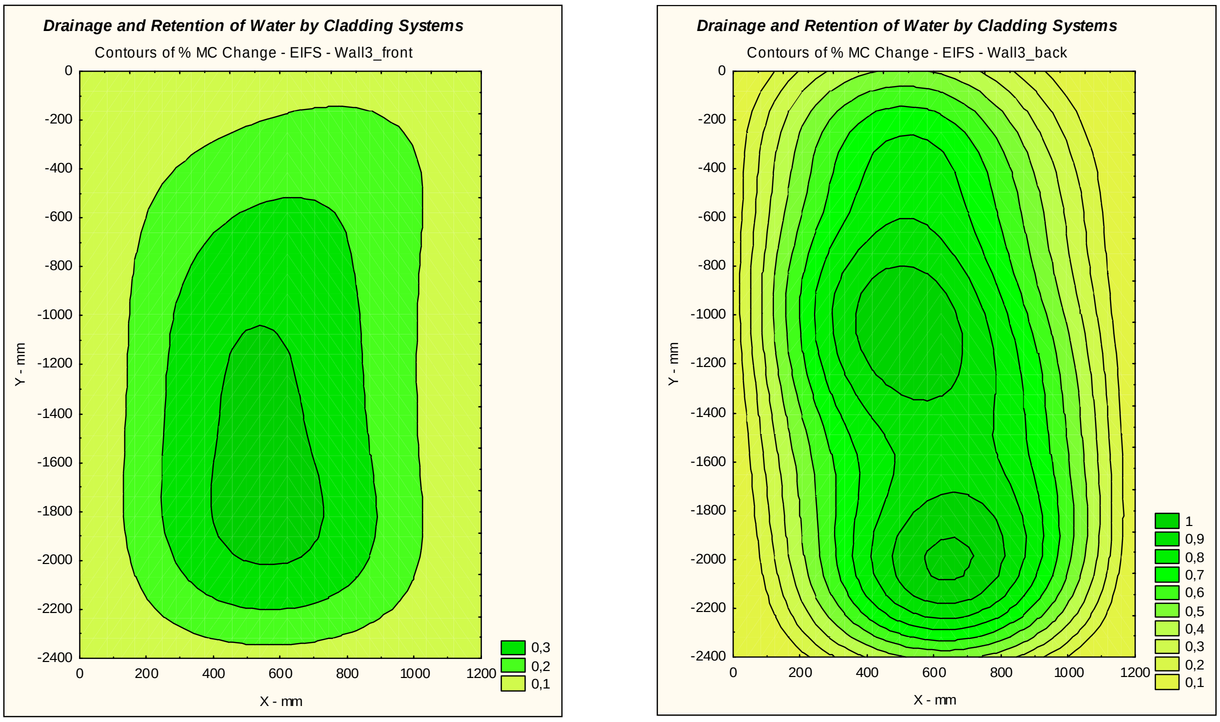


Figure 11 Example of moisture mapping for one wall (Wall 3) when water was trickled down the front (left plot) and the back (right plot) of the drainage cavity

Examples of moisture mapping plots are shown in Figure 11 for Wall 3 tested when trickling water of the back of the EPS or on the back on the LA-WPB. It is pointed out first that the two plots are not to the same colour scale, but they have the same contour increments in detected moisture. The most obvious observation is that trickling water down the back the drainage cavity led to greater retention of moisture and in this case suggests locations where more water had been retained. Additional observations on plots of this nature are:

- The measurement techniques for detecting locations of moisture concentrations made use of a capacitance based moisture meter. The moisture change contours generally reflected the relative retention of water when water was trickled on the front or back of the drainage cavity.
- The moisture maps seemed to reflect the basis for the original selection– namely, that walls that retained the most water in initial tests, also retained more moisture when water was trickled on the back of the EPS.
- The patterns of moisture accumulation were diffuse signifying relatively good dispersion. Localized accumulation in joints was not detected, which is not to say that some did not accumulate there. Wetted concentrations were usually located higher up on the wall. That pattern is understandable because measurements were only undertaken after significant drying had already taken place.
- During drying, the test walls dried from the bottom up since drier make-up air entered the bottom of the drainage cavity and moved upward by buoyancy. The upper wetted areas were the last to dry thoroughly.
- Detection of moisture retained in starter tracks was not possible because of interference with the vertical leg of the metal gutter. One system with a starter panel had the least retention of water.

- There was a trend between drying rates and the ambient vapour pressure as measured by a sensor pair located at a height above the floor corresponding to the gutters and the entry level for makeup air into the drainage cavity. Despite the low variation in vapour pressure experienced, especially compared to the prescribed allowable variation in conditions, the drying curves were subject to considerable fluctuations.
- The measurement grid used did not allow for very detailed location of retained moisture differentials.

Table 2 Retention Ratios for EIFS walls tested

Wall No.	Trickle Designation Re: Cavity	Surface Trickled On	Retention at 2-hr [g]	Retention at 50-hr [g]	50-hr / 2-hr Retention Ratio
1	Front	EPS	165	155	0.94
2	Front	EPS	45	42	0.93
3	Front	EPS	55	35	0.64
1	Back	WPB	137	102	0.74
2	Back	WPB	24	0 [61]*	0.00
3	Back	WPB	109	51	0.47
4	Front	EPS	56	45	0.80
5	Front	EPS	59	33	0.56
6	Front	EPS	63	45	0.71
4	Back	WPB	54	18	0.33
5	Back	WPB	26	0	0.00
6	Back	WPB	95	29	0.31
	Average		74	46	0.54

* Wall 2 - Back gained weight during the 48 hr drying out period, and was assumed to have dried using the results for Wall 5 - Back as a guide.

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. It is 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.

Earlier it was noted that Wall 1-front showed signs of having water collect in joints in the EPS. The high level retained at the end of wetting and at the conclusion of drying reinforces the notion that the availability of the retained water to dry was hampered because of its location in joints. The retention ratio in this case was high at 0.94. Beyond this, it is difficult to conclude, other than in a general way, that a wall test having a low retention ratio is indicative of likely system response in the field. Collection of water in joints at some locations is likely not possible to avoid completely.

The significance or importance of retention in the order of magnitude found here at the 2-hr time level, between 24 and 109 g, was not the aim of the current test program. What is of relevance is how moisture that is retained is distributed. The ready flow of the water to the base with little lateral dispersion, together with what appeared to be generalized distribution with no apparent accumulation in joints evident in the weight gain wetting/drainage profile characteristic of such accumulation, suggests that these walls managed water entry in the best possible manner to minimize potential high localized absorption or storage that could lead to prolonged hidden wet microclimates.

With respect to the impact of adhesive curing, there has been some research that suggests that the moisture absorbent properties of the adhesive mixture become more impermeable as continued curing and wetting occurs. This matter was not considered sufficiently relevant to this study because early repeated tests on walls did not show consistently better performance on retesting, a factor that would have suggested this needed to be accounted for.

Repeat testing of one wall in this test program (3 repeats) showed a small progression to having less water being retained when there were from 9 to 16 days of drying between start of each retest. This matter would require careful planning complemented by small specimen tests to confirm the magnitude of the effect.

The drainage test program on EIFS clad walls formed by adhesively attaching them to a backup wall has been instructive concerning their ability to accept and drain relatively large quantities of water and to retain only a small amount of water.

The EIFS systems were tested without fully knowing how or what surfaces would be most involved in absorption of water draining on to them. The back LA-WPB coating, the adhesive ribbons, the EPS foam and adhesive residue left on that surface, the joints between EPS panels and the starter tracks or starter panels used at the base of the wall are 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 ribbons, these tests showed that exactly how water was introduced into the cavity affected the amount of water retained. But also given the total amount of water passing through each system, the variation found could be considered to be small.

5.3 Summary of 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 without binding. 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, allowed 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 is either free to flow laterally (if a head of water develops depending on the rate of water entry) and potentially find sufficient drain 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. The shape of this vinyl profile (see Figure 1) simulated bevelled wood siding. The momentum of the water leaking out of these holes and sliding along this slope caused some of the water to be thrown away from the wall which wetted the floor for a distance of about 0.4 m away from the gutter at the bottom.

The water that escaped from both edges drained down and wetted some of the wood framing that was not protected by the WRB. As a result, the total weight gained 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 did not build up sufficient momentum to escape from the wall face, but 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 12.

When the walls were dismounted from the test frame at the end of the test, some of the free water still held by the siding drained out on the floor. Some of the water that drained out was recovered by wiping the floor and weighing the wipes. About 10 to 40 grams was recovered this way. Wall 3 (Profile #2 with building paper) had the most water spill out (43 grams). In this case, the moisture content maps showed an increase in moisture content where the free water was expected to be found.

Composite drainage plots of all three test walls are shown in Figure 13 and 14 for the 2-hr and 50-hr time periods.

Figure 12 Example of face drainage from drain holes in vinyl siding (Profile #2)

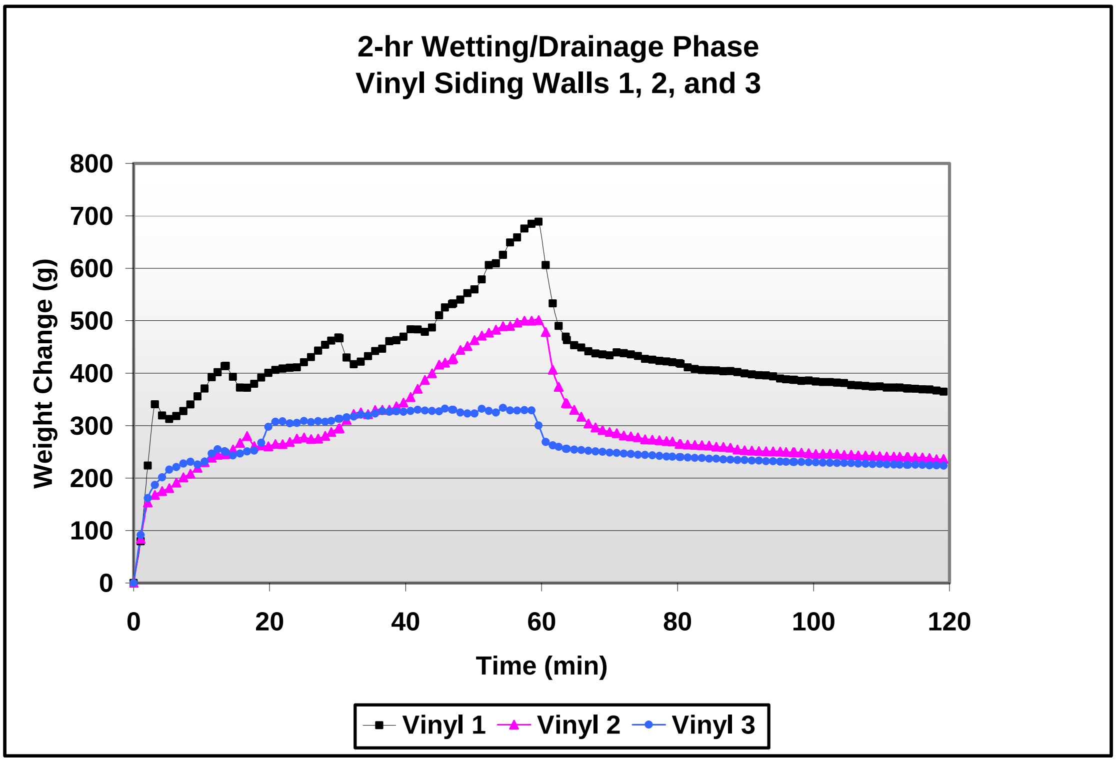


Figure 13 Composite plot of drainage tests on three vinyl clad walls for the 2-hr wetting/drainage period.

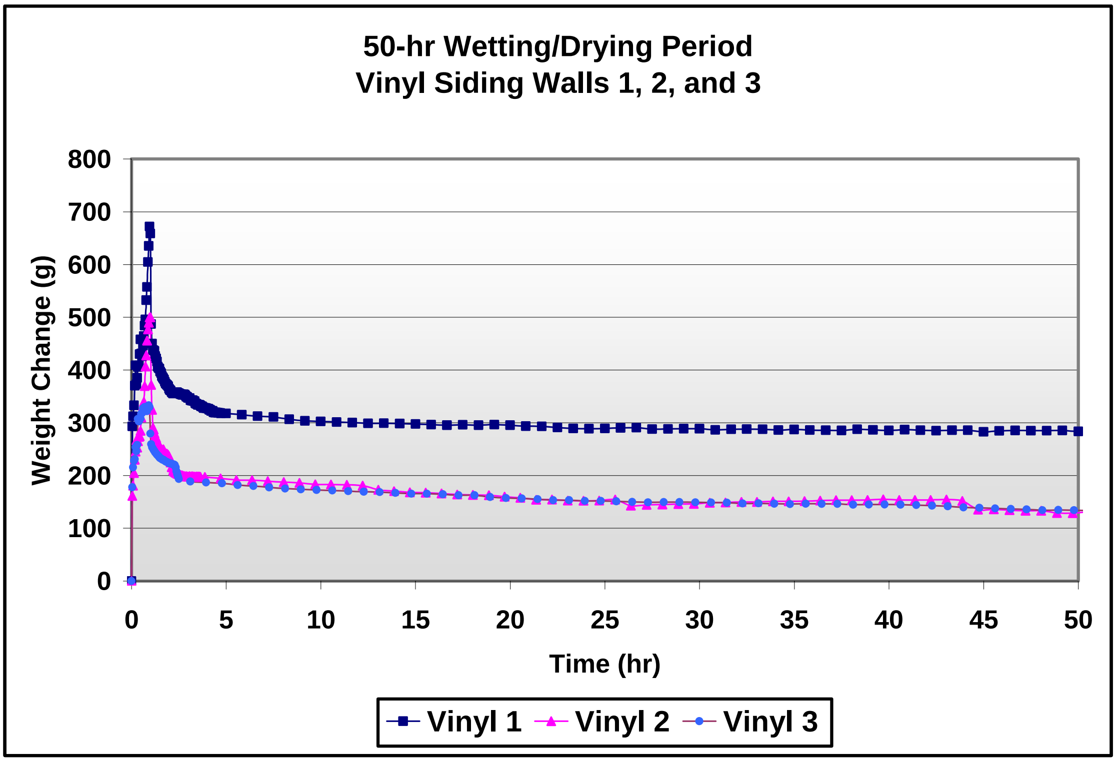
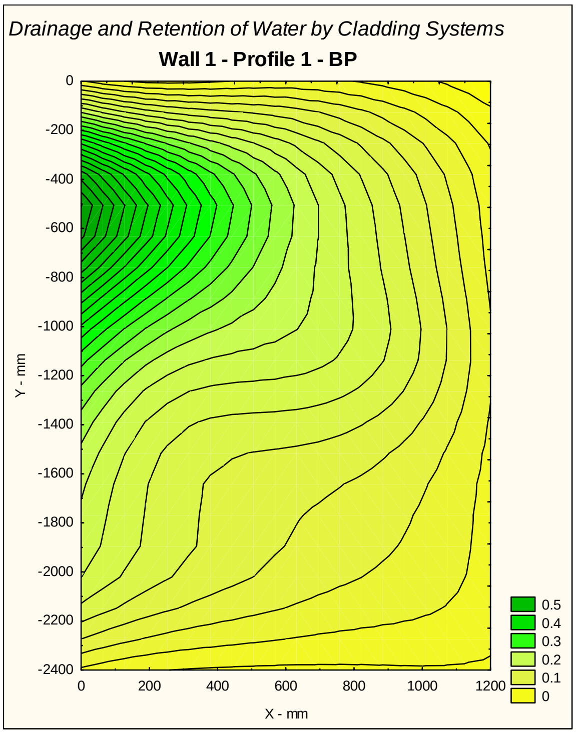


Figure 14 Composite plot for vinyl siding walls over the 50 hour wetting/draining/drying period.

The three plots in Figure 13 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 1 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 2 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 3, 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. Due to the extraneous leakage experienced, it is not possible to compare the ability of the two types of profiles to shed water that may enter a defect as was attempted here.

In Figure 14, the wetting and drying results are presented over the full 50 hours of wetting/draining/drying, Walls 2 and 3 (Profile #2) experienced less storage by wetting of the wood framing than Wall 1 and dried almost identically. The drying rates for Wall 1, 2, and 3 (obtained by regression of the drying curves to the end of the period for each wall) were 0.38, 0.91, and 0.86 g/hr respectively between the 10-hr and 50-hr points on the plot. The total retention at that time was about 130 g for each wall. The free water retained in the joint profile 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. By doing so, rewetting of the WRB may have occurred to allow the contour maps shown in Appendix V of the Part 4 report to show a larger extent of wetting than actually occurred when these walls stood in place during the test.



An example of a moisture map obtained is shown in Figure 15 for Wall 1 that experienced side leakage. Some water may also have leaked behind the WRB. As a result of these undesired events and the fact that the water distribution is concentrated, the retention ratios for these three tests are not reported.

Drying took place from the wood, as well as through the top where the opening was 4 mm.

Figure 15 Moisture change map obtained for vinyl siding wall 1 after the drying period and the wall was dismounted from the balance beam weighing system.

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

- Sealing edges using caulking did not prove to be satisfactory. Subsequent walls built with siding had the edges sealed with sprayed polyurethane foam.
- 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. The loss in weight had several routes for escape.
- At this time, no specific conclusion can be drawn concerning the level of retention compared with other systems. What can be stated generally is that water retention by systems with drainage cavities allow the retention to be spread over a significant area, so the unit concentration is low. The moisture retained by a relatively impermeable direct-applied system, such as vinyl siding, retains the moisture in a more concentrated area.
- The actual area affected was not known but might be assessed with a more discriminating moisture sensing technique than used here.
- Moisture that was retained in the vinyl siding joints as free water is 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 elevations 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.
- Despite the apparent simplicity of the drainage test, and despite the difficulties encountered, the phenomena exhibited have revealed how the test needed improving, and also showed that interpretation of test results is not as simple as originally thought.
- More information is required to investigate direct-applied cladding systems, particularly those involving very low effective vapour permeability. Air and vapour permeability testing of siding systems adds to information and is summarized and discussed in a following section.

5.4 Summary of Results for Wood Based and Fibre Cement Siding Systems

The objective of the program was to involve as many types of siding as possible in combination with various types of drainage cavities. The walls reported on in this section involved 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 this range of systems was their assembly as *direct-applied* or as *drained* systems. The performance of each group will be summarized in this section.

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. On the other hand, walls that were built with an intentional drainage cavity were tested to see if water retention was a function of the way that water enters the wall. 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). The use of urethane spray foam to seal the ends (edges of the assemblies) proved to be more successful in preventing lateral leakage than the use of caulking tried in tests of vinyl siding. In the case of these siding tests, their ability to drain water from behind the siding through the joints was significantly greater than occurred for vinyl siding. Edge sealing was more of a precaution that flow would not take place laterally out of the test walls. In contrast, all walls with drainage cavities permitted water to drain to the bottom of the wall where it was collected by the gutter attached at the base. Most of the water that escaped through joints in the siding dribbled down the face of the siding and was collected as well.

It is worth noting that building paper was used for only one of these walls. For all other walls, SBPO was used. The experimental plan included many variants of siding types and means of providing drainage cavities. It was not realistic to include water retention by the WRB material as one of the key variables. It is believed that for the short test period, given the rates of drying found, that little difference would have been found related to WRB type relative to the uncertainty of results from any one test. That statement should not be construed to imply that the properties of the WRB are not important to the field performance of outer wall systems. The vapour permeability of the WRB has an influence on the moisture flow from a drainage space to wood-based (and other) sheathing and, in climatic locations where chronic wetting can be expected, that variable would have to be accounted for in design of such walls.

A second point to note is that 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.

5.4.1 Direct Applied Siding

Composite drainage plots of all direct-applied sidings are provided in Figures 16 and 17. In all cases a SBPO weather resistant barrier was employed. Also included in this comparison is a retest of one 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. Mismatch of siding with the wall surface and at siding overlaps, depending on the profiles, permitted most of the water to escape 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 the 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 retest was done because the linkages were disturbed during the 48-hr drying period and a step occurred in the plot (Figure 17). For this wall, there was only a 4-day period between the start of each of these tests. Drying of the wall on retest occurred below the starting zero for that test because there was still some residual retained moisture from the first wetting.

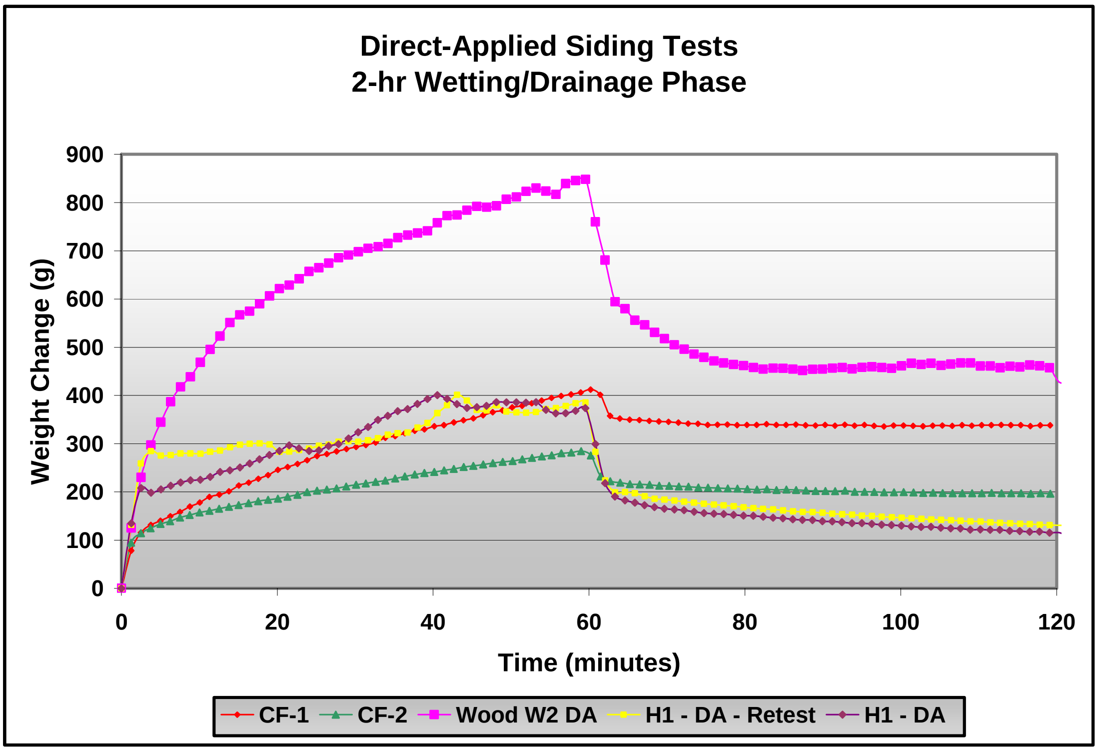


Figure 16 Composite plot of weight changes during the wetting/drainage phase for all walls with siding that was applied directly to the basic wall.

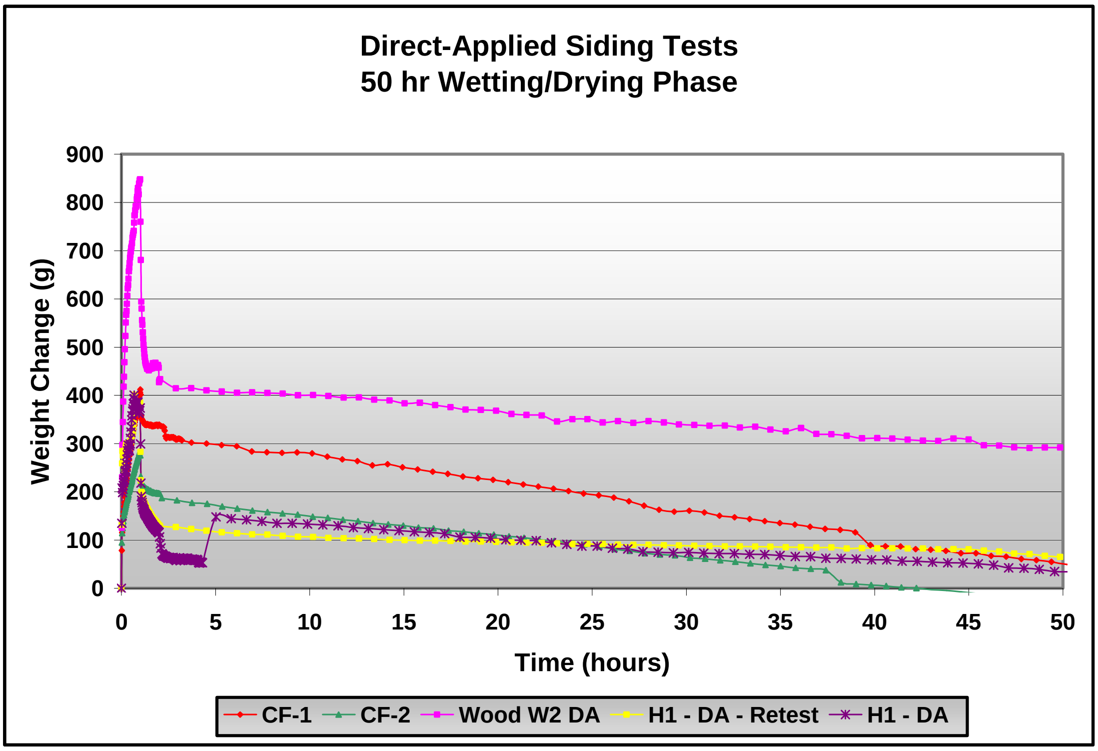


Figure 17 Composite plot of weight changes during the 50-hr wetting/drainage/drying test period for all walls with siding that was applied directly to the basic wall.

- 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 vertical scale for the figures shown was based on the peak weight recorded for this wall.
- The water retained by the hardboard siding increased rapidly at the start of wetting and then tapered off. The fibre-cement sidings, on the other hand, 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.
- The water take-up rate for the first few minutes of the test appeared to be identical for all walls tested.
- The two relatively identical fibre-cement walls retained quite different amounts of water right from the beginning of the drainage tests.
- 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 siding was otherwise exposed to air. The wood siding, on the other hand, was installed flat against the SBPO and was capable of retaining more water. It must be stated that the manufacturer of this siding recommends this siding be installed on batten strips. That recommendation, using this profile, was included for one wall in this study.
- In comparing these plots with those presented earlier for EIFS walls, it is important to appreciate that the area of wall wetted is quite different and the consequences of the magnitude of water retained is different. Concentration of retained water and its location has greater implications for durability than we could demonstrate by these tests.

5.4.2 Siding Applied on Drainage Mats and Batten Strips

In contrast with direct-applied siding, all siding installed on materials intended to allow drainage 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 18 and 19. As a result of the greater surface area wetted by the water on its way to the bottom of the wall, the amount of water retained was likely dispersed over a larger total area and the unit concentrations are likely lower (except at joints).

The following observations were drawn from the plots shown in Figure 18 and 19:

- Contrary to expectations, the system with the largest initial retention was for the wood siding profile W2 installed on wood batten 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. The trickle trough was attached directly to the wall and the fingers on the drip edge were very close to the SBPO sheathing membrane. The droplets from the trough slid down to the SBPO. Retention by SBPO was expected to be relatively low. However at least one trickle of water deposit occurred directly on top of each batten strip and this water was absorbed quickly into the end grain of each batten. Despite the higher retention at these locations, this wall dried more quickly than the others on drainage mats whether water was directed down the back or front of the drainage cavity, because of the larger drainage space. Also the exposed ends of the batten strips were at the top of the drainage cavity and were able to dry quickly.

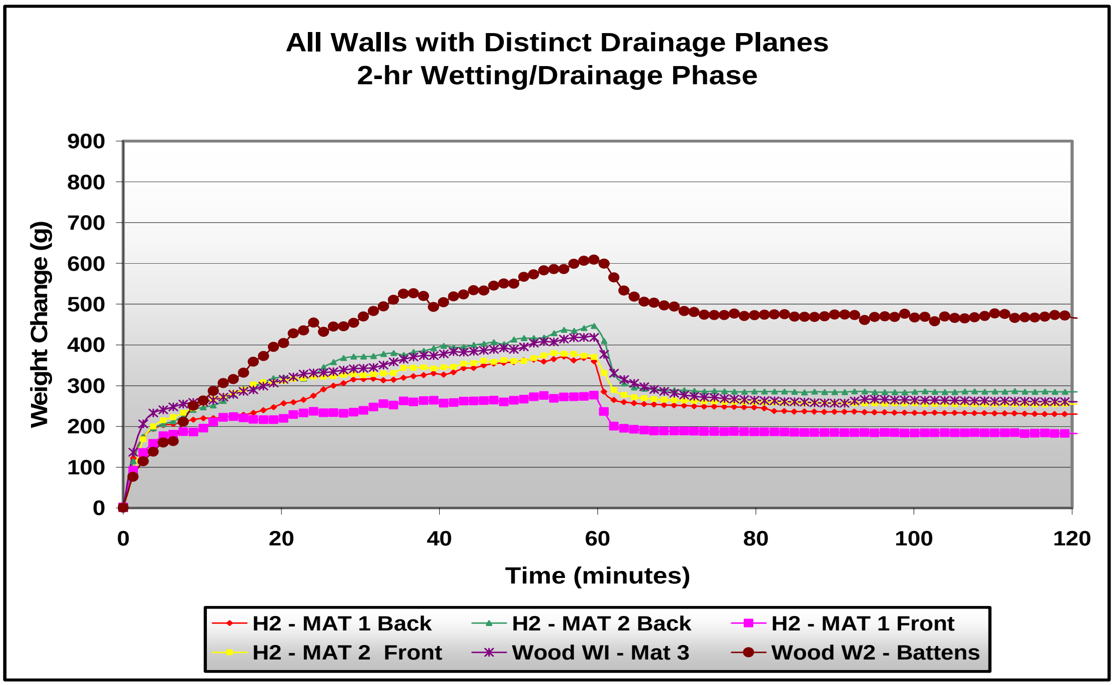


Figure 18 Composite plot of weight changes during the 2-hr wetting/drainage phase period for all walls with siding that was applied over some form of drainage matrix or batten strips.

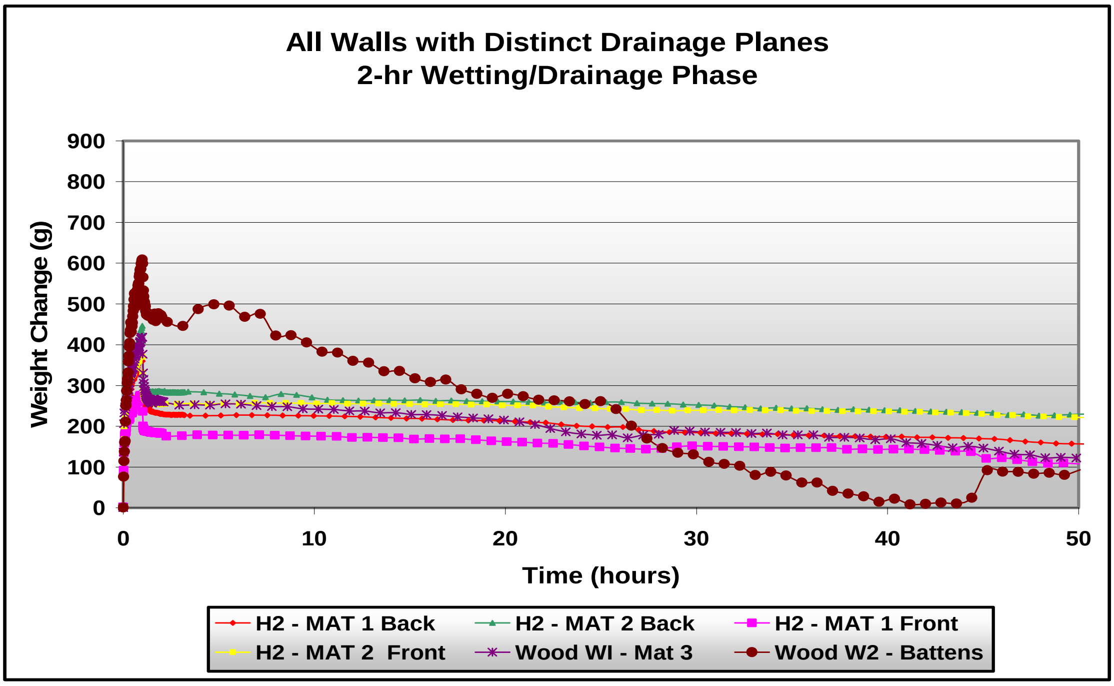


Figure 19 Composite plot of weight changes during the 50-hr wetting/drainage/drying test period for all walls with siding that was applied over some form of drainage matrix or batten strips.

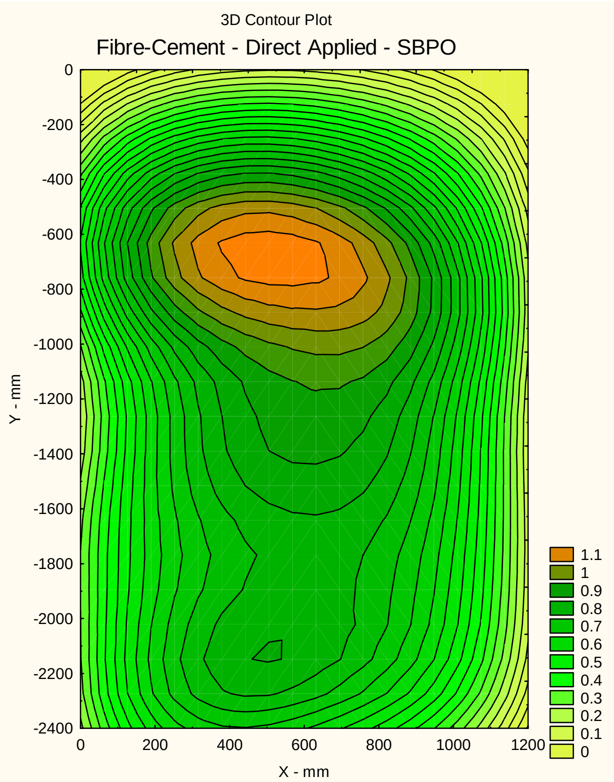
- There was a ripple in the drying curve for the wall with batten strips which suggests that this wall was more sensitive to variations in the environmental conditions in the lab as recorded during this test and as presented in the Part 5 report in this series. That would be expected to occur because the drainage space provided was very large compared to that provided for other walls and would allow more unobstructed flow of air. The data in the plot was decimated for the purpose of clarity and the ripple variation is not obvious. However the full data files were used for the plots in Part 5. The air conditioning cycle was 1.3 hours long and its effect on drying rates was detectable. This suggests that when weather conditions change in practise, cladding on batten strips would respond quickly to attain a different equilibrium state.
- 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.
- The vertical scaling of plots in Figures 16 to 19 was kept the same to allow ready comparison of walls with and without intentional drainage planes.

5.4.3 Location of Water Retention

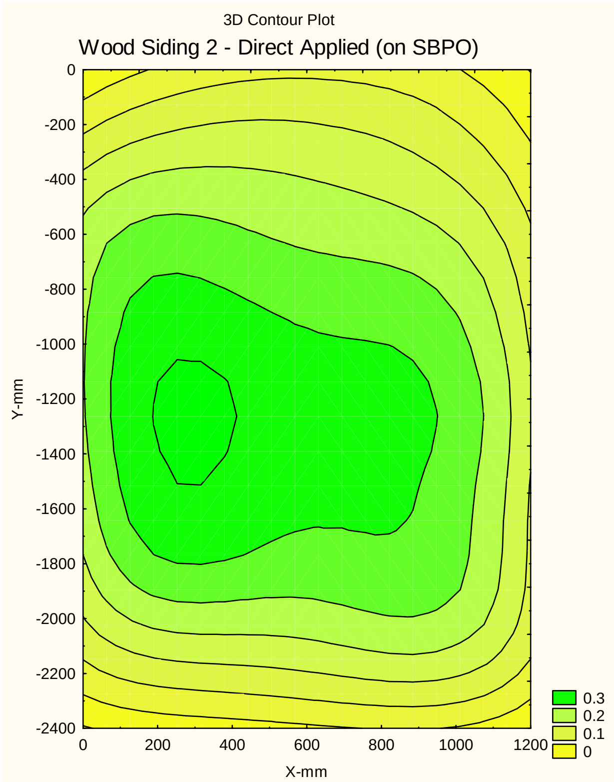
Relatively little can be surmised about the location of retained moisture from the weight measurements alone. The moisture maps provide some indication although, as noted in the earlier testing on EIFS and Vinyl siding, these plots are based on a relatively crude measurement grid. The moisture change plots for these siding walls do however provide some additional information. A few moisture maps are provided in Figure 20 to illustrate what can be learned from them in the case of direct-applied siding:

Several observations about distributions for direct-applied siding in Figure 20 follow:

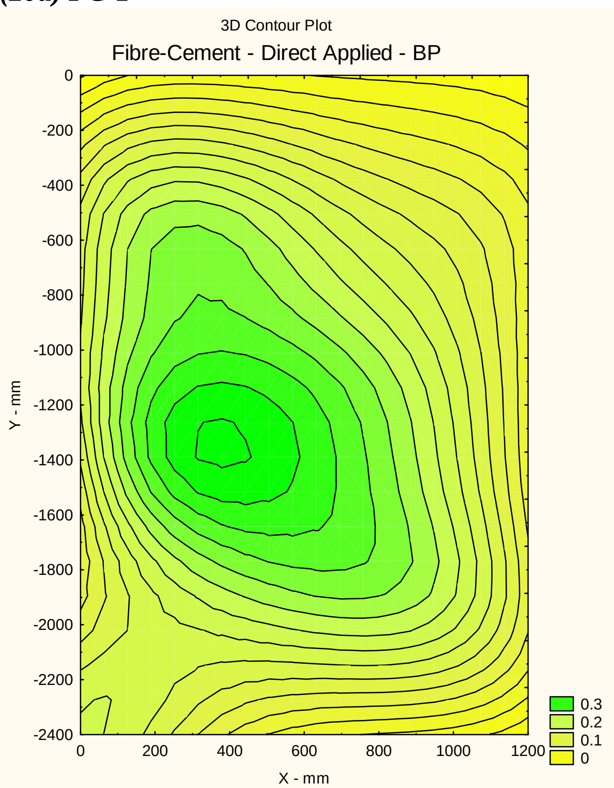
- One of the direct-applied fibre-cement siding walls retained more water than its matching wall. It also appears to have held that moisture in the upper portion where the water was introduced. The retention contours for the second wall peak lower down suggesting that some of the moisture found its way 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.
- The algorithms for contour mapping may infer moisture levels that are not true, particularly where there are high gradients in the moisture content changes. By holding the MC increment constant (0.1 % for example) the algorithm is forced to create contours for each increment and by doing so in that circumstance, a wider region of wall area is apparently involved at a high retained MC. This may be the case in comparing Figures 20(a) and (b). A much higher resolution of measurement points is required to pin point were water has been retained.



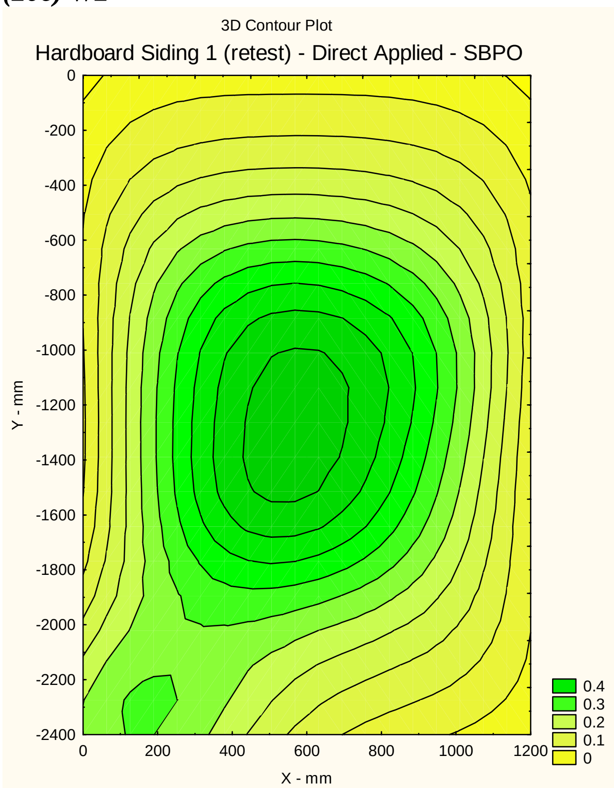
(20a) FC-1



(20c) W2

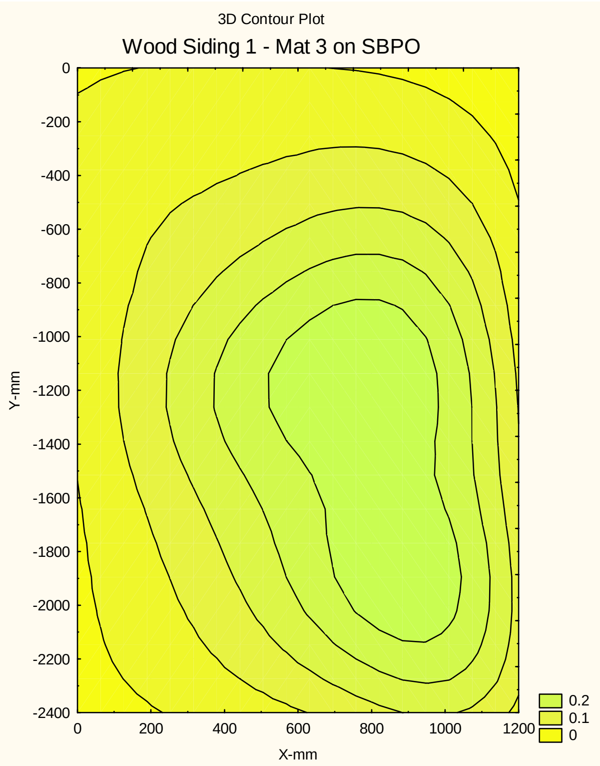


(20b) FC-2

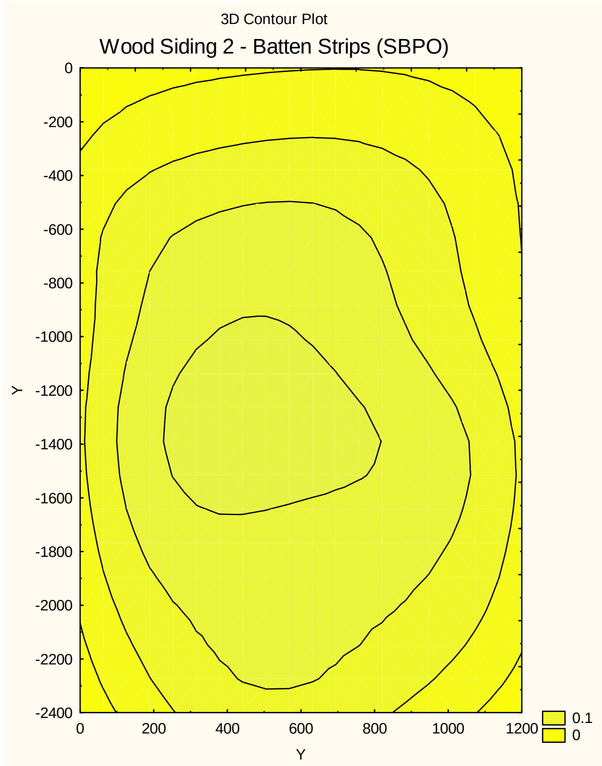


(20d) H

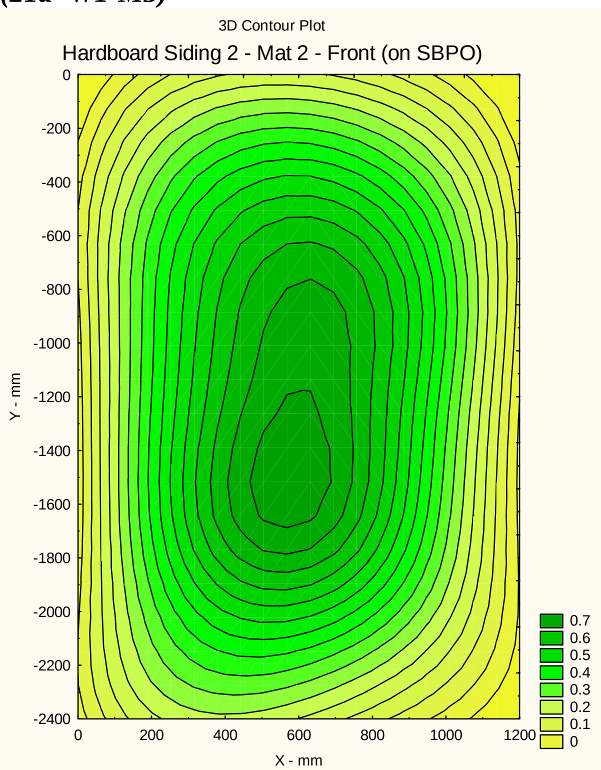
Figure 20 Moisture change maps for several cases involving direct-applied siding



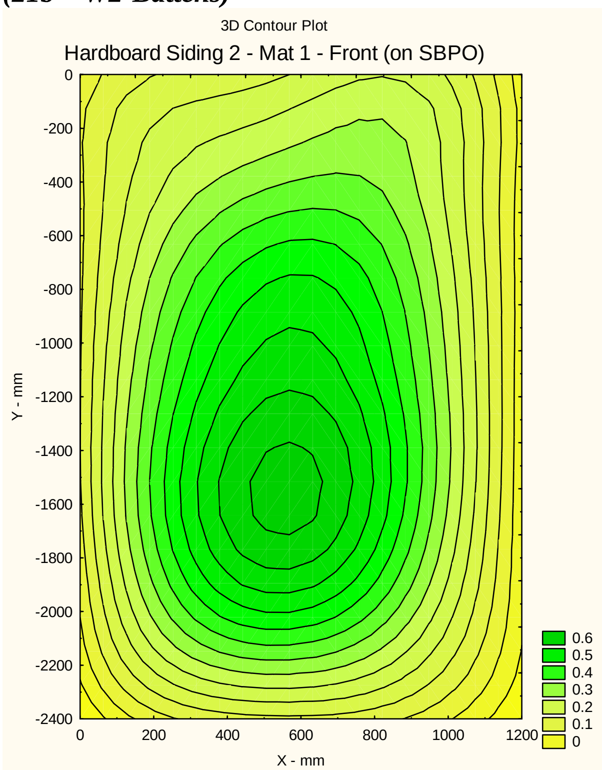
(21a- W1-M3)



(21b – W2-Battens)



(21c-H2-M2)



(21d-H2-M1)

Figure 21 Moisture change maps for siding systems applied over defined drainage cavities

Several additional observations may be made concerning moisture mapping of siding provided with drainage cavities. These relate to moisture change maps shown in Figure 21.

- Whether water was trickled down the front or back of the drainage cavity involving mat systems the maps were very similar. This signifies that about the same degree of wetting occurred in both cases. The comparisons that led to this observation are provided in Part 5 for hardboard siding. Only one of each plot per mat type is shown in this report.
- The case involving wood siding applied to batten strips, with the application of water directed near the back of the drainage cavity and partly over the batten strips themselves, dried very well, but some residual retained moisture appears 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 this was likely due to the way that drying took place. 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. We do know, from the RH records, that the portion of wall width below the trickle trough during wetting and drying has a higher RH than ambient and was particularly different from the sensors on either side of the trough. The temperature measured was either higher or lower than ambient depending on the temperature of water fed into the wall. The temperature of the air rising from the wall was usually warmer than on either side of the trickle trough. Two possible symmetric local convective loops would have air enter the wall at the top on either side of the trickle trough and pick up moisture and then rise, hence drying out the upper portion of the wall. 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.

5.5 Air Flow Characteristics of Drainage Cavities

Air flow characteristics of the drainage cavities of all walls having some form of cavity were measured. The test protocols are described fully in the report on that work – Part 6. In this section we will briefly describe the procedure used and the results obtained.

Simply, an air supply pump was used to force flow through a 7 m long 50 mm diameter heavy duty vacuum cleaner hose to a distribution box attached to the top of each wall which directed air into the top of the drainage cavity. Flow straighteners were employed at the entry point to the drainage cavity to provide relatively laminar flow across the full width of each wall. All air entering that cavity exited out of the base of the wall whether there were starter strips of not. All joints in the siding were taped to prevent leakage so that all flow could be attributed to that being expelled through the drainage cavity. Measurement of air flow was made in-line prior to delivery of air to the distribution box. The RH and T of the air entering the distribution box were also measured.

The pressure differential measurements across the majority of the drainage cavity itself were taken near both ends. The average pressure in the main flow path was obtained by installing 6 pressure taps across the width of the wall at each end of the drainage cavity. Each set of 6 pressure taps was connected to a plastic bucket chamber for pressure averaging. The pressure differential between each plastic bucket chamber provided the pressure drop across this portion of the flow path.

The pressure differences measured were (a) between the distribution box and the top line of pressure taps, (b) between the two lines of pressure taps in the drainage cavity, and (c) between the bottom line of pressure taps and the air outside of the wall. These pressure difference pathways are identified as D1, D2, and D3 respectively. During the analysis it was determined that the pressure in the distribution box had been measured in an inner compartment and that it did not reflect the pressure just prior to entry to the drainage cavities. Pressure differentials were measured appropriately for only the D2 and D3 pathways.

Figure 22 Overview of test set-up for measurement of air flow characteristics of drainage cavities.

The fitting of test data was made to the following power expression:

$$Q = c\,P^{\,n}$$

In keeping with convention, the units for the flow Q will be L/s and pressure drop P is in Pascals (Pa). The coefficients c and n were obtained through regression of the measured flow and differential pressures for the path being evaluated. The units of flow as measured were L/min and the range of flow measured was up to 20 L/min.

The value of the coefficient (c) derived from regression was normalized for path width and path length. Thus,

$$c_n = c/60 \bullet P_L / P_W$$

where P_w = path width (m)

and P_L = path length. (m)

Thus for a given pressure difference, the value of "c" to use in the equation for obtaining flow under other circumstances and dimensions is

$$c_n \cdot P_w / P_L .$$

In the case of concentrated flow resistances, such as that offered by starter tracks or starter panels, it will be more appropriate to treat the path length as unity.

5.5.1 Air Flow Characteristics of Drainage Cavities in EIFS Walls

The flow coefficients for Paths D2 and D3 for paired EIFS walls (by manufacturer) 1-4, 2-5, and 3-6 are summarized in Table 3. For all of the D2 pathways, i.e., the main drainage cavities, the exponent was near or slightly above unity when fitting to the power equation. The regressions for those air flow paths were then repeated as linear regressions with zero intercepts. This signifies that despite the potentially obstructed narrow pathways offered by adhesive ribbons, the flow was essentially laminar. On the other hand, the exponents for the D3 pathways ranged from 0.53 to 0.65 signifying that the measured flow was predominantly turbulent.

Table 3 Summary of flow coefficients for pathways D2 and D3 for EIFS walls.

EIFS Wall No.	Manufacturer	Initially Best/Worst Retention	Path Designation	Length of Path (m)	Measured Flow Coefficients c (min.Pa^n/L)	n	Regression Coefficient R^2	Normalized Flow Coefficient c_n (s.Pa^n/L)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	A	Best	D2	1.905	0.325	1.000	1.000	0.0085
1	A	Best	D3	1.000	0.897	0.587	0.999	0.0123
4	A	Worst	D2	1.905	0.174	1.000	0.997	0.0045
4	A	Worst	D3	1.000	0.722	0.564	0.999	0.0099
2	B	Best	D2	1.905	0.099	1.000	0.999	0.0026
2	B	Best	D3	1.000	1.449	0.652	0.999	0.0198
5	B	Worst	D2	1.905	0.099	1.000	0.999	0.0026
5	B	Worst	D3	1.000	5.983	0.646	0.998	0.0818
3	C	Best	D2	1.905	0.212	1.000	1.000	0.0055
3	C	Best	D3	1.000	0.700	0.543	0.998	0.0096
6	C	Worst	D2	1.905	0.208	1.000	0.997	0.0054
6	C	Worst	D3	1.000	0.700	0.533	0.999	0.0096

Note 1 The width of all pathways in EIFS walls was assumed to be 1219 mm (4 feet)

Note 2 The normalized flow coefficient was the value in column (6) in SLPS divided by the wall width and multiplied by the path length as tested, except for D3 pathways (see note 3).

Note 3 The path length for D3 was 0.077 m for all EIFS walls. Since the flow resistance is largely attributed to the starter track or panel, it will be assigned a concentrated rather than distributed resistance, and the path length will be taken as unity.

The coefficients for the D3 pathways, i.e., some short portion of D2-like cavity plus the concentrated resistance to flow provided by the starter track or starter panel, were considered as lumped resistances. This was because the concentrated effect of that resistance dominated the measurement. The one exception was the starter panel used by Manufacturer B which offered the least resistance. D3 pathway results include the exit flow characteristics.

The flow characteristics based on the flow coefficients in Table 4 for the D2 and D3 pathways are shown over a 20 Pa pressure range in Figure 23 and 24 for the EIFS walls tested. As far as the D2 pathways are concerned, both walls in the pair experienced nearly identical resistance to air flow (Manufacturers B and C) and are nearly indistinguishable from each other on the plots. There were differences between Wall 1 and 4 for Manufacturer A.

In the case of the D3 pathway, the resistance to flow for the starter tracks used by Manufacturer C was identical in the two walls tested. Some difference was seen for the starter track used by Manufacturer A. The starter panel used by Manufacturer B was quite open and offered little resistance.

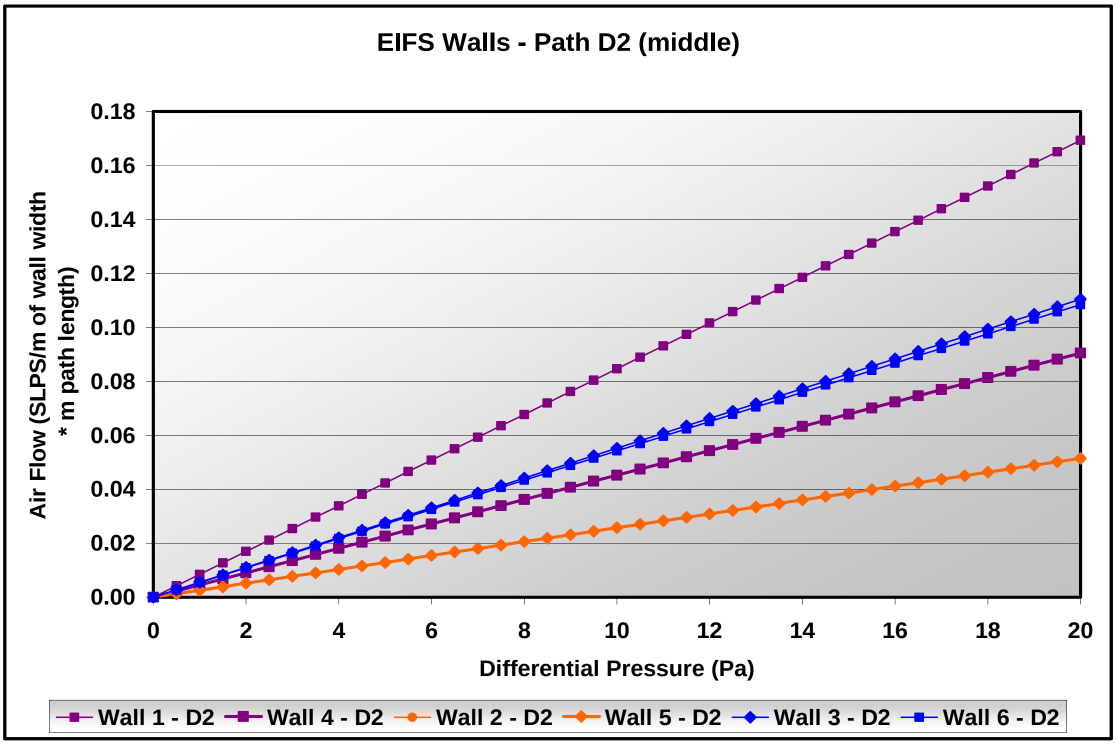


Figure 23 Normalized flow characteristics for EIFS drainage cavities (the D2 pathway).

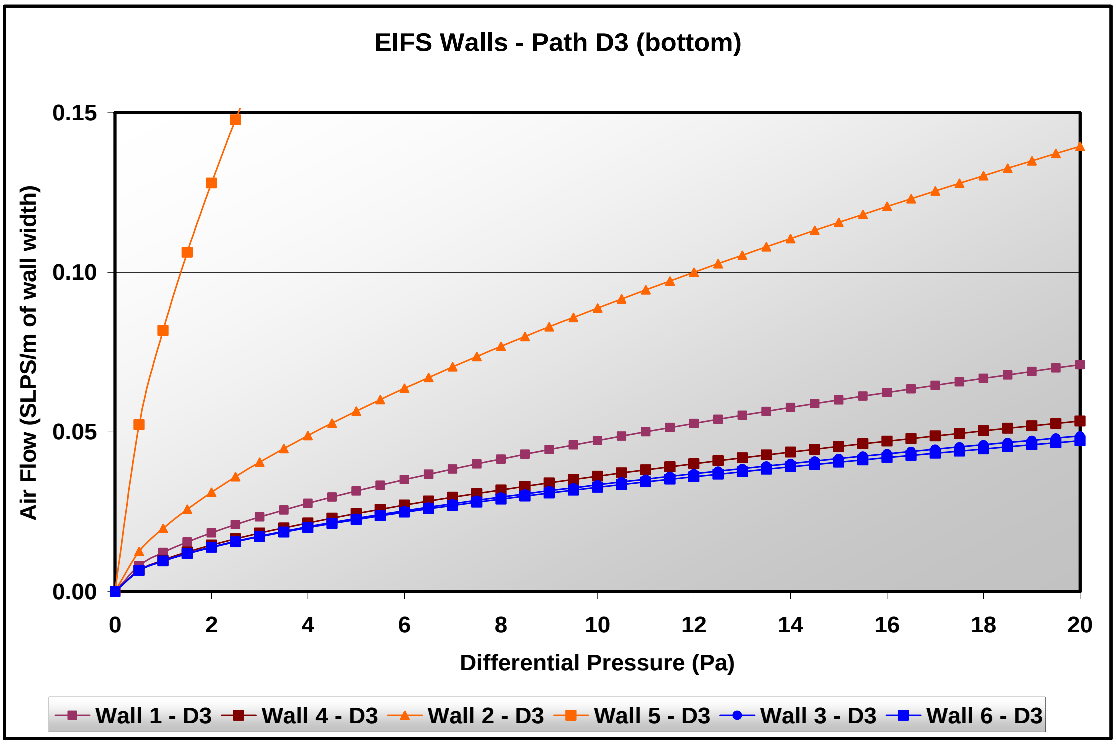


Figure 24 Lumped flow characteristics for EIFS starter tracks and starter panel (the D3 pathway).

5.5.2 Air Flow Characteristics of Drainage Cavities Involving Wood and Hardboard Siding

In a similar manner, air flow tests were conducted on all the remaining walls having distinct drainage cavities. A summary of those results are provided in Table 4. As for the EIFS walls, the D1 pathway results are omitted because of the error in location of the pressure taps on the driving side of the flow stream. One D3 pathway (W2 siding on batten strips) could not be measured reliably because of the very low pressure drop over the short distance involved and by the presence of significant turbulence in the relatively large drainage cavity (19 mm).

As noted in the Table 4, the D3 pathway length was applied in the same way as for the D2 pathway since there were no special starter tracks or gutters used (unlike the tests on the EIFS walls reported in the previous Section).

The D2 pathway exhibited laminar flow (n=1) for the mats that were formed with a matrix of fibrous elements (Mats 1 & 2). On the other hand, Mat 3 which was a dimpled solid sheet of polystyrene plastic offered greater obstruction to flow of air in the cavity which caused turbulence (n = 0.624). The large drainage cavities formed by batten strips experienced a high degree of turbulence which suggests that the flow straighteners, as applied in this case, were not successful in introducing laminar flow to the top of the cavity. It would normally be expected that flow within a cavity of that size would be laminar except for some turbulence associated with surface roughness of the back of the wood siding or crinkles in the WRB used. The plots of the equations described by the coefficients in Table 4 are shown in Figures 24 and 25 for pathways D2 and D3.

Table 4 Summary of flow coefficients for pathways D2 and D3 for siding on drainage cavities.

Wall No.	Manufacturer	Path Designation	Length of Path (m)	Measured Flow Coefficients c (min.Pa^n/L)	n	Regression Coefficient R^2	Normallized Flow Coefficient c_N (s.Pa^n/L)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
H2-Mat1	D	D2	1.677	1.986	1.000	0.993	0.0460
H2-Mat1	D	D3	0.154	13.277	0.795	0.997	0.0283
H2-Mat2	D	D2	1.677	1.759	1.000	0.992	0.0408
H2-Mat2	D	D3	0.154	11.493	0.758	0.968	0.0245
W1-Mat3	E	D2	1.765	2.163	0.624	0.999	0.0527
W1-Mat3	E	D3	0.146	12.024	0.531	0.992	0.0243
W2-Battens	E	D2	1.809	34.498	0.500	0.946	0.8625
W2-Battens	E	D3	0.146	*	*	*	*

Note 1 The width of all pathways in the H2 and W1 walls was assumed to be 1206 mm (4 feet minus 0.5 inches for the foamed sealant). For W2 the width was 1029 mm (4 feet minus the width of 3 batten strips).

Note 2 The normalized flow coefficient was the value in column (5) in SLPS divided by the wall width and multiplied by the path length as tested.

Note 3 The path lengths for D3 measurements are noted in the table. Since no special starter tracks were used the flow resistance should be similar to the distributed resistance found for the D2 measurement.

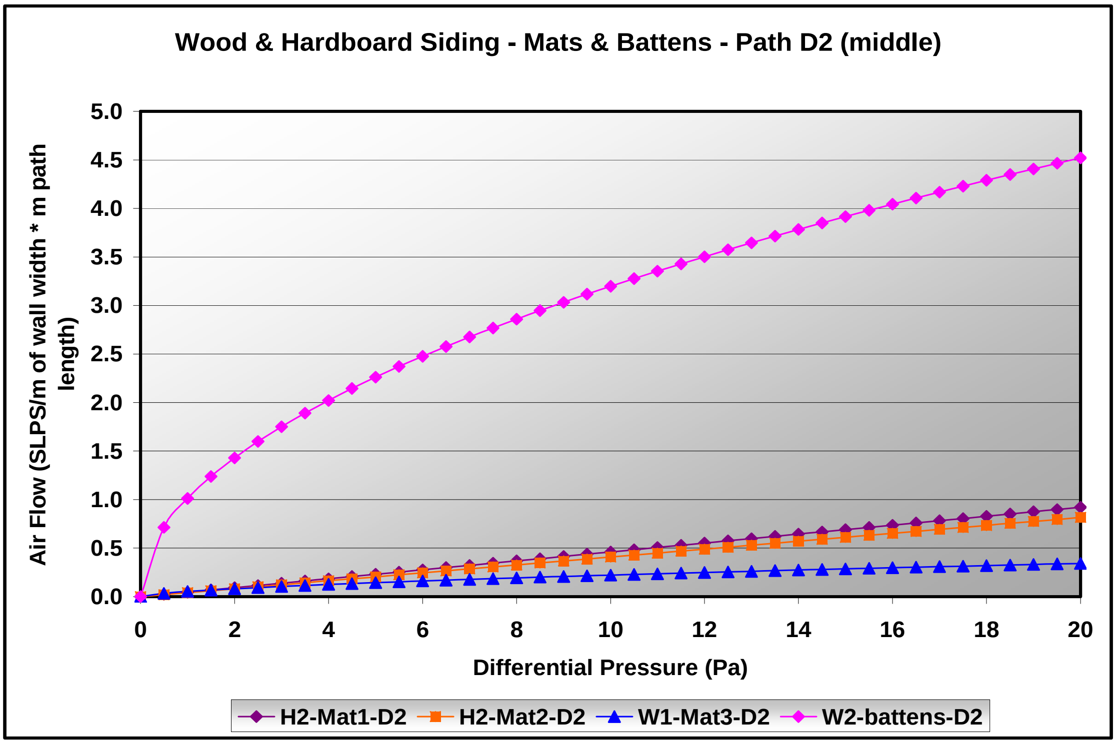


Figure 25 Air flow characteristics of drainage cavities formed by mats and battens, the D2 pathway.

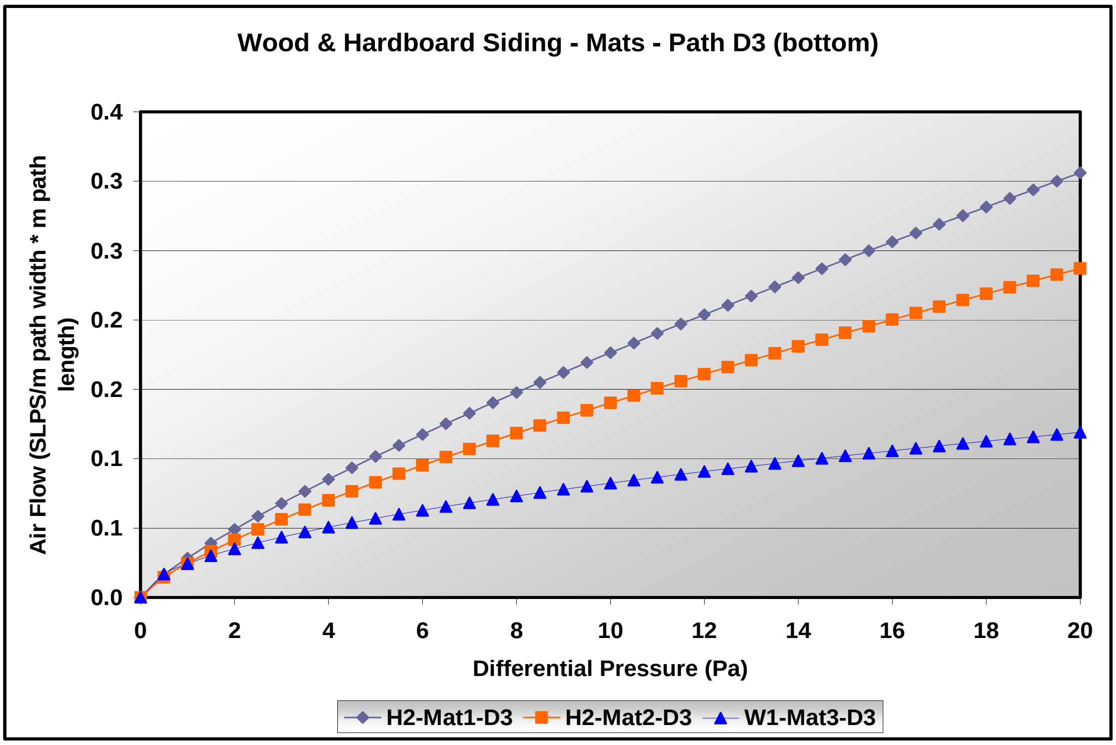


Figure 26 Air flow characteristics of drainage cavities formed by mats, the D3 pathway.

5.5.3 Discussion of air flow characteristics results

For comparison, the results for D2 pathways for all walls having drainage cavities have been plotted in Figure 27. These show the relative ease with which air can flow through the drainage cavity for any given differential pressure for the walls tested. This air flow is not necessarily related to the drying capability of the walls tested; they include different systems that retain water in different ways. It is expected that drainage cavities will have some effect. That question will be considered in Section 6.

Overall comments and findings from the air flow measurements of drainage cavities are:

- The drainage cavities of all EIFS test walls exhibited somewhat similar air flow characteristics; for two manufacturers the pairs of test walls exhibited nearly identical performance.
- All D2 pathways for the EIFS walls possessed laminar flow despite the potential obstructions provided by the adhesive ribbons.
- The flow characteristics of the D3 pathways (involving starter tracks) were relatively restrictive. The starter panels used by Manufacturer B were relatively open as expected. Unexpectedly, the results for one wall (EIFS W2) were relatively restrictive yet were still more open than those with specific starter tracks (Figure 24). Close examination of the raw data files and the experimental technique used, could not resolve why this unexpected result was obtained.
- The flow characteristics of mesh-type drainage mats demonstrated laminar flow.
- The drainage mat involving a dimpled plastic sheet offered multiple obstructions to flow and the air flow was characteristic of more turbulent flow.
- The mesh type mats were considerably more permissive than the drainage cavities of EIFS walls as they provided a drainage space of approximately 6 mm compared with the EIFS walls (2-3 mm).

- Measuring flow characteristics of the drainage cavity formed by use of batten strips proved to be somewhat problematic using the current test set-up. Excessive turbulence was introduced in the space and greater fluctuations were measured. Clearly, at 19 mm thickness, this drainage space should allow relatively uninhibited flow compared with all others in this test program.

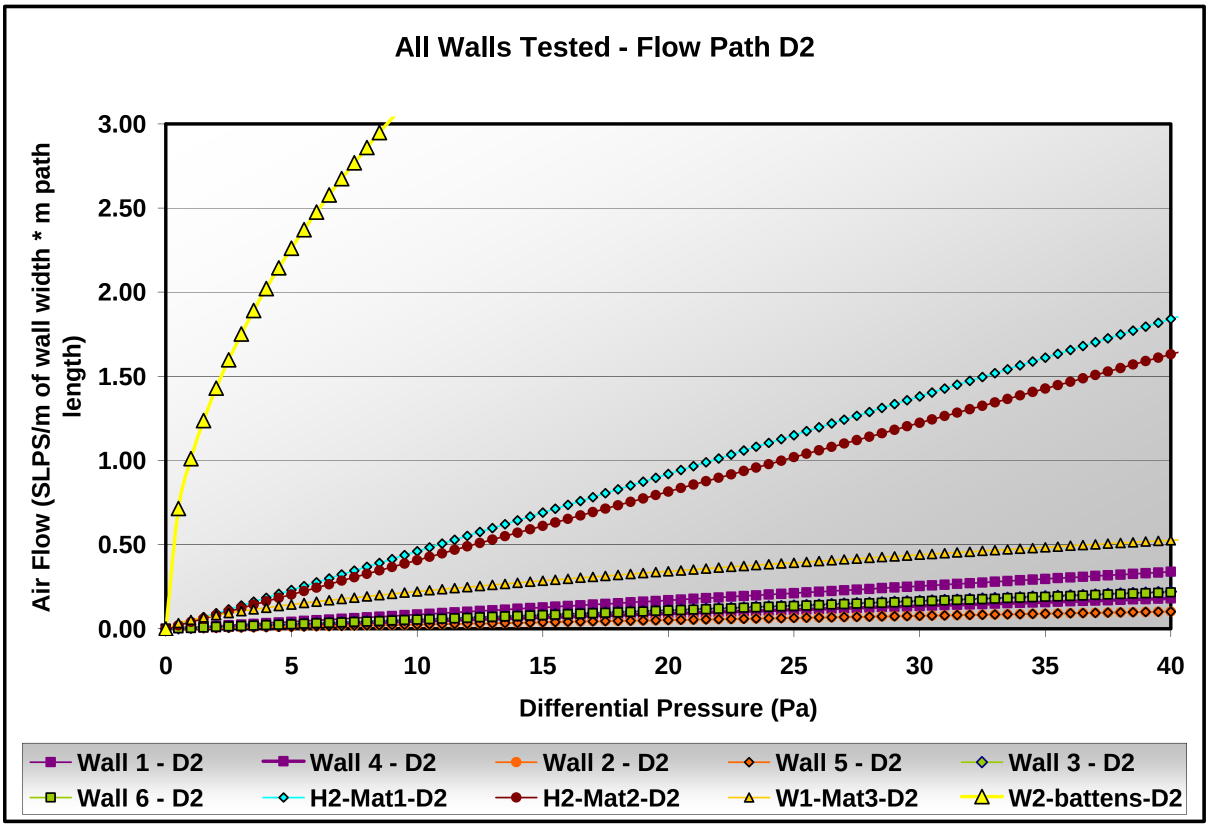


Figure 27 Comparison of all measured main drainage cavity flow characteristics (D2)

From the point of view of the experimental procedures used, this experience suggests several improvements be made.

- The flow of air should be reversed by being drawn from rather than supplied to the drainage cavities. This requires a reversal in the connection at the regenerative pump, and reversal of the flow sensors.
- The distribution box used needs to be made more open to the space at that end of the cavity.
- The negative pressure at the mass flow sensors should be kept as low as possible and be measured together with its temperature in the vicinity of the flow sensors to allow proper correction for the density of the air passing through them
- Preferably, pressure taps should be installed at the time walls are being built in order that they are properly located with respect to the layers at which those measurements are of interest. In this instance, all pressure taps were installed after the drainage tests were completed with less certainty as to the adequacy of their penetration into the flow path.

The results obtained were as expected – more open drainage cavities allowed more air to flow through at any given differential pressure. Of significance were measurements of the flow characteristics of the starter tracks which showed significant restriction for some types. This merely highlights the importance such details might have on the drainage/drying capability of walls. The impact of these characteristics on drying ability will be examined further in Section 6.

5.6 Air Flow and Vapour Flow Characteristics of Siding Joints

This series of supplementary tests were performed on samples of walls built with some of the siding samples represented in the study to enable both their air tightness and vapour permeability to be measured. Siding materials were shipped to Syracuse University and the test samples were assembled and tested there. A detailed investigation of these tests was provided in the Part 7 report in this series.

The size of the test assemblies was big enough to provide representative test results that might be expected in the field. Yet, they were small enough to be handled by two people. Typically, air permeability tests of construction materials were conducted with specimens measuring approximately 3 ft by 3 ft. The specimens for this test program were fabricated to 876 mm by 876 mm (34.5 by 34.5 inches).

To impart an air tight seal between the siding and the perimeter of the wood framing, high density closed cell spray polyurethane foam was applied as shown in Figure 28. The foam was applied in two passes on opposite sides of the frame to ensure that lateral leakage at the perimeter of the frame would not occur.

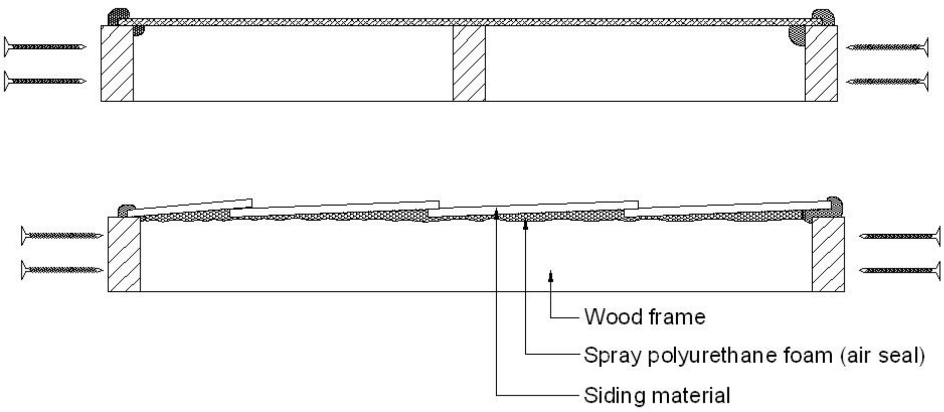


Figure 28 Cross section detail of the siding board/wood frame interface with sprayed in place polyurethane to impart air tightness around the perimeter of the assembly.

Each specimen was mounted in a special pan for air and vapour flow testing. Enough space was provided for the liquid seal, i.e., a hot wax seal was applied between the supporting pan and the frame of the specimen. The square pans were constructed from 1/16 inch thick T6061 aluminium sheet stock. Each pan had a 2-inch ledge, which provided support for the specimen. The pan also had a 2-inch high rim to form a joint for the hot wax seal. Two 2-inch wide flanges were welded to the bottom of the pan to function as baffles to restrict water from splashing the underside of the siding panels when the pan was used for vapour transmission tests. A photo of one such pan is shown in Figure 30.

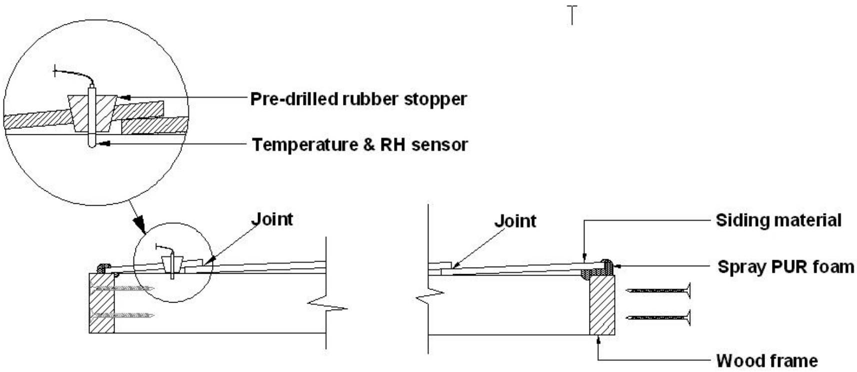


Figure 29 Cross section through a test specimen showing placement of the temperature and RH sensors.

Figure 30 Supporting pan for air leakage and vapour permeability testing of siding wall specimens.

Five siding types were represented in these tests and three specimens were built for each type. Included were the two vinyl siding profiles, the two hardboard siding profiles and the fibre cement board siding. Materials for two wood siding profiles (as used for the drainage tests) were supplied but could not be included in the test series at this time.

5.6.1 Air flow characteristics of siding joints

The air flow rates and differential pressures were recorded when they stabilized at each setting of differential pressure. This was repeated in steps of 0.05 inches of water head to acquire a sufficient number of data points to describe the air permeability function for each assembly.

Some siding types were inherently leakier than others. To stay within the range of the flow meters available for these tests the flow through some types of siding was reduced by blocking one or more joints. One out of three joints for type 4 siding and three out of 5 joints for type 5 siding were blocked with caulking. The caulking was left in place for the vapour transmission testing. All results have been normalized per meter of joint assuming there was no unintended leakage from each assembly tested other than that through the joints left unsealed.

These tests provide the air flow characteristics of siding joints. In the Part 7 report, the differential pressure was assigned to the Y-axis and the resulting flow was assigned to the X-axis for the plots shown with their corresponding power fit equations. Subsequent analysis provided the coefficients for the inverse relationships as well. The results for each type of siding assembly are plotted in each of Figures 31 and 32 for the vinyl siding (P1 and P2) and hardboard profiles (H1 and H2) respectively. The fibre cement board siding tests (FC) were not shown separately here. However, a composite plot of all tests is provided in Figure 33 to which the fibre cement board test results have been added.

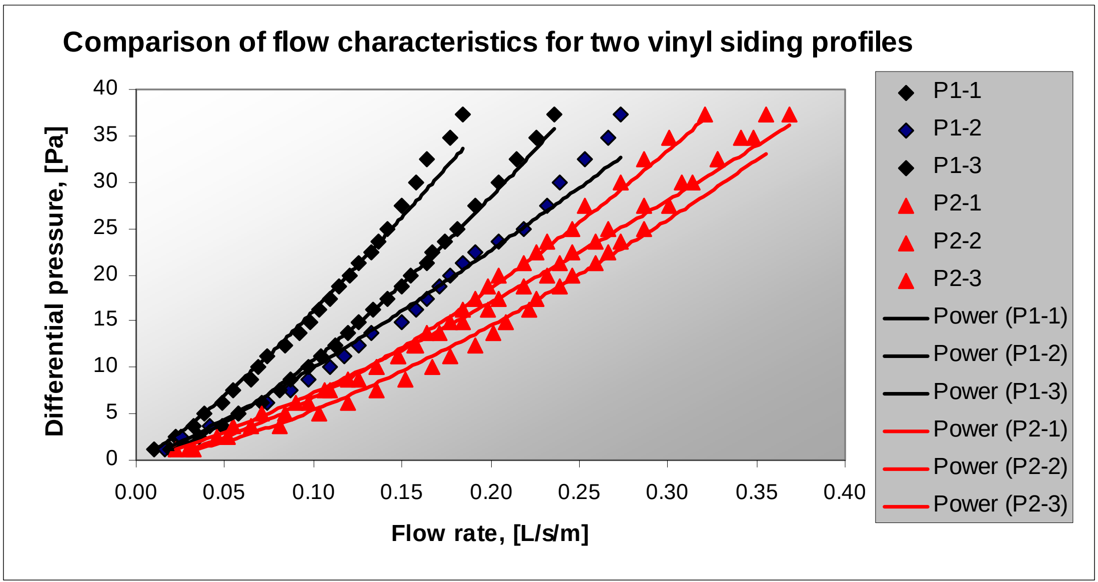


Figure 31 Air flow plots for vinyl siding products 1 and 2 (Profiles #1 and #2).

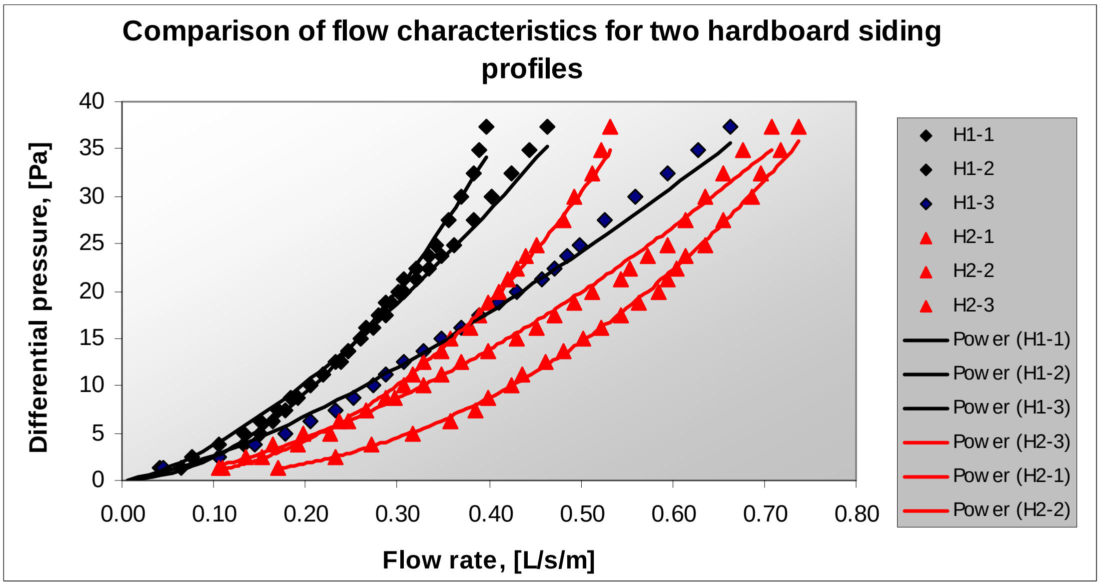


Figure 32 Air flow plots for hardboard siding, product 3 and 4 (H1 and H2).

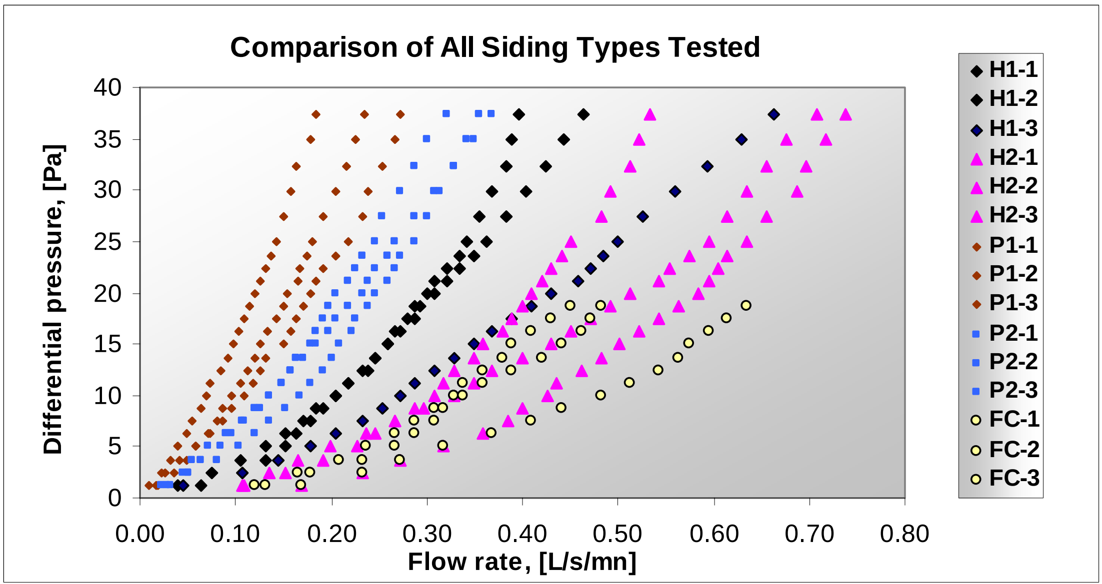


Figure 33 Comparison of air flow plots for all siding assemblies tested

The above plots show the relative air tightness of different systems from the tightest (vinyl siding) to the loosest (fibre cement board). Each system has its own characteristic flows with some variability depending on design and factors related to the assembly. The equations fitted to the data are summarized in a subsequent section for correlation with the vapour transmission test results.

5.6.2 Water vapour transmission tests of siding

On completion of the air flow tests on the 15 test specimens, the vapour transmission tests were performed on the same samples. The test procedure was based on the ASTM E92-00 "Standard Test Methods for Water Vapour Transmission of Materials" in which the supporting pan was flooded with water to provide the necessary high vapour pressure. The test specimens, three at a time, were held in a specially constructed chamber to closely maintain a lower vapour pressure. Periodic weighing of each pan was taken (at from 2 to 3 day intervals) to obtain the weight loss, all of which was assumed to have been lost through joints in the siding. The RH and T of the conditions inside the pans just under the bottom surface of the siding were also measured as shown in Figure 29. This was necessary because of stratification within the space between the water surface and the bottom of the siding.

The rate of mass loss was typically low and a test period of from 16 to 27 days was required to obtain a sufficiently accurate measure of the water vapour transmission rate (WVT). Particularly slow rates were found for the vinyl siding because of the small number of vent holes per unit of area tested. A total cumulative test time of 104 days was required to obtain 15 test values. Large sample sizes are awkward to handle and occupy considerable amount of space. However, this is the only way that realistic construction details can be evaluated. A composite plot of all the calculated WVT per unit of vapour pressure difference, and per meter of joint length is provided in Figure 34 below. These values represent the permeance per unit joint length. The numerical values are provided in the next section.

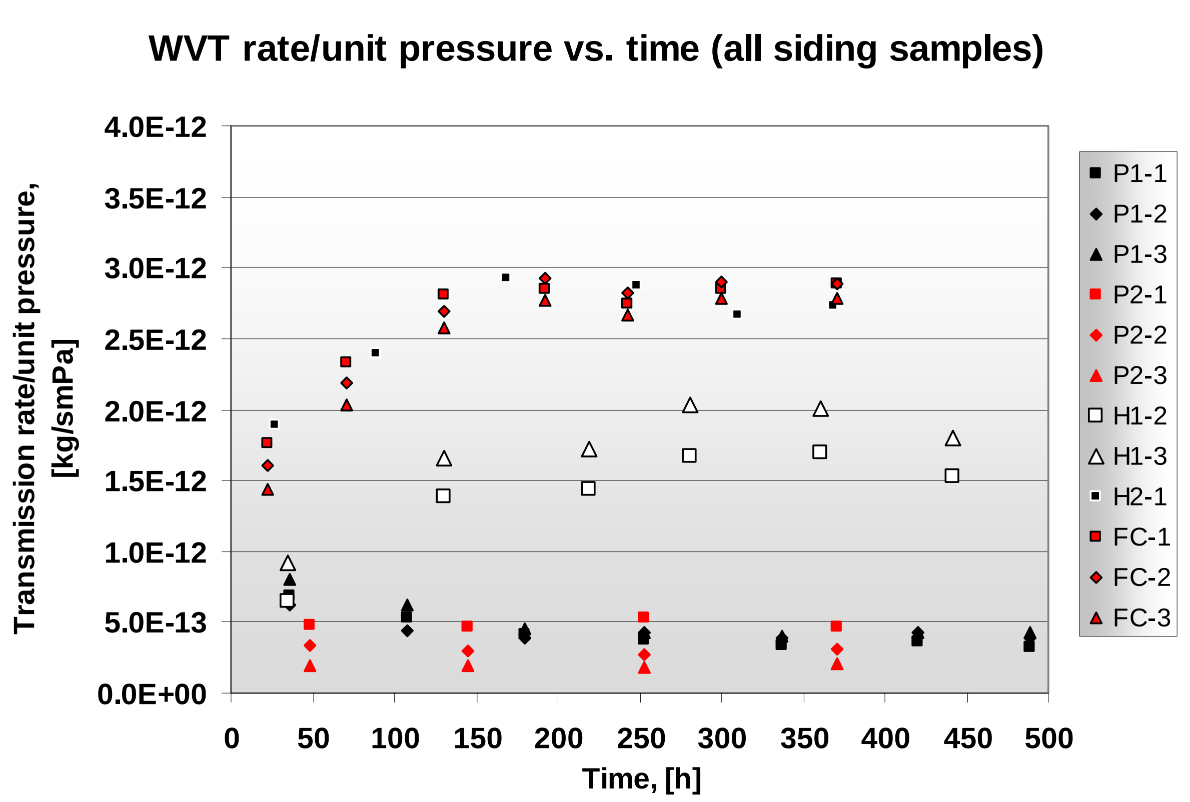


Figure 34 WVT rates for all siding samples tested - Vinyl siding (P1 and P2), Hardboard siding (H1 and H2), and fibre cement board siding (FC).

5.6.3 Correlation of air flow characteristics and vapour permeance of siding joints.

An objective of this investigation was to determine if there was a relationship between the air permeance and vapour permeance of joints in siding. While the air flow characteristics of joints, whether collectively or individually, can be determined quickly, obtaining the vapour permeance of joints is very time consuming and requires great care and accuracy of weight measurement.

To examine the potential relationship noted above, both air and vapour permeance have to be cast in terms of their respective driving potentials. The air flow characteristic of joints needed to be recast in the inverse form from that shown in Figure 33.

The air flow characteristics were first provided in the following power equation form:

$$P = C\, Q^N$$

where P = the differential pressure in Pa; Q is the resulting flow in Litres per second per meter of joint; and C and N are coefficients.

The inverse of that equation is:

$$Q = c\, P^n = (1/C)^{1/N}\, P^{1/N}$$

Thus $n = 1/N$ and $c = (1/C)^n$.

The summary of the coefficients of power law regressions for the air flow tests and their conversion as noted above are provided in Table 5.

Table 5 Recasting the coefficients describing the air flow characteristics of the joints tested

Siding Type	Designation Code	Specimen Number	$P = C\,Q^N$ Coefficient C	Exponent N	$Q = c\,P^n$ Coefficient c	Exponent n
1	P1	1	257.69	1.205	0.010	0.830
		2	150.05	1.176	0.014	0.850
		3	268.42	1.396	0.018	0.716
2	P2	1	193.42	1.457	0.027	0.686
		2	123.76	1.233	0.020	0.811
		3	146.00	1.435	0.031	0.697
3	H1	1	200.93	1.915	0.063	0.522
		2	108.42	1.462	0.041	0.684
		3	62.75	1.379	0.050	0.725
4	H2	1	61.44	1.629	0.080	0.614
		2	135.56	2.160	0.103	0.463
		3	72.03	2.305	0.156	0.434
5	FC	1	102.91	2.089	0.109	0.479
		2	85.35	2.076	0.117	0.482
		3	43.83	1.964	0.146	0.509

The data for both vapour and air flow tests were then aligned in Table 6 following, and the air flow at 1 Pa was chosen to compare with the vapour permeability. At this differential pressure, the flow rate equals the value of the coefficient "c".

Table 6 Summary of air flow characteristics and vapour permeability of assemblies tested.

Siding Type	Designation Name	Specimen Number	$Q = c\,P^n$ Coefficient c	Exponent n	Vapour Permeance kg/smPa	Air Flow at 1 Pa L/s/m
1	P1	1	0.0100	0.830	3.56E-13	0.010
		2	0.0141	0.850	4.14E-13	0.014
		3	0.0182	0.716	4.28E-13	0.018
2	P2	1	0.0270	0.686	5.15E-13	0.027
		2	0.0201	0.811	3.03E-13	0.020
		3	0.0310	0.697	2.27E-13	0.031
3	H1	1	0.0627	0.522	1.57E-12	0.063
		2	0.0406	0.684	1.56E-12	0.041
		3	0.0497	0.725	1.88E-12	0.050
4	H2	1	0.0798	0.614	2.84E-12	0.080
		2	0.1030	0.463	2.63E-12	0.103
		3	0.1564	0.434	1.7E-12	0.156
5	FC	1	0.1088	0.479	2.88E-12	0.109
		2	0.1174	0.482	2.93E-12	0.117
		3	0.1459	0.509	2.79E-12	0.146

Plots of the vapour and air flow characteristics of joints are provided in Figures 35 and 36.

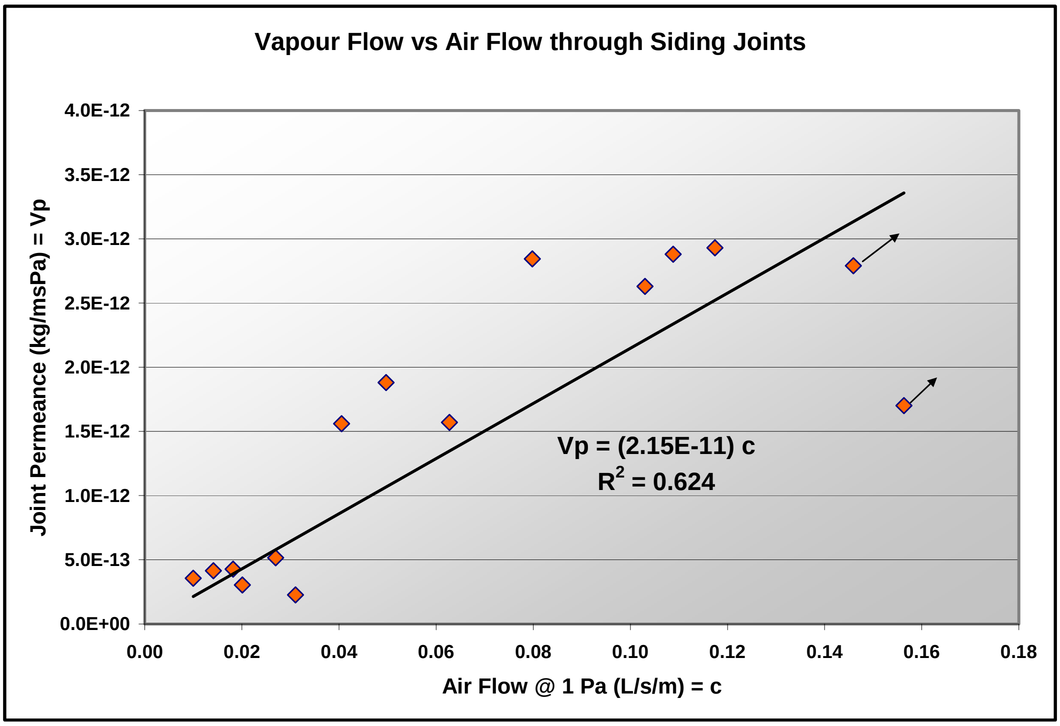


Figure 35 Plot of vapour joint permeance and air flow characteristics (at 1 Pa)

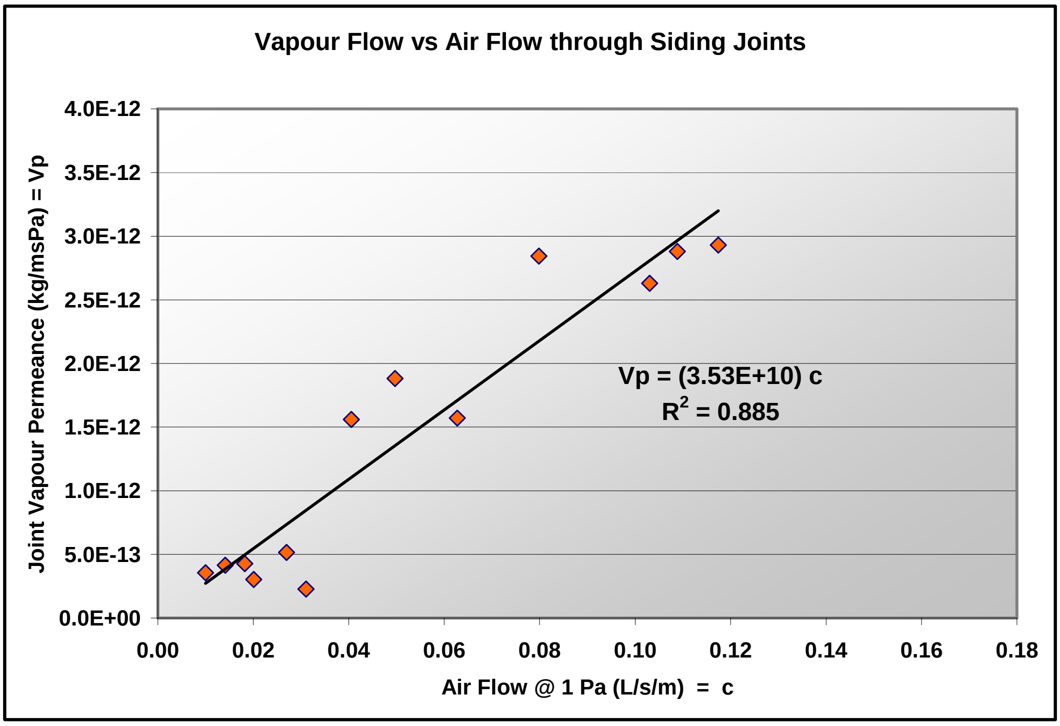


Figure 36 Plot of vapour joint permeance and air flow characteristics (at 1 Pa) excluding two outlier values noted in Figure 35.

The plot in Figure 35 includes two outliers, specimens H2-3 and FC-3, both of which are highlighted in Table 6. Examination of the air flow plots (Figure 11 and 12) reveals that the fitted curves for both specimens are relatively flat at low differential pressures and also do not seem to converge with others in the same group, whereas plots for all other specimens of all types converge. If they are treated as outliers and eliminated from consideration, the plot shown in Figure 36 shows a more consistent relationship between the two joint properties. This is also reflected in the R^2 reported for the linear regressions shown on each plot. For the present, this comparison supports the contention that within the experimental error achieved there is a correlation between these two measures of joint performance.

Part of the variability noted in these plots shown in Figure 35 may be related to effects that affect the repeatability of weight measurements of the pans for the WVT tests. Due to difficulties in handling, and the potential effect that handling had on convective flow within and through joints, as well as on the conditions experienced, unaccounted effects were present. Continuous undisturbed weighing would have been a more desirable approach. However, given the limitations in both time and financial resources, this was the only approach that could have been taken at this time.

In the same vein, the air flow measurements had to be limited to only some of the joints available for products 4 and 5 due to a limitation in the flow measurements. Due to the low flow rates, calibration flow measurements of each assembly should also have been determined in the event that leakage, other than through the assumed joints occurred, such as at edge seals and other sealed joints.

Quite apart from the impact of experimental procedures on the results, there is the fundamental issue of moisture buoyancy. It has been assumed that the weight loss from a pan through a siding assembly has all occurred as a result of the difference in vapour pressure across the assembly. However, it should be noted that the density of moist air inside the pan beneath the assembly is less dense than in the chamber or room. The joints in the siding can allow some moist air to escape directly by air movement in addition to that escaping by diffusion. Any air movement through the joints invites the movement of makeup air from the chamber or room back into the pan air space where it would dilute the moisture content of the air exposed to the free water in the pan. By measuring the RH and T of the air just under the specimen and using that to calculate the vapour pressure difference across the specimen, this partly accounts for the moisture lost by stack effect across the test specimen. The actual moisture exchange across the test specimens is a very complex matter.

Measurement of air flow characteristics of individual joints in full scale walls by Onysko and Jones [2] on a siding product similar to Type 3 (H1) has shown that how the wall is assembled has an effect on the air tightness of joints in siding. For example, it was shown that flat-headed nails were more difficult to overdrive than round-headed nails, and this helped assure a more uniform spacing at ship lapped joints. Joints were more airtight where over-driven nails were applied. Average air leakage was about 15 times greater that obtained on smaller sample walls by others at that time.

Given these findings, it is likely that only an approximate relationship between air flow and vapour flow characteristics of siding systems can be considered for field applied siding systems. Vinyl siding, with its manufactured interlocking joints and small drain holes, can be considered tightest for both vapour and air flow. This is followed in leakiness by hardboard siding with a spline system which registers each siding course relative to the course below. Contact mismatch leads to some air and vapour transmission. Greater transmission resulted for the second hardboard product that had an in-line interlocking shiplap joint which had moderately higher leakiness than the first product. The leakiest siding was the fibre-cement product (as constructed) because of the greater mismatch provided between the adjacent courses of siding. Each system, by design and by assembly, results in a unique range of tightness that may be translated to equivalent vapour permeance, but only in a somewhat general way given all of the factors influencing air tightness and vapour exchange.

6 CORRELATING DRYING RATES WITH WALL PROPERTIES

The test program and reporting has provided an extensive set of databases. Perhaps the most cogent question that might be posed is whether the drying rates experienced by walls subject to isothermal drying conditions can be related with the other properties of the cladding. The ability of walls to dry should be related to the amount of water retained; both retention and drying rates need to be examined.

The retention of water by different systems depended on the nature of each system and the ability of different materials in it to absorb water or to store it in joints. Examples displaying the relative drainage results are provided in Figure 37 to 40 where all wetting/drainage tests are plotted showing how each system compares with all the other tests. Observations drawn from these plots are:

- EIFS walls tended to retain the lowest amount of water despite allowing the water input to flow down entirely within the drainage cavities
- Vinyl siding walls retained more water by storing it in the drainage profiles in the upper portion of each wall. Despite some leakage out of the siding ends, the majority of water drained largely through drain holes in the upper course of siding close to where the water was input.
- Other direct-applied sidings (fibre cement, hardboard, and wood siding) also drained water largely through the joint at the top course of siding. The largest retention was by wood siding placed in direct contact with the WRB membrane. The other direct-applied sidings had only line contact with the WRB membranes and there were air spaces behind the siding. Retention of water in joints in the siding was concentrated in the upper courses.
- Siding systems installed over drainage mats of various types, and for one wall on batten strips, allowed most of the water input to flow down the drainage cavity. Some water draining down the back of the siding flowed through the horizontal joints and down the face of the siding. Despite the provision of a drainage cavity, the total amounts were in the same order of magnitude or larger than when the siding was applied directly. However, the concentrations were likely in joints and not absorbed on back surfaces or the WRB.
- These comparison plots and comments can not be used to provide unqualified conclusions about the potential durability of various siding systems or the walls to which they are attached. Common sense supports the conclusion that the lowest retention and greatest dispersion with the greatest ability to dry is a goal for durability under any conditions when water is allowed to penetrate the primary cladding. However, each system has displayed different responses to water input and this has to be taken into account.

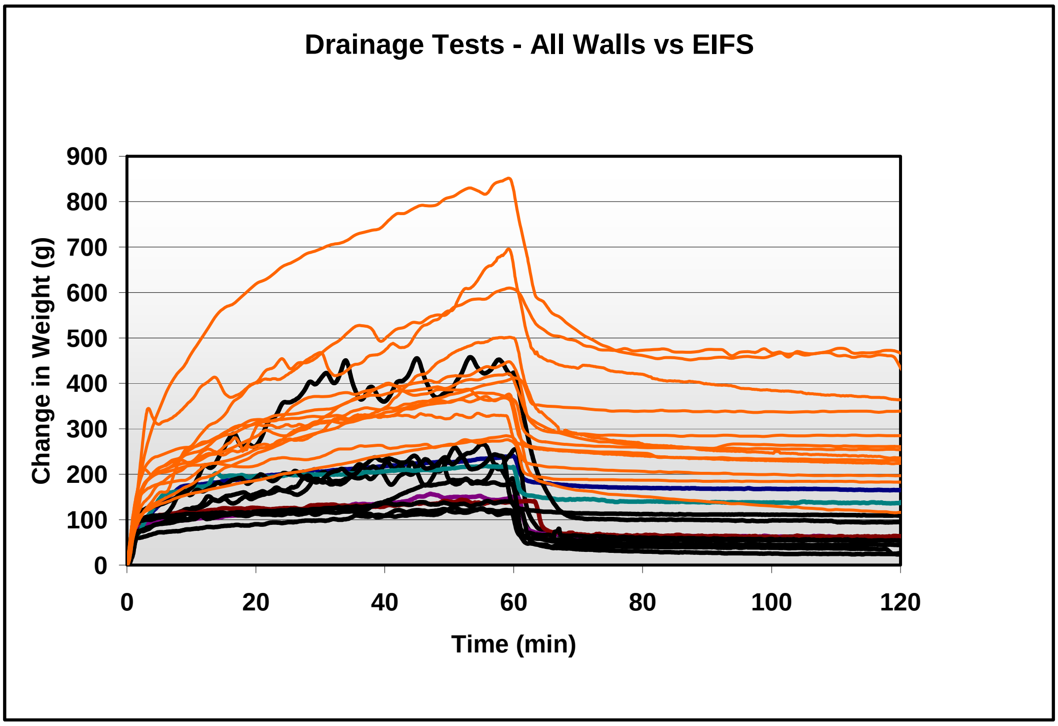


Figure 37 All drainage tests showing EIFS results highlighted.

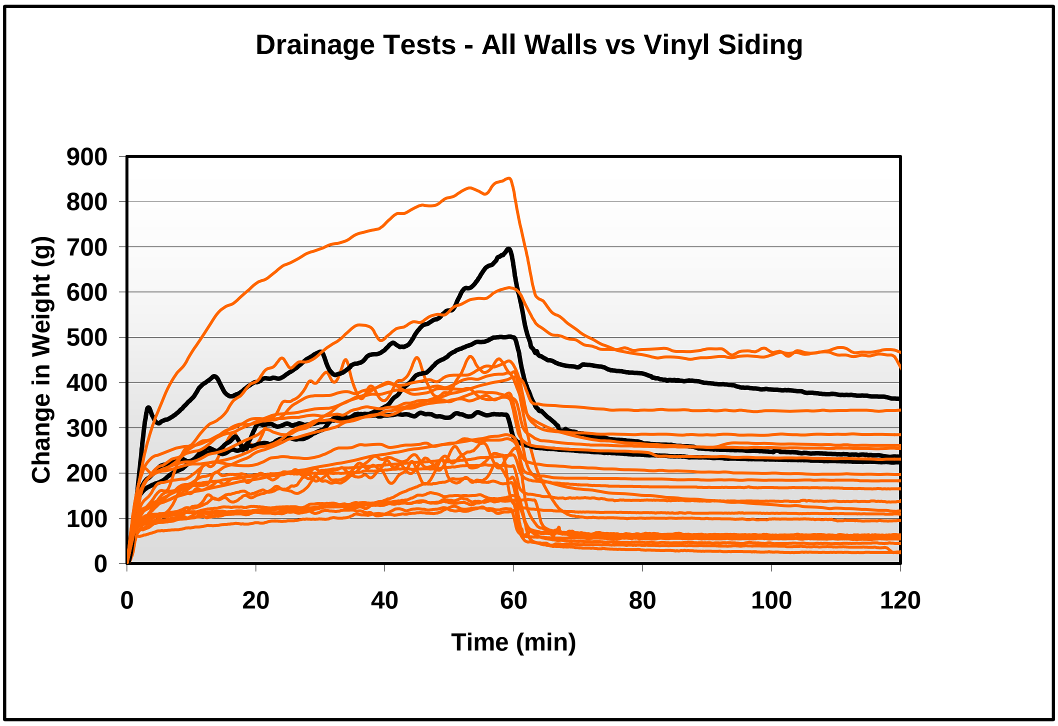


Figure 38 All drainage tests showing results for vinyl siding walls highlighted.

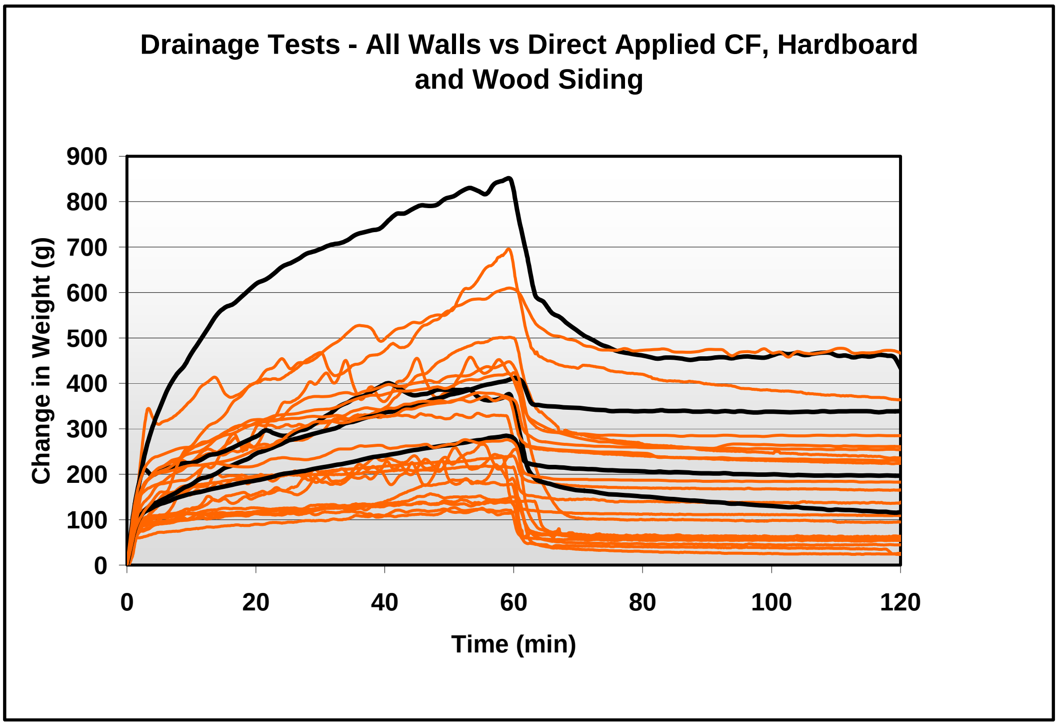


Figure 39 All drainage tests showing results for direct applied fibre cement, hardboard, and wood siding highlighted.

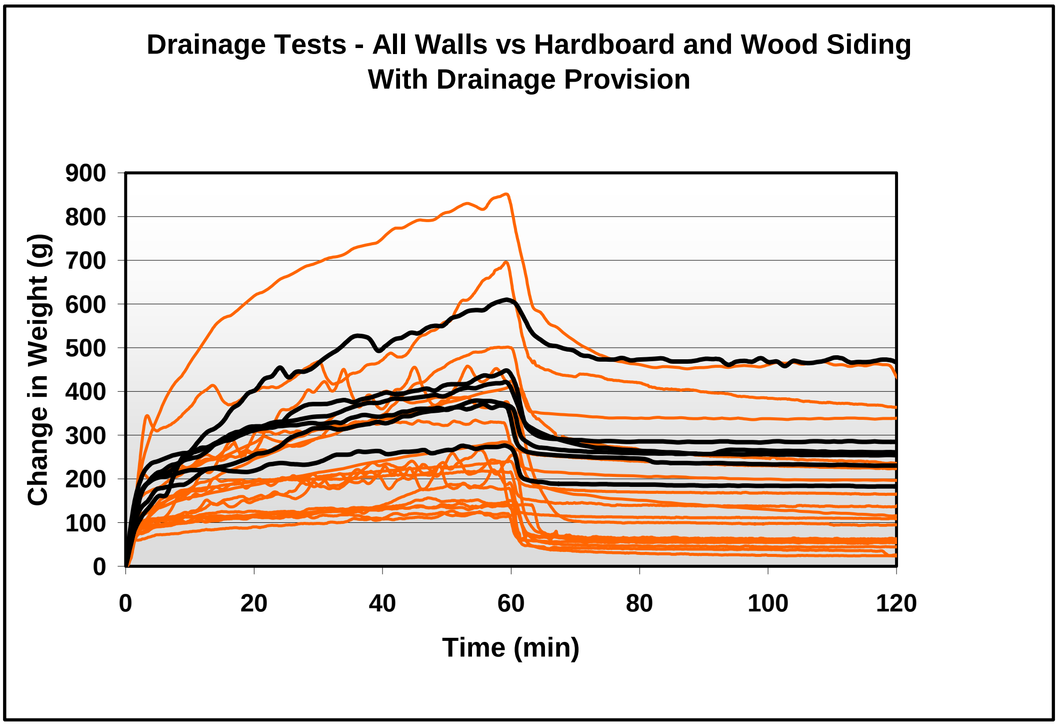


Figure 40 All drainage tests showing results for hardboard and wood siding on drainage mats and batten strips highlighted.

Concerning the influence of environmental conditions on drying of retained water, it has already been noted that the EIFS walls were more susceptible to being affected by those conditions. To study the effect of environmental conditions on drying rates, the latter were obtained for all test walls by regression of weight change over a period of from about 8 hours to the end of the test at 50 hours. These results will be summarized in a subsequent table.

However to illustrate the effect of conditions for one wall, an example is provided in Figure 41 following where the largest variation in vapour pressure was experienced during test. As a benchmark on the ambient conditions, the RH and T results for the sensor pair #16 were chosen because it was located in proximity to the test walls at a level corresponding to the drainage gutters. While this location might not be most appropriate for all walls, this location was chosen for comparative purposes. The vapour pressure was computed to provide a single variable for comparison with drying rates. The example chosen (EIFS Wall 5) had the largest standard deviation for the vapour pressure over that test duration. For comparison, the weight change over that period and the vapour pressure were plotted together in Figure 41. The reference time for this plot is the beginning of the 48 hour drying period.

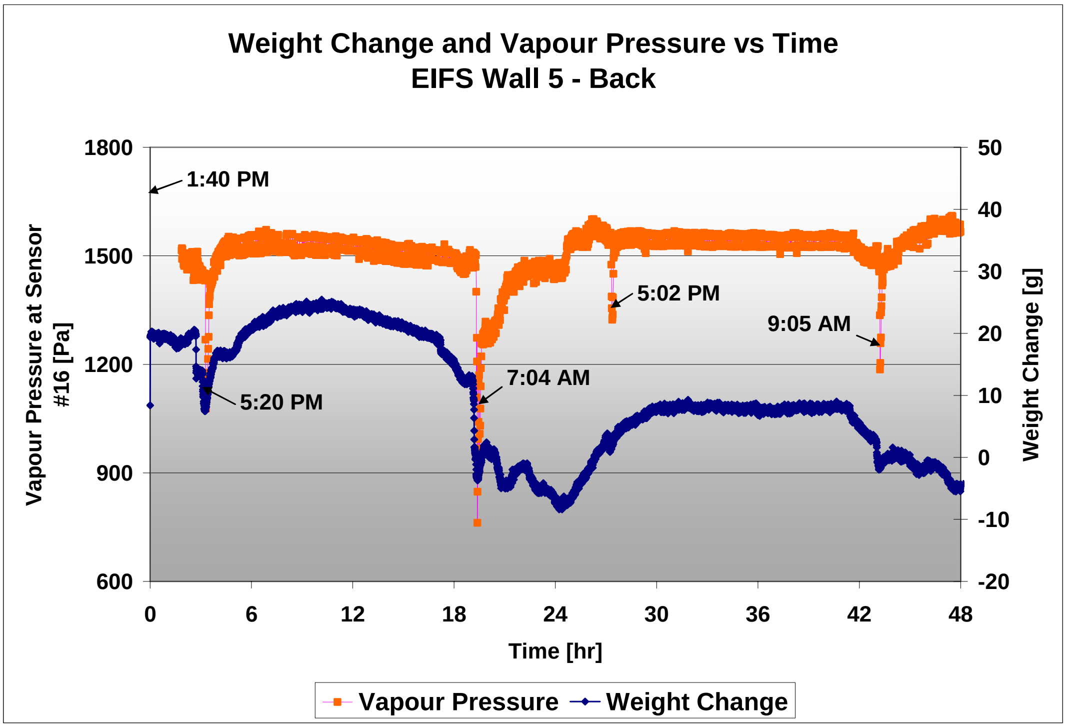


Figure 41 Influence of environmental conditions on drying rate for EIFS wall 5 (Back) over a 48 hour drying period beyond the initial 2-hr wetting/drainage phase.

This wall retained very little water at the end of the 2-hr wetting/drainage phase (a total of 19.5 g). The plots show a period when activities in the laboratory increased or decreased the drying rate. The wall lost all retained water during the second day period, but regained some moisture during the second evening and lost it again the next day. When only a small amount of water is retained, the ability to calculate a drying rate is problematic for EIFS walls when the conditions are not steady state. For some EIFS walls, there was a gain in weight after the 2-hr period on retest possibly because they attained lower weight equilibrium where they were stored in some other part of the lab. The majority of other types of wall systems were not severely affected.

To illustrate the effect of reference ambient conditions at sensor location #16 on drying rates and the amount of retained water, these results are plotted in Figures 42 and 43. Figure 42 illustrates that the environmental conditions at that location did not materially affect the drying rates. System characteristics and the manner that water is held dominated drying rates.

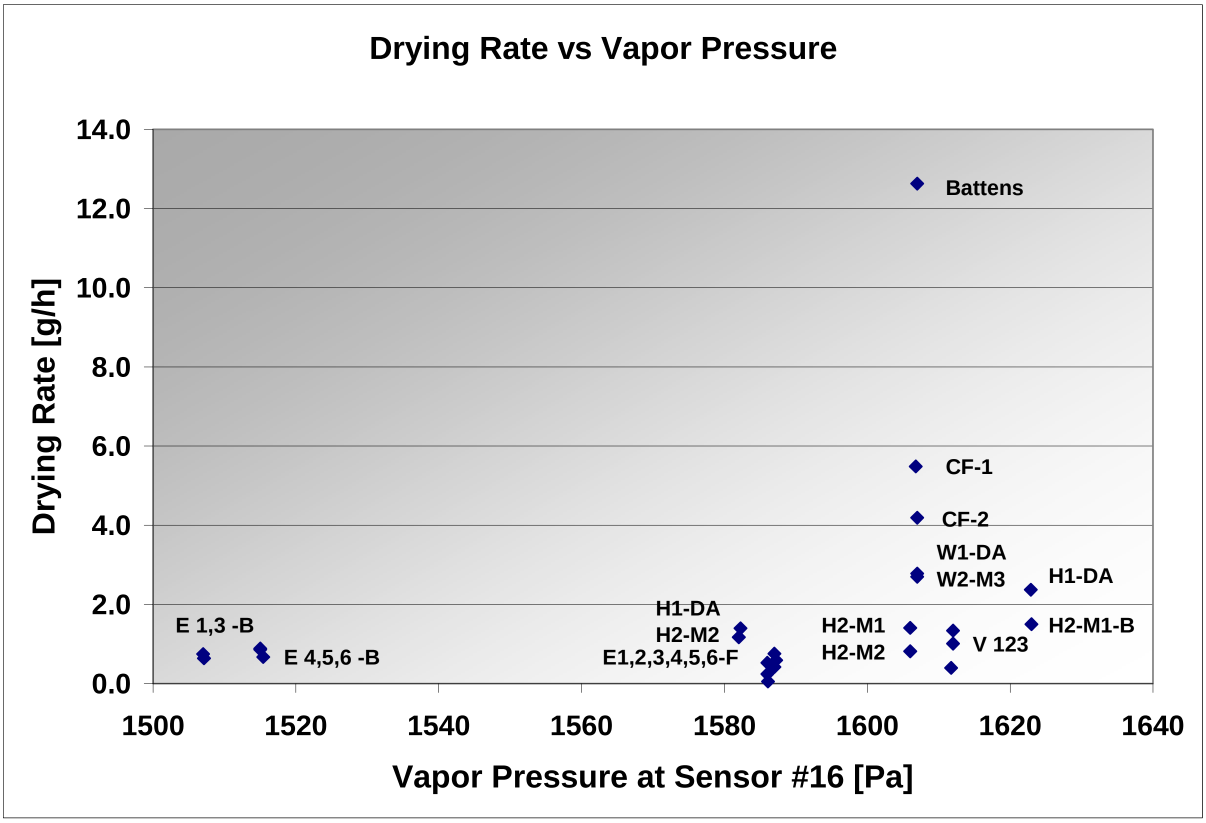


Figure 42 Drying rates versus mean vapour pressure at elevation of gutters (at sensor #16)

Figure 43 provides a plot of drying rates versus retention of water at the 2-hr stage in the test. This figure tends to illustrate that walls that retained more water exhibited higher drying rates because there were higher vapour pressures differentials for longer periods. While generally supporting this presumption, the figure also shows that some walls dried very slowly despite the high retention. Retention in joints is bound to take longer to dry. Consequently, a more generalized study of wall characteristics is warranted to determine the factors that most influenced drying rates. In preparation for that, Table 7 was constructed to summarize all relevant data on the wetting and drying of walls as well as the air and vapour flow characteristics of joints and cavity spaces.

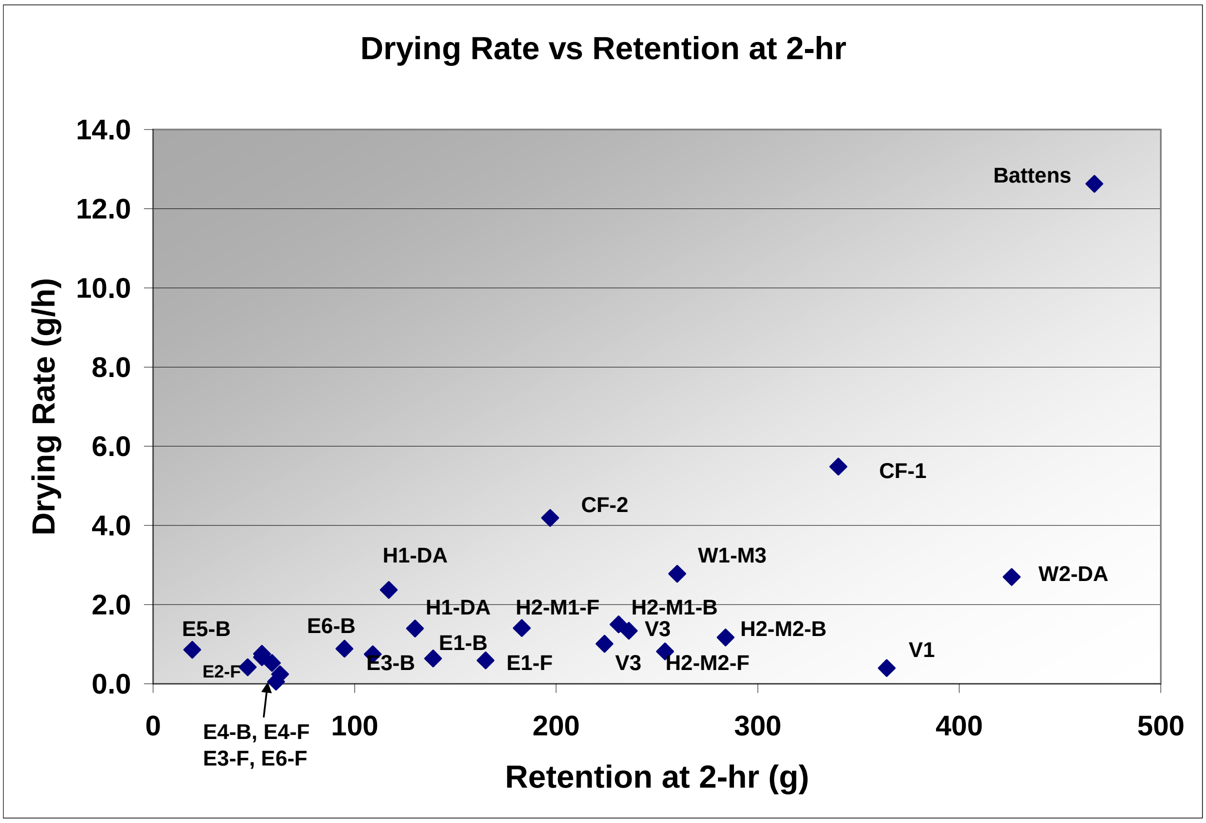


Figure 43 Drying rates versus retention of water at the 2-hr stage in the test for all walls.

The essential parameters in the database summarized in Table 7 were sorted by whether a drainage cavity was provided or not. Each subset was then analyzed by stepwise multiple regression. In the case of the subset with intentional drainage cavity (19 valid sets), the single parameter that best related to the drying rates was the measured unit air flow capability of the main drainage cavity (Path D2). The correlation coefficient was 0.850. The characteristic of the entire flow path which included the starter tracks defined as the composite of the D2 and D3 flow path coefficients at 1 Pa and their lengths was slightly less important. The flow at 1 Pa for the combined flow paths (based on air flow measurements) was highly correlated (0.972) with the assigned cavity thickness. These assigned thickness values were approximate only as they did not account for any obstructions in the flow paths, such as constrictions of mats where siding was fastened to the walls.

There were only 7 valid tests in the subset involving direct-applied siding. Examining the correlation coefficients, with drying rate as the dependent variable, both joint air permeability and vapour permeability were found to be correlated. This data comes from the supplemental tests reported in Section 5.4.9. When variables were selected in a stepwise manner to study their effect on drying rates, only the variable with the largest correlation coefficient was selected. That variable was the air permeance of siding joints (with an R^2 of 0.9295). A plot of the relationship between these two variables is shown in Figure 44. Also shown for reference is the relationship between drying rates and the vapour permeance of joints in Figure 45.

Table 7 Summary of construction parameters and measured characteristics for all drainage/drying tests

Date Tested	Wall Group Tested	Wall Designation	Vapor Pressure @ Sensor 16 Mean [Pa]	Std.Dev. [Pa]	COV [%]	Drying Rate [g/h]	R^2	Std Error [g/h]	Retention at 2-hr [g]	Cavity or DA	Approximate Thickness of Cavity (mm)	Air Flow @ 1 Pa D2 (L/s)	Air Flow @ 1 Pa D3 (L/s)	Air Flow @ 1 Pa Siding Joints (L/sm)	Vapour Permeance of Joints (kg/smPa)
January 17:	EIFS 123 back	EIFS 1	1507	22	1.47%	0.64	0.65	7.29	139	1	2.5	0.0375	0.0150	0.0000	0.0000
		EIFS 2	1507			*	*	*	24	1	2.5	0.0016	0.0242	0.0000	0.0000
		EIFS 3	1507			0.75	0.58	8.65	109	1	2.5	0.0035	0.0117	0.0000	0.0000
January 24:	EIFS 456 back	EIFS 4	1515	70	4.64%	0.67	0.75	6.03	54	1	2.5	0.0077	0.0037	0.0000	0.0000
		EIFS 5	1515			0.86	0.64	5.89	20	1	2.5	0.0016	0.0997	0.0000	0.0000
		EIFS 6	1515			0.89	0.84	5.41	95	1	2.5	0.0035	0.0117	0.0000	0.0000
January 28:	EIFS 123 front	EIFS 1	1587	50	3.13%	0.59	0.99	0.39	165	1	2.5	0.0375	0.0150	0.0000	0.0000
		EIFS 2	1587			0.42	0.90	1.06	47	1	2.5	0.0016	0.0242	0.0000	0.0000
		EIFS 3	1587			0.76	1.00	0.35	54	1	2.5	0.0035	0.0117	0.0000	0.0000
February 1:	EIFS 456 front	EIFS 4	1586	43	2.70%	0.05	0.04	3.67	61	1	2.5	0.0077	0.0037	0.0000	0.0000
		EIFS 5	1586			0.53	0.69	5.47	59	1	2.5	0.0016	0.0997	0.0000	0.0000
		EIFS 6	1586			0.24	0.37	4.33	63	1	2.5	0.0035	0.0117	0.0000	0.0000
February 7:	Vinyl 123	V1	1612	21	1.27%	0.40	0.84	2.22	364	2	0.0	0.0	0.0000	0.0140	3.99E-13
		V2	1612			1.34	0.88	8.03	236	2	0.0	0.0	0.0000	0.0260	3.44E-13
		V3	1612			1.01	0.94	3.66	224	2	0.0	0.0	0.0000	0.0260	3.44E-13
February 14:	Hard DA	H1 - DA	1623	27	1.65%	2.37	0.98	4.41	117	2	0.0	0.0	0.0000	0.0510	1.67E-12
	Hard Mat 1 back	H2 - Mat 1	1623			1.50	0.97	3.96	231	1	6.7	0.0331	0.2213	0.1130	2.74E-12
	EIFS 2 back (retest)	EIFS 2	1623			*	*	*	35	1	2.5	0.0016	0.0242	0.0000	0.00E+00
February18:	Hard DA (retest)	H1 - DA	1582	39	2.44%	1.40	0.99	1.61	130	2	0.0	0.0	0.0000	0.0510	1.67E-12
	Hard Mat 2 back	H2 - Mat 2	1582			1.17	0.98	2.41	284	1	6.9	0.0293	0.1916	0.1130	2.74E-12
	EIFS 2 back (retest)	EIFS 2	1582			*	*	*	24	1	2.5	0.0016	0.0242	0.0000	0.00E+00
February 23:	EIFS 2 front (retest)	EIFS 2	1606	31	1.95%	*	*	*	26	1	2.5	0.0016	0.0242	0.0000	0.00E+00
	Hard Mat 1 front	H2 - Mat 1	1606			1.41	0.87	6.21	183	1	6.7	0.0331	0.2213	0.1130	2.74E-12
	Hard Mat 2 front	H2 - Mat 2	1606			0.82	0.95	3.06	254	1	6.9	0.0293	0.1916	0.1130	2.74E-12
March 2:	Fibercement DA tyvek	CF-1	1607	21	1.34%	5.49	0.99	3.75	340	2	0.0	0.0	0.0000	0.1240	2.90E-12
	Fibre cement DA BP	CF-2	1607			4.19	1.00	1.43	197	2	0.0	0.0	0.0000	0.1240	2.90E-12
March 22:	Wood siding DA	W2 - DA	1607	sensor		2.70	0.98	4.66	426	2	0.0	0.0	0.0000	**	**
	Wood siding Mat 3	W1 - Mat 3	1607	failed		2.78	0.94	8.77	260	1	6.3	0.0360	0.2004	**	**
	Wood siding Battens	W2 -batten	1607			12.63	0.98	19.64	467	1	19.0	0.5750	*	**	**

* Missing information due to unreliable drying curves or weight gained instead of lost. Some walls exhibited

** Air and Vapour permeability tests were not done on wood siding profiles

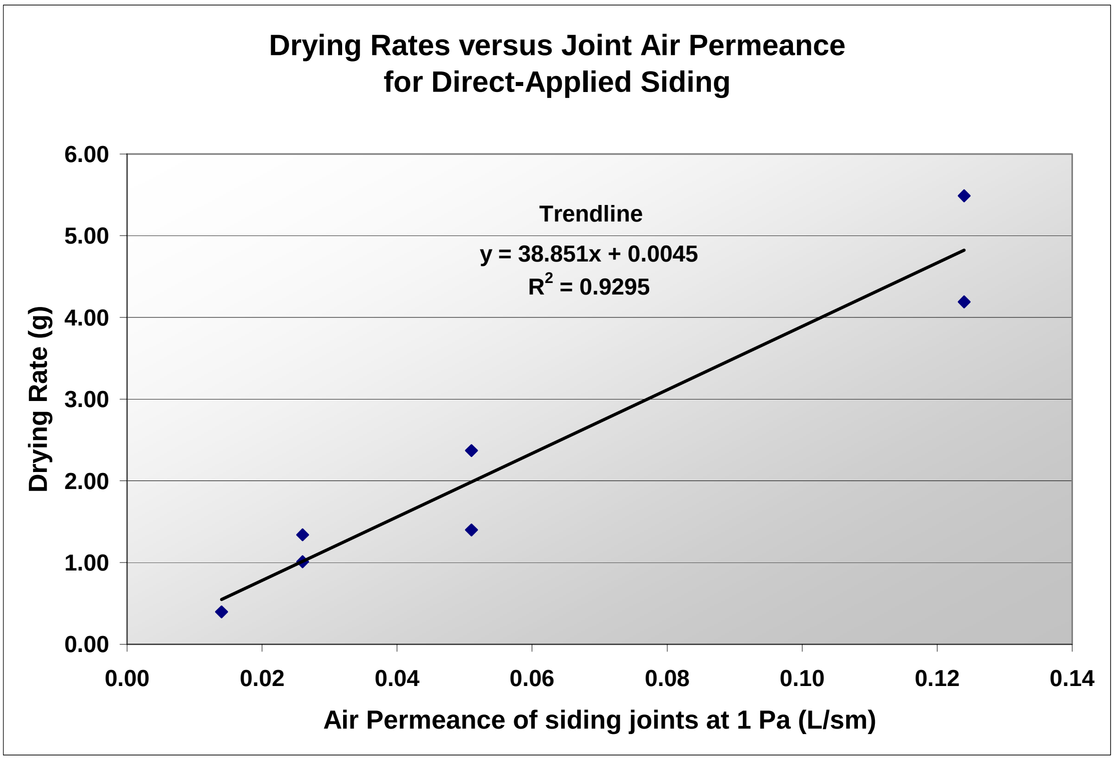


Figure 44 Relationship between joint air flow at 1 Pa differential pressure and drying rate for walls that had direct-applied siding.

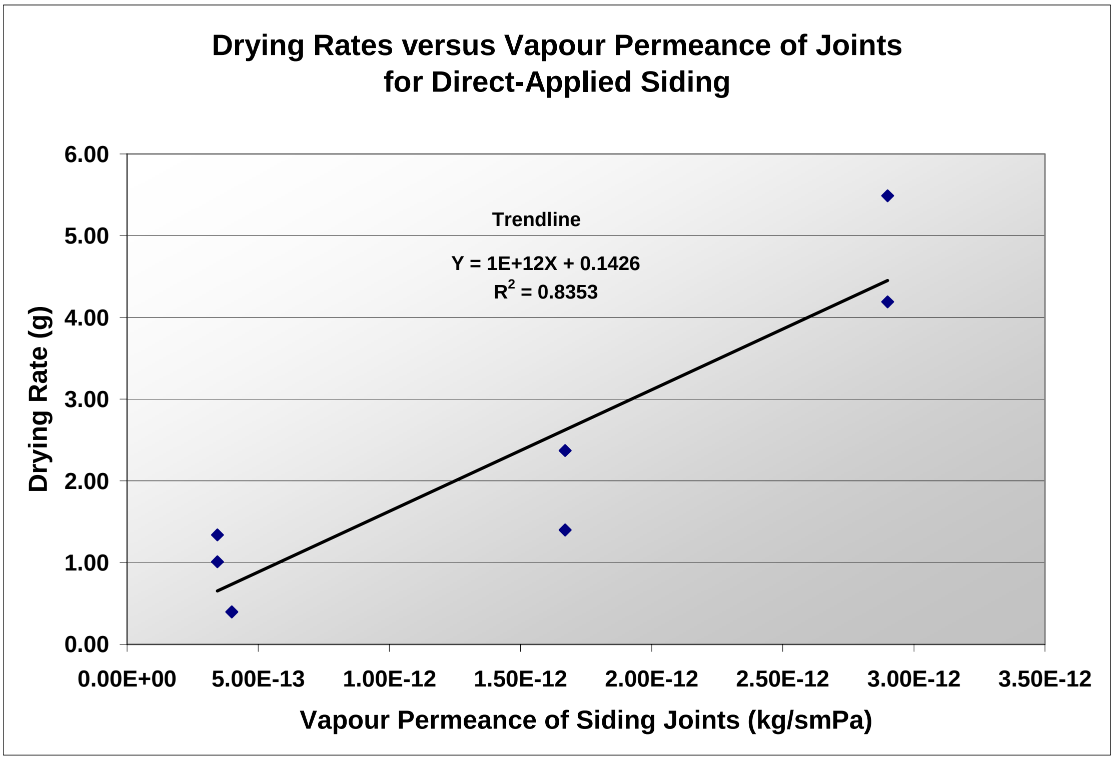


Figure 45 Relationship between joint vapour permeance and drying rate for walls that had direct-applied siding.

The significance of this is that given the lack of correlation with vapour pressure (ambient environmental conditions) and water retention, one should expect that either air flow or vapour flow (or both) through joints would be responsible for removal of water vapour from behind the cladding in these tests. This is expected because vapour diffusion directly through the siding is a relatively slow process. Depending on vapour diffusion through siding for removal of moisture behind it is to be avoided to prevent degradation of the finish systems employed (paint, etc.). Since air flow permeance and vapour permeance of joints are highly correlated, one cannot confidently attribute the drying actually achieved with one or other degree of permeance. Under laboratory conditions with no wind, very likely vapour permeance dominated. The fact that air permeance exhibited a higher correlation may only mean that the actual vapour permeance of the walls as tested was better than that found for the smaller siding samples tested.

Ensuring that air and vapour flow capability at joints is maximized either through design of the siding or by its installation is a worthy design goal. Installation of siding by means of nails having thick heads that assure a gap at laps is an inexpensive solution and also facilitates drainage of water from behind siding close to where it may enter behind it.

The wood siding profiles were not included in this analysis because the properties of those joints were not obtained through supplemental testing. The direct application of shiplap wood siding to the base wall was only done to demonstrate that large amounts of water could be retained. This supports the manufacturer's application advice that these sidings be installed on batten strips.

7 DISCUSSION AND CONCLUSIONS

To a large extent, most of the discussion concerning the ability of these wall systems to manage water behind cladding has already been provided in the presentation of results. From the above observations it is clear that provision of drainage planes leads to a more direct path for the water to flow to the bottom of a wall. But, in the process, a greater area of wetted surfaces becomes involved. Also, 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 were affected, it is possible that the concentration of moisture was lower. The moisture mapping done was too insensitive 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 that the 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 experimental plan only a limited variety of cases and siding systems could be included and the effect of the properties of the WRB was not included.

Clearly, since even the walls with direct-applied siding 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/or 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 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.

While the moisture mapping, as performed in this study, assisted in identifying general areas of moisture retention, the contours are relatively crude. They very probably infer moisture content changes in some locations that did not gain moisture.

The experimental testing of the ability of walls with siding to manage water that enters the space behind the siding has taught us that despite lack of provision of drainage cavities, siding joints can permit drainage close to the source of moisture. The ability to do so safely has not been assessed in this study because knowledge about the detailed concentration of moisture resulting from that form of entry and escape was not available. In any case, a study directed at that subject would require additional detailed measurements that could not be undertaken in this study. The variability in retention from one wall to another of the same construction could only be observed for apparently similar walls with fibre-cement siding. Their relative performance suggests that installation variables of all such walls may have much to do with the reliability of their drainage and retention performance.

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. 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 limited to essentially 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. Researching the performance of siding experimentally must be limited to examining relative conditions. However, if the mechanics of all the air, moisture and thermal paths are understood and properly characterized, it may be possible to employ computer modelling to parametrically assess relative performance of siding systems in widely differing climates. 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.

8 RECOMMENDATIONS

Many small modifications in the testing methods could be undertaken to improve the reliability of the results and the ease with which the data can be analyzed. These need not all be addressed here.

The main recommendations with regard to the testing methods are:

- The drying period, currently 48 hours long, could be reduced and still achieve the information about drying rates. The total test time for any wall could be reduced to a total of 24 hours with a 2-hr wetting/draining period and a 22 hour drying period.
- Measurement of retained moisture is most useful but requires additional care. This may be achieved using a capacitance moisture meter as used here but with many more readings taken to provide a matrix with a finer grid. To improve the degree of moisture measured, one might consider rewetting the wall after the drainage/drying information has been obtained and taking the measurements at that stage.
- The use of additional calibrated RH and T sensors is recommended with the output for all sensors and load cells being recorded directly into one data file per test for up to three walls at a time. This would facilitate analysis.

- Measurement of joint air permeability of siding should be attempted in place to complement any air flow tests done to characterize the air flow of drainage cavities.
- While the trickle trough developed performed suitably, it depends on gravity flow and even distribution of water across its full width. A pumped trickle wand would achieve the desired result provided it had no contact with the wall.
- The balance beam system employed proved to be satisfactory and required only minor checking of calibration for each test. The original detailed calibrations held throughout the entire period; however more direct suspension would reduce the effect of disturbances at linkage connections.

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. Knowing that air permeance of siding joints was most responsible for drying and that vapour permeance is strongly related, only the air permeance need be measured. 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 current test protocols permitted air and vapour flow out of the top of the siding. Introducing water to the top of the wall and then sealing off the entry creates the worst case scenario for drying. Different systems may perform substantially differently than found here and should be investigated.
- 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.
- The current test program was limited to several combinations of materials and profiles. If testing were done to arrive at representative performance, likely three test walls of each system would be sufficient. If testing were done to investigate how a particular system achieved its performance, much more detailed work is required, and for that one test wall is sufficient.

9 REFERENCES

[1] ASTM E 2273-03 Standard Test Method for Determining the Drainage Efficiency of Exterior Insulation and Finish Systems (EIFS) Clad Wall Assemblies. ASTM

[2] Onysko D.M. and S.K. Jones. 1988. Air tightness of one type of hardboard siding. Forintek Canada Corp. Report to the Canadian Forestry Service. Project No. FCC-43-10-016. Also presented at CIB-W40 Meeting, September 11-14, 1989 Victoria, BC.