WEATHER RESISTIVE BARRIERS: NEW METHODOLOGY FOR THEIR EVALUATION

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Abstract

Effective weather resistive barriers (WRB) perform important functions in retarding water entry into walls and in controlling water vapor movement as well as the amount of energy attributed to air leakage (Burnett, 2000; Weston et al 2001). Recognizing this, a public and private sector research consortium[1] was established to develop reliable and precise methods for evaluating their performance.

This paper, third in a series[2], provides an overview of the most significant results obtained during the consortium work. This research included development of two new test methods, namely the modified inverted cup (MIC) and liquid penetration resistance (LPR). The acceptance criteria for these newly developed test methods are also postulated. This research work did not aim to evaluate the performance of the WRB products under various climatic conditions. However, development of this evaluation methodology could lead to generating information on the basis of which such judgments might be made in the future. It is also believed that the proposed test methodology will replace test methods currently used in codes and standards for evaluation of WRB products.

1. PROBLEM STATEMENT

WRB performs many different functions within a building envelope with a primary function of shedding the water that might have penetrated the cladding. It also serves as a second line of defense in control of water penetration and enables designers to address events, which cannot be predicted. While building professionals could design a perfect structure, experience shows that defects created during construction process or those occurring during the service life, eventually lead to the entry of water into a building envelope. Thus a second line of moisture defense allows drainage and drying of any excess moisture.

WRB products also play an important function in controlling the flow of air through the assemblies. Energy efficiency and the resulting economic benefits related to restricting airflow are well known. The addition of WRB demonstrated a 12% reduction in infiltration in homes with existing infiltration rates well below 1.1 air changes per hour. Furthermore, WRB functions to reduce water vapour transport through the wall. This means that the moisture balance of the materials adjacent to WRB could strongly be affected by the thermally driven water vapour flow, which varies depending on the outdoor conditions i.e., temperature, and solar radiation. For instance in a cold climate, WRB must have a high permeance allowing for an outward diffusion of water vapour, yet not too high permeance because water vapour flow under reversed thermal gradient, which causes an inward

[1] This paper presents work performed for a research consortium that includes Concordia University, Canada Mortgage and Housing Corporation (CMHC), Du Pont Inc.(US), Fortiber Corporation (US), Hal Industries Canada, Homeowner Protection Office in British Columbia, with contributions by DMO Associates and Louisiana Pacific Corp.
[2] Bomberg et al (2003) and Bomberg et al (2003a). The following conference paper will be developed into a research paper and published in the Journal of Thermal Envelope and Building Science.

diffusion of water vapour into the wall cavity, should also be limited. Thus, depending on the climate and the service conditions, different types of the WRB should be incorporated within a wall assembly to optimize its performance and to ensure its durability. In other words, the evaluation of WRB products must assess its contribution to the performance of the overall wall system. The research reported here provides a step in that direction.

This series of papers presented the following:

1. A review of current test methods used to evaluation moisture (vapour and liquid) flows through the WRB products (see Bomberg et al 2003)
2. A development of comprehensive testing methodology for characterization of WRB products. (see Bomberg et al 2003a)
3. An evaluation of changes in moisture transport under different condition i.e., presence of surfactant dissolved in the interstitial water, inclusion of fasteners, and outdoor weathering. (see this paper)

The results are presented in this paper series not to characterize various products but to illustrate the scope of use, and the discriminating power of the developed test methods. Whether or not the laboratory results relate to the field performance is unknown. To avoid identification of tested materials, the products were coded with a letter suffix representing WRB type (type C, type P, type PP, and type LA see Bomberg et al 2003a), followed by a number. Unless stated otherwise, the values presented in this report are an average of three tested replicate specimens.

2 CURRENT METHODS FOR TESTING MOISTURE FLOW THROUGH WRB

The current test methods used for characterizing WRB products were adopted from various test standards developed by respective paper, textile, and polymer industries. In spite of attempts to achieve the same objective, the diversity of test methods remained (Table 1).

Table 1 Methods listed in various standards for testing moisture performance of the WRB.

Test number	**Title and standard reference**
1	'Boat test' (Method 181) in the US Federal Specification UU-P-31b
2	'Dry indicator test' (ASTM D779-94)
3	'Ponding test'-Canadian Construction Materials Center (CCMC)
4, 5	'Hydrostatic pressure test'-American Association of Textile Chemists and Colourists (AATCC-127)

Three distinct types of tests used in water transfer testing were identified:

(i) Tests performed without the use of hydrostatic pressure,
(ii) Tests that utilize low hydrostatic pressure, e.g., 25-mm water head
(iii) Tests that characterize the onset of liquid flow through the WRB.

The first group of tests assessed the time required for the color change of moisture sensitive indicator under a simultaneously transmitted liquid and vapour, while the lower surface of WRB was in contact with water. Numerous shortcomings including: poorly controlled boundary conditions, non-uniform distribution of the moisture sensitive indicator, the possibility of air entrapment on the underside of the tested membrane, and the operator's judgment in determining the time of apparent color change of moisture sensitive indicator were identified. Despite, a number of introduced improvements, these test are only suitable for quality control during manufacturing but inappropriate for evaluation of materials.

The second group of tests uses 250 Pa of hydrostatic pressure introduced on the top surface of the WRB to determine the material's resistance to water penetration. The uncertainty introduced by the visual observation used to detect water droplets appearing on the underside of the specimen, and poorly specified temperature and relative humidity conditions on the lower surface of the test specimen, reduces precision of this test method.

The above review showed shortcomings in the existing laboratory test methods:

- These methods include both liquid and vapour phase transports in an undefined ratio
- The unknown composition of moisture excludes using data for computer simulations
- These tests are limited to few hours, and do not represent steady state conditions

The third group of tests employs much higher water heads, ranging between 550 mm to 2800 mm. These tests measure either the pressure or the time required to break the water menisci and create an instantaneous liquid flow. Similar to the first group, these tests methods are suitable for quality assurance but are inappropriate for material characterization.

To achieve a reliable laboratory test the WRB both the upper and lower boundaries must be defined. On the upper surface WRB is exposed to a 25 mm water head and on the lower surface one of the following two conditions: either a near 0% RH maintained by a frequently regenerated desiccant, or water in contact with the tested specimen.

3. NEW LABORATORY TEST METHODS

The ASTM E96 inverted cup method with a standardized thickness of water layer was a method that intuitively appeared to be correct. The boundary conditions on both sides of the material were well defined and represented the most severe conditions resulting in a maximum moisture transfer. The test method is designated as a ***modified inverted cup (MIC)***.

3.1. Modified Inverted Cup for measuring water vapour transmission

To ensure the repeatability and the reproducibility of the test method, constant conditions had to be maintained on both boundaries of the tested specimen. Placement of 25 mm water head (moisture source) on the specimen's upper surface provided the maximum practical level of hydrostatic pressure and a frequently-regenerated desiccant at the lower surface of the tested specimen the RH at near 0%. This created a constant and the highest possible driving force for diffusion of water vapor.

3.2. Moisture Flux test

To examine effects of penetrations on moisture transmission through WRB, a suitable hygroscopic substrate was required. The selected substrate needed to be repeatable, and had to provide a suitable anchor for the fasteners used. The OSB was selected as a choice material. The method was designated as a ***moisture flux (MF)*** test.

3.3. Liquid Penetration Resistance test

To understand moisture flow through WRB membranes, the nature of type C[3] and P products had to be understood. These types of WRB have a porous structure created by the fibrous matrix. The diameter of the fibers and the level of compaction during the manufacturing process both determine the mean pore size of WRB. Furthermore, hydrophobic characteristics of type P fibers and impartment of type C products with asphalt provides a negative wetting angle. The surface of WRB acts as a filter, preventing water

[3] Type C denotes asphalt impregnated cellulose fibers, type P denotes polymeric fibers (see Bomberg et al 2003a)

molecules contained in a liquid phase from penetrating through WRB. Unless there is a continuous field of water across the WRB product the water menisci are created within the material forcing water evaporation and diffusion as vapor. Even when the WRB pores are only partially filled with air, the water vapour diffusion still dominates the transport.

This is not the case with some polymeric perforated type (PP) products in which the size of mechanical perforations in the continuous film determines the nature of porosity. Since the traditionally applied test methods were not suitable to determine the difference in moisture response of these WRB, the hydrostatic pressure of 250 Pa is used in all tests proposed in this research. To break the water menisci in small pores of WRB one may need a considerable pressure (e.g., the 3rd group of existing test methods). However, air can also be evacuated from the WRB pores by means other than the hydrostatic pressure. The dissolution of air in the pore-water and diffusion through the pore-water to the surface of the WRB depends on factors such as the mean size of the pore, pore-size distribution, connectivity of the pores within the matrix, temperature oscillations, presence of salts in the pore water, and even on electric or osmotic conditions on the surface. A test method designated as the ***liquid penetration resistance (LPR)***, is conducted with water on both surfaces of WRB, and the hydrostatic pressure difference of 250 Pa acted as the driving force for the liquid. In this test two variables were measured; (1) the time to the onset of liquid flow; and (2) the water conductivity coefficient under steady state conditions of capillary saturated water flow.

4. APPLICATION OF NEW TEST METHODS

The developed test methods; MIC, MF, and LPR were used to examine changes in liquid and vapour transport through type C, and type P WRB when:

- Penetrations were introduced through the WRB
- WRB was subjected to outdoor exposure for a period of several months
- Surfactants were dissolved in the interstitial water

4.1 Effect of penetrations

Nails and staples penetrating WRB increased moisture flux by one order of magnitude (see Bomberg et al 2003a). Yet, Figure 1 shows that moisture flux through WRB with penetrations is lower than that for an undisturbed product measured with the MIC method.

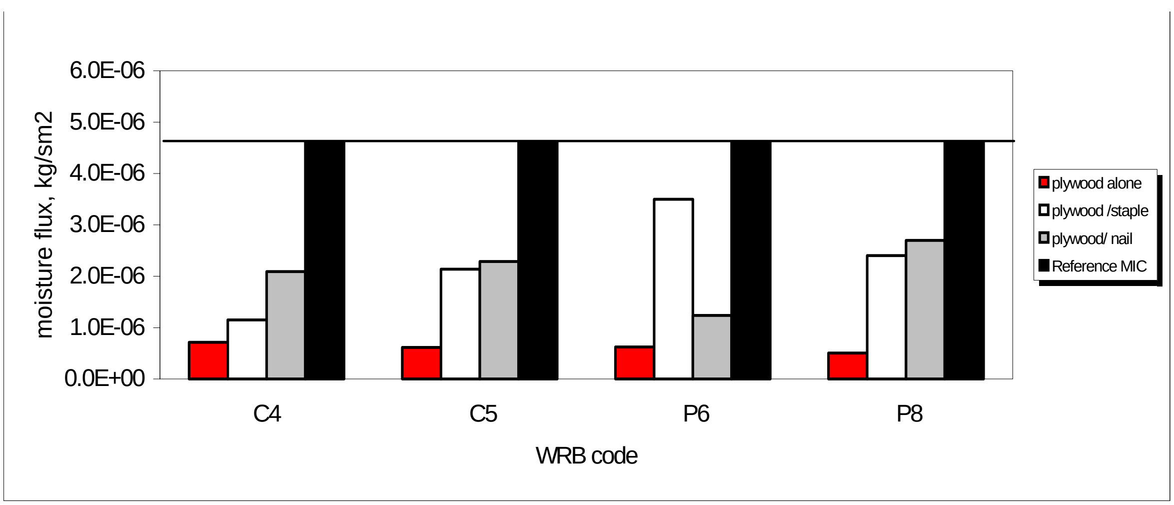

Figure 1. Moisture flux measured on plywood with nails/staples with MF method and that for undisturbed WRB product when tested with the MIC method.

4.2 Effect of weathering

Two series of materials aged for four months, starting at the end of July and November 2002 respectively served as benchmark for comparisons. As discussed elsewhere a small, insignificant reduction in measured moisture transmission was observed with MIC test method. With other words there is no significant change in the vapor dominated moisture flow. Conversely, Figure 2 shows the results of LPR tests performed on one series of fresh and aged WRB products indicating that water transmission was more significantly affected.

The comparison between these results led to the conclusion that both MIC and LPR test methods were needed to evaluate performance of WRB in different service conditions.

4.3 Effect of surfactants

It is known, and has been quantified in this work that chemicals can be leached out of adjacent materials. Presence of soap in water, at a concentration as low as 0.02%, had a significant effect on the surface tension of water. The surface tension measurements were complemented with measurements of the kinematic viscosity. Yet, moisture transfer trough type C and type P membranes performed with a 1% soap solution and the MIC test did not have any significant effect, the results were comparable to those performed with tap water.

Again, the difference observed when using the LPR test was significant.

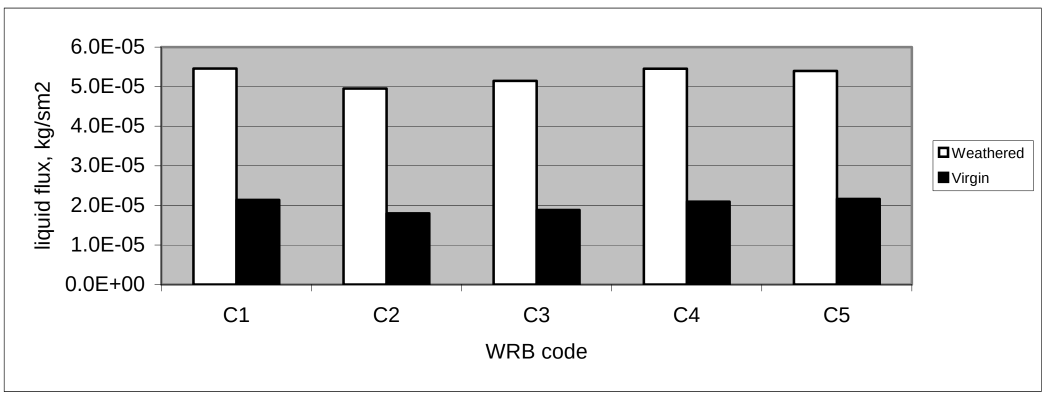

Figure 2. Liquid flux measured on (□) weathered, and (■) virgin type C products

5 ACCEPTANCE CRITERIAL FOR WRB PRODUCTS

To set the acceptance criteria the flow rates measured with different test methods on a single type P WRB were related in Table 2. The comparison indicated that for type P water vapour permeance values measured with the double cup and the MIC were comparable.

Table 2. Comparison of flow rates for a selected Type C product.

Line number	Description of transport conditions	Moisture flux, kg/m^2s
1	Liquid flux (LPR)	5.0 E-05
2	Proposed acceptance criterion for MIC	5.0 E-06
3	Modified Inverted Cup (MIC)[4]	4.0 E-06
4	Double Cup (0 to 100 %RH) (ASTM E96)	2.1 E-06

[4] With WV permeance of 7E-10 g/(m2sPa) and driving force of 3 kPa the flux becomes 2.1E-06

5	Moisture flux OSB + staple (MF)	3.3 E-06
6	Moisture flux OSB alone (MF)	4.5 E-07
7	Moisture flux plywood alone (MF)	4.8 E-07

Except for double cup method, all moisture transfer tests listed in Table 1 involved a 25-mm water head introduced on the top surface of WRB. Total moisture transfer from the water to the substrates such as OSB or plywood was measured with MF method. This method is somewhat arbitrary because it includes combined liquid and vapour phase transport and the results depend on the hygric properties on the substrate (see lines 6 and 7). Nevertheless, this was the only method, which allowed assessing the effects of mechanical penetrations (see line 5).

Line 4 shows water vapour permeance measured with a double cup test method. Water vapor transmission was measured between two environments, one with a near 100 %RH and the other near 0 %RH. One may notice that moisture flux determined with the MIC test method (line 3) was somewhat higher than that represented by the water vapour diffusion test. The difference could have been attributed to the resistance offered by the still air layer and the material surface, and the additional hydrostatic pressure (250 Pa) on the upper surface of WRB. In effect, the MIC test represented the worst conditions for water vapour dominant moisture transport. MIC criterion of 5.0 E-06 $kg/(m^2s)$ is based on the most permeable product amongst all tests performed with type C, P and LA-WRB. Yet as shown in line 1 it is still one order of magnitude lower than moisture flux under water filtration.

6. CONCLUSIONS

Two new methods to evaluate WRB products were found acceptable and are recommended for use in material standards. Both of them involve 25 mm layer of water on the top surface of the WRB and either near 0% RH with the use of frequently regenerated desiccant (Modified Inverted Cup) or 100% RH created by the use of water layer (Liquid Penetration Resistance) test. In the latter case, the WRB were subjected to 250 Pa pressure form the top and 500 Pa from the bottom so that a 250 hydrostatic pressure difference is pushing the water upwards through the WRB. Some WRB products (PP9 and PP11) displayed onset of liquid flow within few minutes even though they passed evaluation with the existing test methods. Furthermore, a significant effect of natural weathering was measured with LPR test while no such an effect was noted in results obtained with MIC or other methods. As a criterion for LPR it was proposed, that the onset of liquid flow should not take place for at least 1 day.

Another method, called *moisture flux (MF),* was used to examine moisture transport through different products even though its results depended on test conditions and the substrate used. One measured the rate of moisture flow from the 25 mm thick layer of water to an OSB substrate. This allowed assessing of the effect of penetrations and proposing an acceptance criterion for the MIC method.

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