Evaluation of Water-Resistive Barrier Performance Using Simple Ponding and Vapor Diffusion Tests

Mark F. Williams, FAIA

ABSTRACT

This paper describes a study comparing the water-resistive behavior of two commonly available housewrap products and No. 15 building felt in which the WRB materials were exposed to water (with and without surfactants) and three typical construction scenarios: no contact with OSB sheathing, contact with OSB sheathing, and contact with OSB sheathing combined with a staple fastener.

INTRODUCTION

Field investigators have recorded instances where wood sheathing was heavily stained or damaged even though the sheathing was covered by a water-resistive barrier (WRB). Much of this damage may be attributed to bulk water that enters the building enclosure through breaches in the wall assembly (such as window frame corners) and migrates behind the WRB at rough openings, specifically where “X” or “inverted Y” cuts are made in the WRB at those openings. However, damage has also been observed behind WRBs in wall areas that are separate and remote from such obvious moisture sources (Nisson 1998; Kardel 1999; Snyder 2001). The latter phenomenon suggested a need for further investigation into factors that may affect a WRB’s performance over its expected service life. Among these factors are surfactant contamination from other sources, water intrusion through fastener penetrations, and solar-driven vapor diffusion through WRB materials.

The present study compared and contrasted the water-resistive behavior of two commonly available housewrap products (which had different permeance values) and No. 15 building felt under the above conditions. These materials were selected because they are readily available in our region and are commonly used by our local homebuilders. The materials were exposed to three types of bulk moisture challenge: rainwater, a cedar extractive/rainwater solution, and a powerwash/water solution. At the same time, each of the WRBs was also evaluated using three different installation scenarios: no contact with oriented strand board (OSB) sheathing, contact with OSB sheathing, and contact with OSB sheathing, with a staple fastener driven through the WRB into the sheathing. Finally, this study also attempted to examine the effects of a solar heat-induced water vapor pressure differential on the selected WRB materials. The latter test series employed a simple “hot plate” methodology.

As a background to this study, it will be useful to briefly review some testing issues that have arisen due to the recent proliferation of water-resistive barrier materials. Since the early 1980s, numerous polymeric sheet materials (“housewraps”) have been introduced as WRBs to serve as alternatives to traditional paper/felt-based materials such as Grade D asphalt building papers and No. 15 asphalt-impregnated building felts. The alternative housewrap materials were originally intended to reduce air infiltration. However, over time, housewraps were marketed and relied upon as secondary water barriers as well. National building code organizations have required alternative WRB materials to have the same performance properties as traditional paper- and felt-based products. These properties were originally set forth in Federal Specification UU-B-790A, issued in the 1960s (GSA 1968). The specific properties that the codes agreed upon as being relevant to WRB performance are

Mark F. Williams is president of Williams Building Diagnostics Inc., Maple Glen, Pa.

water resistance, water vapor permeability, and tensile strength (bending/tear resistance). Interestingly, the ASTM standard specification for No. 15 building felt (D-226) contains no moisture-related performance criteria (ASTM 1998). In order for an alternative material to be accepted as "equal" to No. 15 building felt, both materials must be compared with standard tests for water resistance using hydrostatic pressure, as well as a standard test for water vapor transmission (Thorsell 1999).

Because the physical properties of polymer-based WRBs are quite different from those of paper/felt-based WRBs, it has become evident that test methods used to compare water resistance of one class of WRBs with another are inappropriate. For example, a traditional method for measuring the water resistance of paper/felt-based WRBs has been ASTM D-779, *Test Method for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry Indicator Method* (ASTM 1994). Sometimes called the "boat test," this method establishes the time required for water to pass through a given material and change the color of a moisture-sensitive indicator powder. Since traditional WRBs have relatively low water vapor permeance (on the order of 1 to 5 perms at room temperature), the test is suitable for evaluating the passage of liquid water through these materials. However, it is not suitable for testing the more vapor-permeable polymeric housewraps because the indicator powder does not accurately discriminate between water vapor and liquid water, producing inconsistent results and "false positives."

Recognizing this, housewrap manufacturers began using other tests to demonstrate the properties of their housewraps and to help establish that their products' water resistance was equal to or better than traditional felt/paper WRBs, as required by the codes. In contrast to ASTM D-779, these tests reflected more favorably on certain polymer-based products than paper/felt-based WRBs. A widely used test of this kind is the AATCC (American Association of Textile Colorists and Chemists) Test Method 127, "Water Resistance: Hydrostatic Pressure Test," which requires that a horizontally oriented material specimen withstand a vertical column of water for several hours without leaking (AATCC 1998). Some researchers (notably Bosack and Burnett [1998] and Butt [2003]) have questioned the validity of this test approach for WRB materials that are intended to serve as vertical drainage planes and are further protected from rain impacts by exterior claddings. Finally, it is doubtful that a high resistance to hydrostatic water pressure is of value when a WRB has been compromised by punctures from staples or other fasteners during the installation process.

In an effort to further clarify the process of WRB testing, the International Conference of Building Officials (ICBO) issued *Acceptance Criteria for Weather Resistive Barriers AC-38*. This document sets forth various standard tests for evaluating dry tensile strength, water resistance, and water vapor transmission (ICBO 2000). *AC 38* allows either AATCC-127 or the "water ponding test" set forth in the Canadian Construction Materials Centre's *Technical Guide for Sheathing Membrane, Breather-Type* (CCMC 1993) for hydrostatic pressure tests of paper/felt- and polymer-based materials. At the same time, it restricts the D-779 "boat test" to paper/felt-based WRB materials. In the present author's opinion, the CCMC test appears to be more appropriate than AATCC-127 because it is performed at a lower hydrostatic pressure (1 in. [25.4 mm] of water), which may be considered a reasonable water-resistive value for residential windows (0.549 in. [14 mm] of water). In essence, the performance characteristics of the WRB should at least equal the performance characteristics of other wall elements in order to provide consistency across building enclosure components and an appropriate level of service. Accordingly, a portion of the present study employed the CCMC procedure. This procedure was modified to provide quantitative data (weight gain/loss) as well as a purely qualitative (visual) evaluation, as explained further below.

METHODOLOGY

Test Series 1, 2, and 3 involved exposing WRB specimens to water (with and without surfactants) and to three typical construction scenarios: no contact with oriented strand board (OSB) sheathing, contact with OSB sheathing, and contact with OSB sheathing combined with a staple fastener driven through the WRB into the sheathing. Test Series 4 utilized an original test design to directly compare the water-resistance behavior of WRB materials under conditions duplicating the effects of solar heating and high relative humidity, which may occur in typical wall constructions under foreseeable conditions. Test configurations are summarized in Table 1.

Apparatus for Test Series 1, 2, and 3

Test series 1, 2, and 3 utilized a modified "water ponding test" published by the Canadian Construction Materials Centre (CCMC 1993). In the original CCMC test, a single thickness of water-resistive barrier (WRB) material is sandwiched between two nested aluminum rings whose meeting surfaces are fitted with watertight gaskets. The rings and WRB specimen are clamped together and then filled with water to a depth of 1 in. (25.4 mm). This water depth creates a hydrostatic head equal to a static wind pressure of 5.2 psf (7.74 Pa) or a wind velocity of 45.6 mph (73.4 km/h). The specimen is inspected frequently for two hours at constant conditions of temperature and relative humidity. During this period, the rings are suspended over a sheet of blotting paper to monitor the appearance of any bulk water that penetrates the WRB specimen. Failure is recorded if any seepage appears on the paper or on the underside of the specimen during the two-hour test period. The CCMC test serves as a simple qualitative screening procedure for water resistance of WRB materials. To provide additional information for the present study, the CCMC test procedure was modified by weighing the specimens before and after each test to quantify the amounts of moisture passing through the WRB materials.

Nine pairs of square frames were fabricated from aluminum. Each outer frame is 9 in. × 9 in. (228 mm × 228 mm), and each inner frame is slightly smaller (8-1/8 in. × 8-1/8 in., or 206 mm × 206 mm). The frames are 2 in. (51 mm) deep, and each includes a 5 in. × 5 in. (127 mm × 127 mm) opening in the bottom. A self-adhering membrane (Carlisle "Sure Seal" pressure-sensitive EPDM flashing) was used to provide a watertight gasket seal between the frame surfaces. WRB specimens were taped to the bottoms of the inner frames using foil-backed double-sided tape. These frames were then nested inside the larger frames and clamped together so that the WRB specimen was sandwiched between the gasket material to form a watertight condition. The frames were clamped with adjustable C-clamps (Bessey Model LM23004).

In each series, three replicate samples of each material, labeled A, B, and C, were cut from the same stock rolls for testing under the three construction scenarios described above. Accordingly, nine pairs of frames with mounted specimens were placed on a metal framework bolted to two trestles. All frames, test solutions, and specimens were weighed with a standard triple-beam balance (Ohaus Corp.). Ambient air temperatures and relative humidity levels were monitored during the tests with a hand-held Dickson TH-300 temperature/humidity/dewpoint indicator. Each test series was documented photographically. After each test series was completed, the specimens were labeled and stored in plastic recloseable bags.

Table 1. Overview of Test Protocols

Test Series	Test Modality
Series 1	1.1 – Rainwater Ponding Over WRB (Typar, Tyvek, and No. 15 felt)
	1.2 – Rainwater Ponding Over WRB + OSB
	1.3 – Rainwater Ponding Over WRB + OSB + Staple
Series 2	2.1 – Powerwash Solution Ponding Over WRB (Typar, Tyvek, and No. 15 felt)
	2.2 – Powerwash Solution Ponding Over WRB + OSB
	2.3 – Powerwash Solution Ponding Over WRB + OSB + Staple
Series 3	3.1 – Cedar Extractive Solution Ponding Over WRB (Typar, Tyvek, and No. 15 felt)
	3.2 – Cedar Extractive Solution Ponding Over WRB + OSB
	3.3 – Cedar Extractive Solution Ponding Over WRB + OSB + Staple
Series 4	1A, 1B, 1C – Moisture/Heat + Typar + Plexiglass
	2A, 2B, 2C – Moisture/Heat + Tyvek + Plexiglass
	3A, 3B, 3C – Moisture/Heat + No. 15 Felt + Plexiglass

Test Series 1—Rainwater

In this test series, rainwater (collected on site at Maple Glen, Pa.) was used as a "control," to which no surfactant materials had been added. Three samples each of the Typar, Tyvek HomeWrap, and No. 15 building felt were tested using the modified CCMC procedure, in the following configurations.

Test 1.1, Rainwater and WRB. The WRB samples were mounted in the frames and exposed to a 1 in. (25.4 mm) hydrostatic head of water for two hours. Frame assemblies were weighed before and after the tests. The undersides of the WRB specimens were monitored visually for the appearance of moisture. An 8 in. × 8 in. (203 mm × 203 mm) formed aluminum pan containing white absorbent paper toweling was placed approximately 2 ft. (0.6 m) beneath each pair of nested frames. The pan was used only in Series 1.1 to catch any bulk water passing through the WRB materials.

Test 1.2, Rainwater, WRB, and OSB. The WRB samples were installed over 7/16 in. (11 mm) thick OSB sheathing (Georgia-Pacific exterior grade, Exposure 1). Both materials were then mounted in the frames and exposed to a 1 in. (24.5 mm) hydrostatic head of water for two hours. Frame assemblies were weighed before and after the tests. OSB moisture levels were measured before and after the tests with a Delmhorst Model BD-9 Moisture Tester.

Test 1.3, Rainwater, WRB, OSB, and Staple. The WRB samples were installed over 7/16 in. (11 mm) thick OSB sheathing (Georgia-Pacific exterior grade, Exposure 1). A single 0.25 in. (6 mm) Arrow #T50 (Monel) staple was driven through the WRB into the sheathing. All materials were mounted in the frames and exposed to a 1 in. (24.5 mm) hydrostatic head of water for two hours. Frame assemblies were weighed before and after the tests. OSB moisture levels were measured before and after the tests with the Delmhorst moisture meter. Results of this test series are presented in Tables 2, 3, and 4.

Test Series 2—Powerwash Solution

This test series utilized a commercial powerwashing solution, ZEP Commercial House & Siding Cleaner Concentrate, mixed as directed with water in a 20:1 dilution (122 oz. [3.6 L] water to 6 oz. [0.17 L] Zep Concentrate). Three samples each of the Typar, Tyvek HomeWrap, and No. 15 building felt were tested using the modified CCMC procedure, in the following configurations.

Test 2.1, Powerwash Solution and WRB. The WRB samples were mounted in the frames and exposed to a 1 in. (25.4 mm) hydrostatic head of powerwash solution for two hours. Frame assemblies were weighed before and after the

Table 2. Series 1.1 Test Results: Rainwater Ponding Over WRB Ambient Air Temperature, 63°F (17°C), RH 53%

Test Specimen Number	Initial Weight, g (oz)	Elapsed Time to Moisture Penetration (Min)	Net Change in Weight, g (oz)	Comments
1.1 Typar A	1332.8 (47.01)	N/a	0	No pass-through moisture observed.
1.1 Typar B	1344.3 (47.41)	N/a	0	No pass-through moisture observed.
1.1 Typar C	1344.0 (47.40)	N/a	0	No pass-through moisture observed.
1.1 Tyvek A	1348.9 (47.58)	N/a	0	No pass-through moisture observed.
1.1 Tyvek B	1346.8 (47.50)	N/a	0	No pass-through moisture observed.
1.1 Tyvek C	1350.6 (47.64)	N/a	0	No pass-through moisture observed.
1.1 No.15 A	1389.6 (49.01)	N/a	+ 0.9 (0.03)	No pass-through moisture observed, but WRB gained 0.9 g (0.03 oz).
1.1 No.15 B	1371.2 (48.36)	N/a	+ 1.8 (0.06)	No pass-through moisture observed, but WRB gained 1.8 g (0.06 oz).
1.1 No.15 C	1372.2 (48.40)	N/a	+ 1.3 (0.04)	No pass-through moisture observed, but WRB gained 1.3 g (0.04 oz).

Table 3. Series 1.2 Test Results: Rainwater Ponding Over WRB on OSB, Ambient Air Temperature 63°F (17°C), RH 53%

Test Specimen Number	Initial Weight, g (oz)	Initial Delmhorst Readings (%)	Final Delmhorst Readings (%)	Net Change in Weight, g (oz)	Comments
1.2 Typar A	1669.4 (58.88)	6	6	0	No pass-through moisture observed.
1.2 Typar B	1693.3 (59.72)	6	6	0	No pass-through moisture observed.
1.2 Typar C	1675.1 (59.08)	6	6.5	0	No pass-through moisture observed.
1.2 Tyvek A	1675.2 (59.08)	6	7	0	No pass-through moisture observed.
1.2 Tyvek B	1662.0 (58.62)	6	6.5	0	No pass-through moisture observed.
1.2 Tyvek C	1686.5 (59.48)	6	7.2	0	No pass-through moisture observed.
1.2 No.15 A	1722.5 (60.75)	7	7	+ 1.1 (0.04)	No pass-through moisture, but WRB gained 1.1 g (0.04 oz).
1.2 No.15 B	1729.2 (60.99)	9	9	+ 1.1 (0.04)	No pass-through moisture, but WRB gained 1.1 g (0.04 oz).
1.2 No.15 C	1742.2 (61.45)	9	9	+ 1.5 (0.05)	No pass-through moisture, but WRB gained 1.5 g (0.05 oz).

Table 4. Series 1.3 Test Results: Rainwater Ponding Over WRB on OSB with Staple, Ambient Air Temperature 62°F (16°C), RH 52%

Test Specimen Number	Initial Weight, g (oz)	Initial Delmhorst Readings (%)	Final Delmhorst Readings (%)	Net Change in Weight g (oz)	Comments
1.3 Typar A	1674.2 (59.054)	6	28 at staple, 6 elsewhere	+ 0.1 (0.004)	Moisture observed at puncture, migrated to about ¼ of OSB area.
1.3 Typar B	1673.5 (59.02)	6	30 at staple, 6 elsewhere	+ 1.4 (0.05)	Moisture observed at puncture, migrated to about ¼ of OSB area.
1.3 Typar C	1659.3 (58.52)	6	30 at staple, 6 elsewhere	+ 2.5 (0.08)	Moisture observed at puncture, migrated to about 1/3 of OSB area.
1.3 Tyvek A	1668.5 (58.85)	7	8 at staple, 7 elsewhere	+ 0.5 (0.02)	Moisture observed at puncture.
1.3 Tyvek B	1684.7 (59.42)	7	35 at staple, 7.5 elsewhere	+ 6.5 (0.23)	Moisture observed at puncture, migrated to about 1/3 of OSB area.
1.3 Tyvek C	1684.5 (59.41)	6	35 at staple, 7 elsewhere	+ 2.0 (0.07)	Moisture observed at puncture, migrated to about 1/4 of OSB area.
1.3 No.15 A	1713.8 (60.45)	6	6	+ 1.5 (0.05)	Dry at staple; WRB absorbed moisture.
1.3 No.15 B	1674.6 (59.06)	7	7	+ 1.7 (0.06)	Dry at staple; WRB absorbed moisture.
1.3 No.15 C	1689.2 (59.58)	6	6	+ 1.2 (0.04)	Dry at staple; WRB absorbed moisture.

tests. The undersides of the WRB specimens were monitored visually for the appearance of moisture. An 8 in. × 8 in. (203 mm × 203 mm) formed aluminum pan containing white absorbent paper toweling was placed approximately 2 ft. (0.6 m) beneath each pair of nested frames. The pan was used only in Series 2.1 to catch any bulk water passing through the WRB materials.

Test 2.2, Powerwash Solution, WRB, and OSB. The WRB samples were installed over 7/16 in. (11 mm) thick OSB sheathing (Georgia-Pacific exterior grade, Exposure 1). Both materials were then mounted in the frames and exposed to a 1 in. (24.5 mm) hydrostatic head of powerwash solution for two hours. Frame assemblies were weighed before and after the tests. OSB moisture levels were measured before and after the tests with the Delmhorst moisture meter.

Test 2.3, Powerwash Solution, WRB, OSB, and Staple. The WRB samples were installed over 7/16 in. (11 mm) thick OSB sheathing (Georgia-Pacific exterior grade, Exposure 1). A single 0.25 in. (6 mm) Arrow #T50 (Monel) staple was driven through the WRB into the sheathing. All materials were mounted in the frames and exposed to a 1 in. (24.5 mm) hydrostatic head of powerwash solution for two hours. Frame assemblies were weighed before and after the tests. OSB moisture levels were measured before and after the tests with the Delmhorst meter. Results are presented in Tables 5, 6, and 7.

Test Series 3—Cedar Extractive Solution

This test series utilized water infusions of wood extractives. First, an infusion was made by steeping 1000 grams (35.3 ounces) of cedar sawdust in 17 liters (18 quarts) of tapwater for approximately 90 days. The top (exterior) surfaces of each specimen of Typar, Tyvek HomeWrap, and No. 15 building felt were preconditioned by being wetted with this infusion and left to dry until they acquired a dry film residue of extractive particles. The preconditioned specimens were then tested using the modified CCMC procedure, using a fresh extractive solution made by steeping 1127 g (40 oz) of Western Red Cedar sawdust in 4 gal (15 L) of rainwater for three days. Test configurations were as follows.

Test 3.1, Cedar Extractive Solution and WRB. The WRB samples were mounted in the frames and exposed to a 1 in. (25.4 mm) hydrostatic head of cedar extractive solution for two hours. Frame assemblies were weighed before and after the tests. The undersides of the WRB specimens were monitored visually for the appearance of moisture. An 8 in. × 8 in. (203 mm × 203 mm) formed aluminum pan containing white absorbent paper toweling was placed approximately 2 ft (0.6 m) beneath each pair of nested frames. The pan was used only in test series 3.1 to catch any bulk water passing through the WRB materials.

Test 3.2, Cedar Extractive Solution, WRB and OSB. The WRB samples were installed over 7/16 in. (11 mm) thick OSB sheathing (G-P exterior grade, Exposure 1). Both materials were then mounted in the frames and exposed to a 1 in. (24.5 mm) hydrostatic head of cedar extractive solution for two hours. Frame assemblies were weighed before and after the tests. OSB moisture levels were measured before and after the tests with the Delmhorst moisture meter.

Table 5. Series 2.1 Test Results: Powerwash Solution Ponding Over WRB, Ambient Air Temperature 64°F (17°C), RH 50%

Test Specimen Number	Initial Weight, g (oz)	Elapsed Time to Moisture Penetration (Min)	Net Change in Weight, g (oz)	Comments
2.1 Typar A	1332.1 (46.98)	N/a	0	No pass-through moisture observed.
2.1 Typar B	1342.7 (47.36)	N/a	0	No pass-through moisture observed.
2.1 Typar C	1348.6 (47.57)	N/a	0	No pass-through moisture observed.
2.1 Tyvek A	1350.7 (47.64)	27	+ 6.6 (0.23)	Numerous droplets on bottom surface.
2.1 Tyvek B	1348.4 (47.56)	41	+ 9.0 (0.31)	Numerous droplets on bottom surface.
2.1 Tyvek C	1337.9 (47.19)	39	+ 6.5 (0.22)	Numerous droplets on bottom surface.
2.1 No.15 A	1373.0 (48.43)	N/a	0	No pass-through moisture observed.
2.1 No.15 B	1382.7 (48.77)	3	+ 0.4 (0.01)	Moisture observed (1 droplet in 2 hours).
2.1 No.15 C	1380.0 (48.67)	N/a	0	No pass-through moisture observed.

Table 6. Series 2.2 Test Results: Powerwash Solution Ponding Over WRB on OSB, Ambient Air Temperature 64°F (17°C), RH 55%

Test Specimen Number	Initial Weight, g (oz)	Initial Delmhorst Readings (%)	Final Delmhorst Readings (%)	Net Change in Weight, g (oz)	Comments
2.2 Typar A	1667.3 (58.1)	7	9.2	0	No pass-through moisture observed.
2.2 Typar B	1699.6 (59.95)	6	9	0	No pass-through moisture observed.
2.2 Typar C	1707.2 (60.21)	7	8.5	0	No pass-through moisture observed.
2.2 Tyvek A	1688.3 (59.55)	7	> 35	+ 1.8 (0.06)	OSB partially wetted (lower left corner)
2.2 Tyvek B	1685.9 (59.46)	8	35	+ 12.1 (0.43)	OSB completely wetted.
2.2 Tyvek C	1674.7 (59.07)	7	> 35	+ 5.9 (0.21)	OSB partially wetted (about 50% of area).
2.2 No.15 A	1712.1 (60.39)	7	> 35 (part) 7.2 (most)	+ 5.4 (0.19)	No pass-through moisture but WRB gained 5.4 g.
2.2 No.15 B	1690.7 (59.63)	8	8	+ 3.7 (0.13)	No pass-through moisture but WRB gained 3.7 g.
2.2 No.15 C	1700.2 (59.97)	8	8	+ 1.3 (0.04)	No pass-through moisture but WRB gained 1.3 g.

Table 7. Series 2.3 Test Results: Powerwash Solution Ponding Over WRB on OSB with Staple, Ambient Air Temperature 64°F (17°C), RH 55%

Test Specimen Number	Initial Weight, g (oz)	Initial Delmhorst Readings (%)	Final Delmhorst Readings (%)	Net Change in Weight, g (oz)	Comments
2.3 Typar A	1664.2 (58.70)	6	>40 (part) 8.5 (part)	+ 9.3 (0.32)	Approx. 50% of OSB wetted.
2.3 Typar B	1675.0 (59.08)	6	32	+ 17.6 (0.62)	Most of OSB wetted.
2.3 Typar C	1675.5 (59.10)	7	35	+ 11.0 (0.38)	All of OSB wetted.
2.3 Tyvek A	1644.5 (58.00)	6	12 to 40	+ 16.8 (0.59)	Most of OSB wetted.
2.3 Tyvek B	1680.9 (59.29)	6	40	+ 14.1 (0.49)	All of OSB wetted.
2.3 Tyvek C	1681.7 (59.31)	6	8 to 35	+ 5.1 (0.18)	Moisture observed at staple.
2.3 No.15 A	1726.8 (60.91)	7	8 to 40	+ 3.2 (0.11)	Moisture observed only at staple.
2.3 No.15 B	1690.0 (59.61)	6	7.5 to 11.5	+ 1.6 (0.05)	Moisture observed only at staple.
2.3 No.15 C	1715.0 (60.49)	6	6.5 to 28	+ 8.4 (0.29)	Approx. 1/3 of OSB wetted; highest reading at staple.

Test 3.3, Cedar Extractive Solution, WRB, OSB, and Staple. The WRB samples were installed over 7/16 in. (11 mm) thick OSB sheathing (G-P exterior grade, Exposure 1). A single 0.25 in. (6 mm) Arrow #T50 (Monel) staple was driven through the WRB into the sheathing. All materials were mounted in the frames and exposed to a 1 in. (24.5 mm) hydrostatic head of cedar extractive solution for two hours. Frame assemblies were weighed before and after the tests. OSB moisture levels were measured before and after the tests with the Delmhorst meter.

Results of this series are presented in Tables 8, 9, and 10.

Test Series 4—Hot Plate Testing

Porous claddings such as wood-based siding materials and brick veneer absorb some water during rain events and serve as moisture reservoirs until they dry out. Water vapor migrates from areas of high pressure to low pressure, e.g., from the cladding material and related cavity spaces into the wall assembly and the building exterior. Surface temperatures on exterior walls can range from approximately 140°F to 180°F (60°C to 82°C) depending on season, cladding color, building orientation, and other factors (Stephenson 1963). The air space immediately behind some claddings can reach or exceed 120°F (49°C) (Lstiburek and Carmody 1994). Solar heating of rain-soaked exterior claddings causes an inward vapor drive that may penetrate through the WRB materials (Straube and Burnett 1998; Straube 2001). As the sun exposure changes, the temperature of the wall may drop below the dew point, causing condensation. Without sufficient drying to the exterior or interior, or a means of ventilation, the condensate may accumulate behind the WRB, where it may be trapped and cause damage to underlying wall components. This type of moisture entrapment and resulting damage has been observed behind polymeric housewraps by the author as well as by other investigators (Lstiburek 2001; Nisson 1996; Snyder 2001). Accordingly, the present study investigated the effects of simulated solar heating on the selected WRB materials in a simulated "warm wet wall" assembly.

Apparatus for Test Series 4

The "warm wet wall" assembly used in this test series consisted of a pan of heated water, which simulated the high temperature and humidity conditions that typically occur when a wall covered with porous claddings is exposed to solar heating after a rain event. A sheet of clear acrylic represented the exterior wall sheathing, which lies directly behind the WRB in a vertical wall. The WRB material was placed directly beneath this clear plastic, which allowed visual monitoring of any moisture condensation at the acrylic/WRB interface.

Samples of Typar, Tvyek HomeWrap, and No. 15 felt were taped to 8 in. × 8 in. (203 mm × 203 mm) aluminum frames similar to those used in Test Series 1, 2, and 3. The frames were inverted and placed over 8 in. × 8 in. (203 mm × 203 mm) formed aluminum pans, which were filled with water to a depth of 1 in. (25.4 mm). This created a small chamber or "head space" for water vapor to collect. To ensure that each pan received the same amount of water, the pans were weighed upon

Table 8. Series 3.1 Test Results: Cedar Extractive Solution Ponding Over WRB, Ambient Air Temperature 64°F (17°C), RH 52%

Test Specimen Number	Initial Weight, g (oz)	Elapsed Time to Moisture Penetration (Min)	Net Change in Weight, g (oz)	Comments
3.1 Typar A	1342.9 (47.36)	N/a	0	No pass-through moisture observed.
3.1 Typar B	1345.5 (47.46)	N/a	0	No pass-through moisture observed.
3.1 Typar C	1349.0 (47.58)	N/a	0	No pass-through moisture observed.
3.1 Tyvek A	1348.7 (47.57)	N/a	0	No pass-through moisture observed.
3.1 Tyvek B	1352.2 (47.69)	N/a	0	No pass-through moisture observed.
3.1 Tyvek C	1329.9 (46.91)	N/a	0	No pass-through moisture observed.
3.1 No.15 A	1372.2 (48.40)	N/a	+ 3.8 (0.13)	No pass-through moisture observed, but WRB gained 3.8 g (0.13 oz).
3.1 No.15 B	1381.5 (48.73)	N/a	+ 5.5 (0.19)	No pass-through moisture observed, but WRB gained 5.5 g (0.19 oz).
3.1 No.15 C	1368.6 (48.27)	N/a	+ 7.4 (0.26)	No pass-through moisture observed, but WRB gained 7.4 g (0.26 oz).

Table 9. Series 3.2 Test Results: Cedar Extractive Solution Ponding Over WRB on OSB, Ambient Air Temperature 64°F (17°C), RH 52%

Test Specimen Number	Initial Weight, g (oz)	Initial Delmhorst Readings (%)	Final Delmhorst Readings (%)	Net Change in Weight, g (oz)	Comments
3.2 Typar A	1672.3 (58.98)	6	6	0	No pass-through moisture observed.
3.2 Typar B	1657.7 (58.47)	6	6	0	No pass-through moisture observed.
3.2 Typar C	1689.0 (59.57)	6	6	0	No pass-through moisture observed.
3.2 Tyvek A	1649.4 (58.17)	7	8	0	No pass-through moisture observed.
3.2 Tyvek B	1669.0 (58.87)	6	8	0	No pas-through moisture observed.
3.2 Tyvek C	1689.0 (59.57)	6	8.6	0	No pass-through moisture observed.
3.2 No.15 A	1701.0 (60.00)	8	10	+ 2.2 (0.077)	No pass-through moisture observed, but WRB gained 2.2 g (0.077 oz).
3.2 No.15 B	1713.5 (60.44)	6	6.5	+ 2.0 (0.070)	No pass-through moisture observed, but WRB gained 2.0 g (0.070 oz).
3.2 No.15 C	1723.4 (60.79)	6	7	+ 2.1 (0.074)	No pass-through moisture observed, but WRB gained 2.1 g (0.074 oz).

Table 10. Series 3.3 Test Results: Cedar Extractive Solution Ponding Over WRB on OSB with Staple, Ambient Air Temperature: 65°F (18°C), RH 53%

Test Specimen Number	Initial Weight, g (oz)	Initial Delmhorst Readings (%)	Final Delmhorst Readings (%)	Net Change in Weight, g (oz)	Comments
3.3 Typar A	1698.4 (59.80)	9	27 (part); 8 (most)	+ 3.1 (0.11)	Approx. ¼ of OSB wetted; high reading at staple.
3.3 Typar B	1675.8 (59.11)	9	9	+ 1.7 (0.06)	No pass-through moisture observed, but WRB gained 1.7 g.
3.3 Typar C	1697.2 (59.86)	8	>35 (part); 8 (most)	+ 1.5 (0.05)	Approx. 1/8 of OSB wetted; high reading at staple.
3.3 Tyvek A	1684.7 (59.42)	8	28 (part); 10 (most)	+ 1.5 (0.05)	Approx. 1/8 of OSB wetted; high reading at staple.
3.3 Tyvek B	1694.7 (59.77)	8	30 (part); 9 (most)	+ 1.3 (0.045)	Approx. 1/6 of OSB wetted; high reading at staple.
3.3 Tyvek C	1683.3 (59.37)	8	>30 (part); 10 (most)	+ 1.4 (0.049)	Approx. 1/8 of OSB wetted; high reading at staple.
3.3 No.15 A	1719.3 (60.64)	8	9	+ 2.2 (0.08)	No pass-through moisture observed, but WRB gained 2.2 g (0.08 oz).
3.3 No.15 B	1717.5 (60.58)	7	8.1	+ 3.1 (0.11)	No pass-through moisture observed, but WRB gained 3.1 g (0.11 oz).
3.3 No.15 C	1702.9 (60.06)	9	9	+ 1.4 (0.049)	No pass-through moisture observed, but WRB gained 1.4 g (0.049 oz).

filling. Each pan received 1049 grams (approximately 37 ounces) of water.

Three completed pan/frame assemblies, one of each WRB material, were positioned side by side on a 24 in. × 8 in. (610 mm × 203 mm) base plate of sheet aluminum, which was placed on an electric hot plate with two heating elements (Windermere Model DB-1, Applica Consumer Products). The top of each assembly was then covered with an 8 in. × 8 in. (203 mm × 203 mm) sheet of clear acrylic plastic. The edges of the aluminum pans and acrylic sheets were not sealed.

Prior to beginning the tests, each acrylic sheet was weighed. A square of paper toweling, which would be used to wipe any anticipated moisture from each acrylic sheet, was also weighed at this time. Bottom heat was applied to the pan/frame assemblies. The water temperature was maintained at approximately 120°F (49°C) for the duration of the tests and was monitored using a Minitemp MT-4 portable noncontact infrared thermometer (Raytek Corp.).

At the end of each test, the visible film of liquid water that had condensed at the acrylic sheet/WRB interface was observed and photographed in place. The condensate was then wiped with the previously weighed paper towels, and the acrylic sheets and towels were then weighed together within 10 seconds to reduce evaporative moisture loss. This procedure allowed an approximate quantitative comparison to be made of the amounts of moisture that passed through each WRB material.

Results of this test series are presented in Table 11.

DISCUSSION

Series 1 (Rainwater)

Both the polymeric housewraps and the No. 15 felt resisted a hydrostatic head of 1 in. (25. 4 mm) of rainwater for two hours, thus passing the modified CCMC test (Tables 2, 3, and 4). The No. 15 felt absorbed moisture in each test, and, as one would expect, moisture absorption was highest when penetrated by a staple. However, even in the latter case, the felt kept the underlying OSB sheathing dry. In contrast, both the polymeric housewraps evidenced small amounts of bulk water at the staple penetrations; the water migrated from the penetration point to wet a relatively small area of the underlying OSB.

Series 2 (Powerwash)

When exposed to a powerwash/water surfactant solution, Typar housewrap resisted a hydrostatic head of 1 in. (25. 4 mm) for two hours, thus passing the modified CCMC test. However, Tyvek Homewrap failed the first two tests in this series (Tables 5 and 6), permitting numerous droplets to form and wetting the underlying OSB. As in the previous test series, the No. 15 felt absorbed moisture while protecting the OSB, except in one instance where a single droplet was observed penetrating one of the felt specimens. When penetrated by staples, all of the materials allowed the powerwash solution to wet the underlying OSB and in greater amounts than were observed in the preceding test series (Table 7).

Table 11. Series 4 “Hot Plate” Test Results: Rainwater, WRB, and Plexiglas, Ambient Air Temperature 66°F (19°C), RH 53%

Specimens	Initial Plexiglas and Towel Weight, g (oz)	Final Plexiglas and Towel Weight, g (oz)	Weight of moisture passed through WRB, g (oz)
1A Typar/Plexiglas	127.8 (4.51)	128.1 (4.52)	+ 0.3 (0.01)
1B Typar/Plexiglas	127.6 (4.50)	127.7 (4.504)	+ 0.1 (0.003)
1C Typar/Plexiglas	127.6 (4.50)	127.6 (4.50)	0
Avg. Wt. Gain: Typar			+ 0.13 (0.004)
1A Tyvek/Plexiglas	129.1 (4.553)	132.5 (4.67)	+ 3.4 (0.12)
1B Tyvek/Plexiglas	129.0 (4.550)	130.8 (4.613)	+ 1.8 (0.063)
1C Tyvek/Plexiglas	129.0 (4.550)	133.4 (4.705)	+ 4.4 (0.155)
Avg. Wt. Gain: Tyvek			+ 3.20 (0.11)
1A No.15 Felt/Plexiglas	129.5 (4.567)	134.1 (4.730)	+ 4.6 (0.162)
1B No.15 Felt/Plexiglas	129.4 (4.564)	133.4 (4.705)	+ 4.0 (0.14)
1C No.15 Felt/Plexiglas	129.4 (4.564)	131.5 (4.638)	+ 2.1 (0.07)
Avg. Wt. Gain: No.15 Felt			+ 3.56 (0.13)

Series 3 (Cedar Extractives)

When exposed to a cedar extractive solution, all of the WRB materials resisted a hydrostatic head of 1 in. (25.4 mm) of rainwater for two hours, thus passing the modified CCMC test (Tables 8 and 9). In this series, the specimens were preconditioned with a cedar extractive solution on the exterior face and dried prior to the remainder of the procedure. When penetrated by staples, all of the materials allowed the cedar extractive solution to wet the underlying OSB (Table 10), but moisture amounts were less than the tests using powerwash solution. Other investigators (Fisette 1999) have reported that cedar extractives caused observable water penetration in housewraps and No. 15 felt after similar testing for two hours. This may be due in part to Fisette’s use of a higher hydrostatic pressure (3.4 in. [86.4 mm]).

Fisette also noted that cedar extractives exerted a weaker surfactant effect than a soap-based solution, a finding that agrees with the present study. Soaps (such as those in powerwash products) are designed to exert immediate effects on the surface tension of water. In contrast, naturally occurring water-soluble tannins, starches, and lignins are leached slowly out of wood-based siding and sheathing components over months and years. Given certain conditions, such extractives may still be capable of causing damage. The well-known phenomenon of “extractive bleeding” occurs with some wood-based siding products (such as redwood, cedar, or Douglas fir clapboards) that have not been back-primed (Joint Coatings/Forest Products Committee, n.d.).

It has been suggested that the inside face of the WRB may also be exposed to extractives from wood-based wall sheathings, such as oriented strand board (OSB) or plywood (Nisson 1996). Due to the complex nature of OSB (wood flakes glued together with phenol-formaldehyde resins under heat and pressure), the composition of extractives from this source may vary widely, even within different areas of the same sheathing board (Baumann et al. 1999). The effects of wood extractives on the bonding performance of adhesives, coatings, and veneers for wood-based sheathing products has been extensively studied (Dietenberger et al. 1999), but relatively little has been done on the interaction of extractives/surfactants and WRB materials.

Relatedly, the deleterious effects on WRBs of additives used in Portland cement stucco have also been noted (Bucholtz 1984; McCoy 2003). Additional research is needed to further elucidate the effects of extractives/surfactants on the long-term performance of WRB materials.

Surfactants and Fasteners

Water penetration through all WRB materials increased upon puncturing with staple fasteners. Surfactants augmented this effect, with powerwash solution acting more strongly than cedar extractives (see Table 12). Bosack and Burnett's (1998) survey found that staples were used in 70% of housewrap installations. The staples were commonly overdriven, causing tears and holes in the housewrap. Some housewrap manufacturers (such as Ludlow [2003]) recommend using cap nails to minimize water penetration around the fasteners. It is likely that No. 15 building felt has similar problems with punctures and consequent water penetration. However, unlike polymer-based housewraps, felts are hygroscopic. Some moisture will be absorbed by the material fibers, which causes them to swell. As a result, felts are described by some to "self-seal" around fastener penetrations (Greenlaw 1994; BIA 1999).

Water penetration through fastener punctures may be a significant pathway for moisture, whatever WRB material is used. A 1,000 ft^2 area of wood siding is fastened to a wall with approximately 1,100 to 4,000 nails, depending on fastener spacing and type of siding (Manasquan 2003). These penetrations are in addition to the staples used to fasten the WRB to the sheathing. Designers wishing to minimize the effects of water penetration from this source might consider installing a layer of No. 15 felt in addition to a polymer-based housewrap on vertical walls.

Series 4 (Hot Plate Testing)

As noted in Table 11, Typar was more resistant to an "inward" vapor pressure drive than either Tyvek or No. 15 felt in this "warm wet wall" simulation. The difference could be observed upon visual examination of the condensation that appeared beneath the clear acrylic panels. These findings highlight an essential difference between polymeric housewraps and fiber-based WRBs. Among polymeric housewraps, Tyvek's published perm rating is 58, while Typar's is approximately 14. In contrast, No. 15 building felt is rated at approximately 5 to 8 perms, but its permeance increases with relative humidity—to more than 60 perms at 95% RH (Fisette 1999; Tonyan et al. 1999), which approximates the perm rating of Tyvek. Under the high solar heat/high vapor pressure conditions simulated here, it appears that Tyvek and No. 15 felt were equally permeable to water vapor.

Moisture condensing on wall sheathing behind either of these two materials may be trapped when the wall assembly cools down. But because Tyvek's high permeability is a fixed material property, it will allow some water vapor to flow back out to the building exterior under some conditions. In contrast, No. 15 felt returns to a less permeable state as temperature and humidity levels fall, so that, like Tyvek, it probably will trap some bulk water. However, felt can absorb some of this excess moisture, while Tyvek cannot. Typar, which is both nonabsorptive and less permeable than either Tyvek or No. 15 felt, would be less likely to trap bulk moisture under conditions of high solar heat and vapor pressure. In practical terms, these findings suggest that installation of a WRB having low permeability would be beneficial in wall assemblies that include a space behind the cladding and/or absorptive cladding materials that retain moisture under foreseeable conditions.

See Table 12 for a comparison of the effects of extractives, staples, and solar heating.

CONCLUSIONS

The following conclusions are based on the work reported here.

- Test results reported by WRB manufacturers are derived from many different test procedures for air and water resistance, tensile strength, etc., which seldom apply to actual on-site installation conditions. To date, there has been little effort to coordinate either the tests or the criteria for important material properties of these materials. Thus, it is difficult for designers and specifiers to choose among the many WRB materials available to find the product best suited for their projects.
- The CCMC water ponding test, as employed in Test Series 1, 2, and 3 and modified to obtain change in weight data, provides a simple means of comparing and quantifying the performance of water-resistant barrier materials under hydrostatic head conditions approximating the performance of other wall components such as windows.
- The "hot plate" or "warm wet wall" simulation, as employed for Test Series 4, provides a simple and rapid means of evaluating the permeance of any WRB material. This type of analysis provides useful insights when contemplating wall construction that includes a space behind the cladding and/or absorptive cladding materials that may retain moisture under certain conditions.
- Surfactant substances, whether derived from wood-based wall components or from powerwashing solutions, act to reduce the moisture resistance of some felt- and polymer-based water-resistant barrier materials. In our tests, Typar resisted a powerwash solution, whereas Tyvek did not. The powerwash solution was more potent than cedar extractives and acted almost immediately upon the Tyvek. Some building owners may powerwash once or twice a year, while others do not use powerwashing at all. However, powerwashing is becoming an increasingly popular maintenance tool. The effects of surfactant exposure may take months or years to manifest as reduced performance of the wall assembly behind WRB materials. Because powerwashing is a relatively recent innovation, surfactant/detergent issues should be further considered.
- Under conditions of solar heating and high water vapor pressure, low-permeance Typar performed better than high-permeance Tyvek or No. 15 building felt in preventing entrapment of condensate between the WRB and a

Table 12. Comparing the Effects of Extractives, Staples, and Solar Heating (Weight Gained by Specimens in g [oz] in Two Hours)

Test Series	Rain-water + OSB	Cedar + OSB	Power-wash + OSB	Rainwater + OSB + Staple	Cedar + OSB + Staple	Powerwash + OSB + Staple	Hot Plate Tests
Typar A	0	0	0	0.1 (0.003)	3.1 (0.10)	9.3 (0.32)	0.3 (0.01)
Typar B	0	0	0	1.4 (0.049)	1.7 (0.059)	17.6 (0.62)	0.1 (0.003)
Typar C	0	0	0	2.5 (0.08)	1.5 (0.05)	11.0 (0.38)	0
Avg. Wt. Gain	0	0	0	1.3 (0.045)	2.1 (0.07)	12.6 (0.44)	0.13 (0.004)
Tyvek A	0	0	1.8 (0.063)	0.5 (0.017)	1.5 (0.05)	16.8 (0.59)	3.4 (0.12)
Tyvek B	0	0	12.1 (0.42)	6.5 (0.23)	1.3 (0.045)	14.1 (0.49)	1.8 (0.06)
Tyvek C	0	0	5.9 (0.20)	2.0 (0.07)	1.4 (0.049)	5.1 (0.18)	4.4 (0.15)
Avg. Wt. Gain	0	0	6.6 (0.23)	3.0 (0.10)	1.4 (0.049)	12.0 (0.42)	3.20 (0.11)
No.15 A	1.1 (0.03)	2.2 (0.077)	5.4 (0.19)	1.5 (0.05)	2.2 (0.077)	3.2 (0.11)	4.6 (0.16)
No.15 B	1.1 (0.03)	2.0 (0.070)	3.7 (0.13)	1.7 (0.059)	3.1 (0.10)	1.6 (0.056)	4.0 (0.14)
No.15 C	1.5 (0.05)	2.1 (0.074)	1.3 (0.045)	1.2 (0.04)	1.4 (0.049)	8.4 (0.29)	2.1 (0.07)
Avg. Wt. Gain	1.2 (0.042)	2.1 (0.074)	3.5 (0.12)	1.5 (0.05)	2.2 (0.077)	4.4 (0.15)	3.56 (0.12)
Avg. Weight Gain (All)	N/a	N/a	N/a	1.9 (0.067)	1.9 (0.067)	9.7 (0.34)	2.29 (0.08)

sheathing layer. Permeability is a desirable characteristic of a WRB material during initial construction and drying out. However, WRB permeance data should be carefully considered in the design of certain types of wall assemblies, particularly those oriented toward the sun and/or those located in hot, humid climatic zones, where long-term effects of moisture entrapment may be more significant.

- Staple fasteners, like surfactants, also reduce the moisture resistance of WRBs. Over time, it is possible that bulk water may be transported through fastener penetrations, further degrading the WRB performance.
- Besides using a consistent testing strategy, as suggested by this study, it is important for designers and specifiers to understand the moisture control implications of the particular project's climatic zone to help gain insight into the material properties of the WRB materials that may be utilized.

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