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Mark F. Williams, FAIA[1]

Evaluating Drainage Characteristics of Water Resistive Barriers as Part of an Overall Durable Wall Approach for the Building Enclosure

ABSTRACT: The most recent model residential building code has been modified to require increased use of water/weather resistive barrier (WRB) materials in construction, and to require some means of draining water from the building enclosure. However, "drainage" performance is not defined, and the Code is unclear about which currently available WRB products and design approaches help provide a durable water-resistant exterior wall enclosure. The present work is a qualitative, "order of magnitude" study of the drainage characteristics of various types of WRB materials (felts, housewraps, drainage wraps, drainage boards, and furring strips), and is a "first step" toward developing an overall durable wall approach for the building enclosure. The ASTM E2273 drainage efficiency test was used in 40 wall assembly mockups to evaluate 11 WRB materials in 8 design configurations. Traditional WRBs and housewraps provided little or no drainage capability to the exterior wall designs tested. Drainage-enhanced housewraps provided an improved level of drainage, but they still retained water. The retained water can migrate through fastener holes to the underlying construction. Best drainage performance was obtained by using WRBs with furring, drainage mats, and profiled sheets (drainage boards). These overall results are in general agreement with similar research by others. These results can guide designers and builders in the proper selection and use of such materials, which should be used as part of an overall durable wall approach to protecting the building enclosure.

KEYWORDS: building enclosure, building codes, water resistive barrier, fasteners, water penetration, housewrap, building felt, furring strips, drainage efficiency

Introduction

The author's recent field experience indicates that many residential construction projects that utilize absorptive/reservoir type claddings (such as stucco, manufactured stone veneer, and masonry) have experienced water intrusion and entrapment with consequent deterioration of wood-based sheathing and wood framing members. These problems have occurred despite the widespread use of water/weather resistive barrier (WRB) membrane materials, as required by building codes for secondary moisture protection behind exterior claddings. Some dwellings are experiencing moisture related deterioration shortly after they are built. Unacceptable levels of moisture related building enclosure failures are occurring in areas of the country where this had not been a notable concern.

To help address these problems, an overall approach to promoting durable exterior wall performance is needed. This approach should begin with an understanding of the drainage and drying characteristics of water/weather resistive barriers (WRBs). The building enclosure includes the horizontal, vertical, and inclined assemblies that work together to provide separation between the interior and exterior environments. Proper selection and use of WRBs, which are intended to protect the underlying enclosure assemblies, and integration of these with other enclosure components, are key first steps to implementing an overall approach. Designers and builders have access to many types of WRB materials, including building felts, building papers, polymer-based housewraps, and "drainage enhanced" housewrap materials. However, there is minimal comparative information about the performance characteristics of WRBs, or about which products are most appropriate for specific project applications.

Concerns relating to WRB selection and performance have intensified in light of recent national building code developments. Prescriptive and performance-based Code requirements for WRBs have been modified in the most recent (2006) edition of the International Residential Code (IRC). The minimum IRC

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[1] President, Williams Building Diagnostics Inc., Maple Glen, PA.

performance requirement is that "Exterior walls shall provide the building with a weather-resistant exterior wall envelope" [1]. Additionally, the 2006 IRC requires WRBs to be installed behind nearly every type of exterior siding (cladding) material, as set forth in Table R703.4. The previous (2003) edition of this Table allowed numerous exceptions, such as behind vinyl siding, aluminum siding, or beveled wood lap siding. Finally, IRC Section 703.1 was modified to require "...a means of draining water that enters the assembly to the exterior." While this is an important new performance criterion, which could help to address moisture related problems behind many types of claddings, the Code does not define what constitutes "drainage." A variety of new WRB products are purportedly designed to provide "drainage" in exterior walls. However, this attribute is not clearly defined, either by manufacturers or the Code.

The 2006 edition of Section R703.1 also includes several new exceptions. (See the Code Comparison Table, Appendix A.) One of these drops the requirement for a "means of drainage" if the exterior wall enclosure has been tested (per ASTM E331) and demonstrated to resist wind-driven rain. This new testing requirement does not appear to be commonly published by manufacturers of many types of claddings.

Section R703.2 was also modified to delete the prescriptive requirement for asphalt-saturated felt to weigh "not less than 14 pounds per 100 square feet" (0.68 kg/m^2). This removes one element of confusion. There are several ASTM standards for asphalt saturated felt. ASTM D226 lists two grades of the product. Type I (a.k.a. No. 15) is specified to weigh 0.56 kg/m^2 (11.5 lb/100 sf), and Type II (a.k.a No. 30) is specified to weigh 1.27 kg/m^2 (26 lb/100 sf) [2]. Based on this standard, only Type II (No. 30) felt would have been Code compliant. ASTM D4869 currently lists four grades of the product (Types I through IV). It specifies Type I felt (No. 8 Underlayment) as weighing not less than 0.39 kg/m^2 (8 lb/100 sf), which is less restrictive than the Type I felt specification in D-226 [3]. Specified weights for the other three grades in D4869 are as follows: Type II (No. 13 Underlayment)=0.63 kg/m^2 (13 lb/100 sf); Type III (No. 20 Underlayment)=0.98 kg/m^2 (20 lb/100 sf); and Type IV (No. 26 Underlayment)=1.27 kg/m^2 (26 lb/100 sf).

It should also be noted that the weight of building felts apparently may never have actually been as much as 0.73 kg/m^2 (15 lb/100 sf), but has varied over the years from 0.68 kg/m^2 (14 lb/100 sf), in the mid 1960s, to the 0.56 kg/m^2 (11.5 lb/100 sf) set forth in ASTM D226 [4]. A quick check of some available felts by the author found that most weighed less than 0.56 kg/m^2 (11.5 lb/100 sf). Thus one cannot assume that today's "No. 15" felt provides as much water penetration resistance as in the past.

Section R706.3, "Water Resistive Barriers," now stipulates that, when using "exterior plaster" (e.g., stucco) over wood based sheathing (e.g., OSB or plywood), a water-resistive vapor permeable barrier with a water penetration resistance at least equal to two layers of Grade D paper must be installed. However, if the WRB has a water penetration resistance equal to or greater than 60-min Grade D paper and is separated from the stucco by a "substantially" non-water-absorbing layer or "designed drainage space," then only one layer of WRB is necessary. This Code section introduces further options that allow the specifier and contractor some additional freedom to develop a customized enclosure drainage approach, but again, "drainage" remains undefined.

Finally, it should also be noted that, while the Code now addresses "drainage," it does not mention "drying," although the "drying rate" is probably more significant than "drainage efficiency" for long-term performance and durability of the building enclosure.

In summary, the Code now requires increased use of WRB materials in construction, and requires them to have some means of draining water from the building enclosure. However, we are still left wondering if current WRB products will satisfy the "overall" performance requirement that exterior walls provide the building with a "weather-resistant exterior wall envelope."

Based on these considerations, the current study was undertaken to learn more about the drainage characteristics of various types of WRB materials commonly used in the Mid-Atlantic States (felts, housewraps, drainage wraps, drainage boards, and furring strips). Specifically, this study evaluated a material's "drainage efficiency." Drainage efficiency, expressed as a percentage, is calculated as 1) the amount of water that passes through a vertically oriented wall mockup and is collected, divided by 2) the amount of water that is initially applied to the mockup. This procedure is included in ASTM E2273 [5] and was used in the first series of laboratory tests reported herein. An additional test series further explored water related concerns that are not directly addressed by E2273, but were deemed to be significant. These results are also presented and discussed below.

The author has previously investigated specific wall durability issues, focusing on the performance of various WRB and pan flashing materials. A 2004 study [6] compared the water penetration resistance behavior of two commonly available housewrap products (which had different permeance values) and No. 15 building felt, when subjected to surfactant contamination from other sources; water intrusion through fastener penetrations; and water vapor diffusion through WRB materials. Among other things, it was found that fastener (staple) penetrations significantly reduced the moisture resistance of WRBs, thereby potentially degrading exterior wall "weather resistance" performance. In another study [7], the author conducted field evaluations of pan flashing/sill protection components installed in conjunction with fenestration units in a single-family dwelling and in a low-rise health care facility. Moisture levels were monitored in building walls in the vicinity of these fenestration units. All of the pan flashing/sill pan protection components performed satisfactorily. To date, no water retention has been detected beneath any of the sill pans.

Before initiating the study described in this paper, the author reviewed various methods used by manufacturers for evaluating the drainage characteristics of exterior wall claddings, water resistive barriers, and the like. ASTM E2273-03 was selected as the basis for the laboratory testing methodology. Overall, the procedure is simpler to use and requires less complex apparatus than other tests. It is worth noting that E2273-03 was originally developed in the late 1990s by the EIFS industry as they were developing alternatives to the face-sealed barrier claddings (e.g., concealed barrier/drainage type systems), in an effort to respond to water intrusion and entrapment concerns inherent in the face-sealed barrier approach. While this test remains useful, some concerns have emerged, which are discussed further below.

Another test employed by some manufacturers is ASTM D4716, "Test Method for Determining the (In Plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using a Constant Head." This procedure involves mounting the drainage material between two horizontal plates, compressing the "sandwich" from above, and then forcing a hydrostatic head of water through the material from one end to the other. A similar test, ASTM D4491, "Standard Test Methods for Water Permeability of Geotextiles by Permittivity," includes hydrostatic head tests meant to evaluate geosynthetic filter fabrics. In sum, we have an EIFS industry-based test on one hand, and some geosynthetic industry-based tests on the other, all of which are intended to analyze "drainage."

Methodology

Two laboratory test series were performed. In Series A, 40 wood framed wall mockups, 122 cm × 244 cm (4 ft × 8 ft) in size, were constructed to evaluate different combinations of water resistive barriers, drainage products, and mediums, utilizing the ASTM E2273 test method. These mockups were tested by an independent third-party laboratory (Architectural Testing, Inc., York, PA), which has performed similar testing for building component manufacturers.

In Series B, four smaller-scale mockups were constructed to further investigate some additional WRB performance characteristics, and also to demonstrate that a less cumbersome mockup size (i.e., one-fourth the size used in E2273) could be used. These mockups used the overall E2273 methodology, but included provisions for observing how bulk water interacts with the WRB and drainage surfaces within the wall assembly.

Series A: Modified ASTM E2273 Mockup Tests

In the ASTM E2273 test, water is introduced at a stated flow rate from a pair of standard nozzles into a "fault slot" near the top of the mockup; water that drains downward past the WRB material in the mockup assembly is collected at the bottom and weighed, and drainage efficiency is calculated.

The WRB specimens included traditional No. 15 and No. 30 building felts; three brands of traditional polymer based housewraps; five brands of surface-modified (drainage-enhanced) housewraps; one brand of "profiled sheet" (drainage board) material; and drainage mediums that incorporated a drainage mat or furring strips. These were tested in a variety of configurations, as follows:

- *Design A:* 1 layer WRB (No. 30 felt, housewrap, or drainage board).
- *Design B:* 2 layers of WRB (2 layers of No. 15 felt, or 1 layer of another WRB with 1 layer of No. 15 felt on "exterior" [front side, exposed to water entry] of the other WRB).

- *Design C:* 1 layer WRB, with 6.35 mm ($\frac{1}{4}$ inch) plywood furring strips on "exterior" (front side, exposed to water entry) of the WRB.
- *Design D:* 1 layer WRB, with 6.35 mm ($\frac{1}{4}$ inch) foam plastic furring strips on "exterior" (front side, exposed to water entry) of the WRB.
- *Design E:* 1 layer WRB, with 19 mm ($\frac{3}{4}$ inch) plywood furring strips on "exterior" (front side exposed, to water entry) of the WRB.
- *Design F:* 1 layer WRB, with 6.35 mm ($\frac{1}{4}$ inch) foam plastic furring strips on "interior" (back side, protected from water entry) of the WRB.
- *Design G:* 1 layer WRB, with 6.35 mm ($\frac{1}{4}$ inch) foam plastic furring strips aligned with each other, on both ("exterior" and "interior") sides of the WRB.
- *Design H:* 1 layer WRB, with drainage mat on "exterior" (front side, exposed to water entry) of the WRB.

Series "A" Procedure—Test mockups were constructed as follows. Each unit included a 122 cm × 244 cm (4 ft × 8 ft) sheet of 11 mm (7/16 in.) oriented strand board (OSB) sheathing. The back of the sheathing was fastened to a frame of 51 mm × 102 mm (2 in. × 4 in.) wood studs of the same overall dimensions. WRB specimens were installed on the face of the sheathing horizontally, shingle-fashion, and attached with T-50 staples spaced 203 mm (8 in.) on center. Some mockups included the WRB alone, while others included the WRB together with other materials such as a drainage mat or plywood/plastic furring strips spaced 203 mm (8 in.) apart. In mockups using furred material, the WRB was fastened to the sheathing only through the furring strips. The WRB specimens were then covered with a 122 cm × 244 cm (4 ft × 8 ft) sheet of 25 mm (1 in.) thick extruded polystyrene (XPS) board, which was intended to function as an exterior "faux cladding." The mockup edges were then caulked with sealant and self-adhering flashing. The field area of the XPS board was further secured through the WRB specimen to the sheathing with 51 mm (2 in.) cap nails. These cap nails were applied 203 mm (8 in.) on center with a compressed-air-driven coil nailer. The head of each cap nail was further caulked with sealant. The completed mockup was then affixed to the ATI testing frame to hold the mockup plumb and vertical for the test.

The upper portion of the XPS faux cladding included a 61 mm × 51 mm (24 in. × 2 in.) "fault slot," to receive bulk water from a dispensing device. This device consisted of a clear acrylic plastic box fitted with two spray nozzles that were mounted 127 mm (5 in.) to either side of the center of the box. The nozzles were connected to the water supply by plastic tubing. A pressure regulator, flow meter, and in-line water filter controlled water flow to the nozzles. The dispensing device was mounted at an angle to ensure that all water was directed into the slot. The water spray was delivered at the rate of 3.4 $L/m^2/min$ (5.0 U.S. $gal/ft^2\,h$), or 2.12 gal/75 min, with a tolerance of ±10 %.

Although not required by the E2273 procedure, a record was also made of the time that elapsed from the initial introduction of water to its first appearance at the bottom of the mockup. These data are noted in the matrix in Appendix B as "Time To First Water (TFW)." During the test proper, the weight of drained water was recorded every 15 min until the test was terminated at 75 min. Any remaining water was allowed to drain from the mockup for an additional 60 min, and this water was also weighed.

Results and Discussion—Data for the 40 test mockups is summarized in the matrix in Appendix B. Eleven WRB materials were evaluated in eight design configurations. Based on the results of these tests, some qualitative, "order of magnitude" comparisons can be made as follows. Test results are considered informative but not authoritative. The percentage figures provided are averages derived from the data on "drainage efficiency" and "Time to First Water" (TFW), and are intended to highlight what appear to be noteworthy patterns in the data.

1. Traditional WRBs, installed alone, provided little drainage.
   - The drainage efficiency of *building felts* was 0 %, while that of *traditional housewraps* was 9 %.
   - TFW for *building felts* was N/A (no water appeared), while that of *traditional housewraps* averaged 27 min 27 s.
2. Drainage-Enhanced WRBs performed better than traditional WRBs.
   - The drainage efficiency of *drainage-enhanced* housewraps averaged 71 %; that of *traditional* housewraps averaged 9 %.

- TFW for *drainage-enhanced* housewraps averaged 3 min 5 s, while that of *traditional* housewraps averaged 27 min 27 s.

3. Drainage Board product performance was better than Drainage-Enhanced WRBs, and was on a par with those WRBs used with furring or a drainage mat.
   - The drainage efficiency of one *drainage board product* was 97 %, compared to an average of 71 % for *drainage-enhanced housewraps.*
   - TFW for the *drainage board product* was 16 s, compared to an average of 3 min 5 s for *drainage-enhanced housewraps.*
4. Building Felt, when used in conjunction with Drainage-Enhanced WRBs, negated the drainage benefits of the latter.
   - The drainage efficiency for *drainage-enhanced housewraps used with felt* was only 1.7 %, compared to an average of 71 % for *drainage-enhanced housewraps used alone.*
   - TFW for *drainage-enhanced housewraps used alone* was an average of 3 min 5 s, compared to None (no water appearance) for *drainage-enhanced housewraps used with felt.*
5. Furring installed behind the WRB (i.e., the side away from the fault slot) enhanced drainage.
   - The drainage efficiency of *building felt with furring* installed behind it was 38 %, compared to None for *felt used alone.*
   - TFW of *building felt with furring* installed behind it was 22 min, compared to None (no water appearance) for *felt used alone.*
   - The drainage efficiency of a *drainage-enhanced housewrap with furring* installed behind it was 77 %, compared to an average of 71 % for *drainage-enhanced housewraps used alone.*
   - TFW of a *drainage-enhanced housewrap with furring* installed behind it was 16 s, compared to an average of 3 min 5 s for *drainage-enhanced housewraps used alone.*
6. Furring or a Drainage Mat placed in front of the WRB (i.e., exposed to the fault slot) dramatically enhanced drainage.
   - The drainage efficiency of *building felt with furring* installed in front averaged 88 %, compared with 0 % for *felts used alone.*
   - TFW of *building felt with furring* installed in front averaged 15 s, compared to None (no water appearance) for *felts used alone.*
   - The drainage efficiency of *traditional housewraps with a drainage mat or furring strips* installed in front averaged 88 %, compared to an average of 9 % for *traditional housewraps used alone.*
   - TFW of *traditional housewraps with a drainage mat or furring strips* installed in front averaged 15 s, compared to an average of 27 min 27 s for *traditional housewraps used alone.*
   - The drainage efficiency of *drainage-enhanced housewraps with furring* installed in front averaged 89 %, compared to an average of 71 % for *drainage-enhanced housewraps used alone.*
   - TFW of *drainage-enhanced housewraps with furring* installed in front averaged 10.5 s, compared to an average of 3 min 5 s for *drainage-enhanced housewraps used alone.*
7. Furring placed on both sides of the WRB generally performed better than when it was placed in front of the WRB. (Foam plastic furring strips tested.)
   - The drainage efficiency of traditional housewraps with foam plastic furring *installed on both sides* averaged 87 %, compared to an average of 78 % for traditional housewraps with foam plastic furring *installed in front.*
   - TFW of *traditional housewraps* with foam plastic furring *installed on both sides* averaged 18 s, compared to an average of 12 s for traditional housewraps with foam plastic furring *installed in front.*
   - The drainage efficiency of a *drainage-enhanced housewrap* with foam plastic furring installed *on both sides* was nearly 100 %, compared to an average of 89 % for *drainage-enhanced housewraps* with foam plastic furring *installed in front.*
   - TFW of a *drainage-enhanced housewrap* with foam plastic furring installed *on both sides* was 3 s, compared to an average of 11 s for *drainage-enhanced housewraps* with foam plastic furring *installed in front.*

From these preliminary results, it appears that the highest level of drainage performance (90 % and above) can be obtained by using WRBs with furring, drainage mats, or profiled sheets (drainage boards).

About "Time to First Water."—The "Time to First Water" (TFW) data obtained in these modified E2273 tests appeared to offer significant additional insights about how quickly bulk water will pass through a given wall assembly. The TFW period was generally shorter with furring strip/drainage mat or profiled sheet (drainage board) materials, than with "drainage-enhanced" WRB products. However, in several instances the author found significant differences in TFW between the same type of product, from the introduction of water to its first appearance at the bottom of the mockup. Thus, some "drainage-enhanced" WRB materials retained water in the drainage space for a considerably longer time than others with lower drainage efficiencies. (Compare, e.g., data for Mockups 7A and 8A in the matrix in Appendix B.) This finding further illustrates the need to better understand the behavior of WRB materials in service, as well as related drainage/drying mechanisms in exterior walls. Finally, in the author's experience, bulk water can easily flow through a WRB fastener/staple penetration and migrate to the underlying sheathing. It appears that products having a longer TFW may allow larger amounts of water to persist for a longer time in proximity to fasteners, with a potential effect on the long-term performance of the underlying sheathing/framing.

Further Thoughts on ASTM E2273—The author's mockup testing has revealed some problematic aspects of the ASTM E2273 procedure. The test is intended to provide information regarding the "drainage efficiency" of a wall cladding. Water is applied to the specimen via two spray nozzles. A pressure regulator, flow meter, and inline water filter control the flow rate of water supplied to the nozzles. The flow rate is stipulated as 106 g (0.234 lb) per minute, ±10 %. When calibrating this test, the flow rate must be adjusted to obtain a weight of water of 1590 g (3.5 lb) to 1745 g (3.8 lb) during a 15-min period. Theoretically, the required pressure regulator would hold the flow rate within this variable range of 155 g (0.3 lb) during the test. The author found that changes in water line pressure may affect the calibrated spray nozzles' output. If the line pressure changes, the nozzles may deliver more or less water to the specimen. Although this variability would be maintained within the ±10 % tolerance specified by the ASTM test, a ±10 % tolerance will affect the overall drainage efficiency. This makes it difficult to gauge water management performance within samples of the same wall assembly design, let alone trying to compare different designs.

For example, if one specimen tested at 92 % efficiency and another tested at 88 %, it is unclear what significance, if any, should be attributed to the 4 % difference between these two results. Such a difference would amount to a few ounces of water over the required 135 min of the test. Beyond this, it is impossible to know how quickly one wall assembly will dry out compared to the other wall assembly, based on this test. By design, the E2273 test is limited to assessing how quickly a wall assembly may drain bulk water. It is not intended to assess the fate of any water that is retained within that assembly. Based on this testing, it is not known if an assembly with a 98 % drainage efficiency will dry out more or less quickly than an assembly rated at 88 %. The "time to first water" data shed some light on this aspect of the problem. The author is aware of research by others, which also indicates that the ASTM E2273 test can give misleading results in its current form. Recent work by Canadian investigators [8] shows that wall designs using furring strips may dry more quickly than designs utilizing other drainage mediums. The actual amounts of water retained are also dependent upon the cladding type and by the manner in which water entry occurs.

A recent study by the Building Research Association of New Zealand (BRANZ) [9] measured drying rates of wall mockups over a three-year period. The study found that it is critical to isolate the back of a cladding from the framing, because framing lumber gives up moisture very slowly; water dried 100 times faster from the back of a given cladding than from the underlying framing. The study also found that drained/ventilated and "open rainscreen" walls dried approximately three times faster than walls without an airspace. However, drained/ventilated designs did not improve drying of wet framing, because the drying rate was still limited by moisture transport rates in the timber.

Series B. Additional WRB Mockup Tests

Some of the preceding ATI tests showed that asphalt felt and traditional housewraps, when used alone, had very low drainage efficiencies, on the order of 0 % to 9 %. Although these materials may comply with certain performance requirements, it would appear that they fail to meet the Code's performance requirement for drainage. Indeed, approximately 90 % to 100 % of the introduced moisture was retained in these particular mockups. While other tests showed that WRB products used with drainage mediums or furring materials had much higher drainage efficiencies, some portion of the introduced moisture remained within the mockup assemblies after the tests were completed. The E2273 test procedure was not intended to address the mechanisms by which water that does not drain is held in the test specimen. Specifically, the test procedure cannot identify the relative amount retained outboard of the WRB versus the amount which may penetrate or otherwise breach the WRB.

To further explore this concern, several smaller-scale mockup tests were conducted. The overall E2273 approach was utilized, but with some important differences. "Drainage efficiency" was not calculated. Rather, the intent was to qualitatively evaluate and compare the water resistance behavior of: (1) a "traditional" housewrap, (2) a "drainage-enhanced" housewrap; (3) a "traditional" housewrap used with furring strips; and (4) a "drainage enhanced" housewrap used with furring strips. All housewraps products were from the same manufacturer.

Series "B" Procedure—The mockups were one-fourth the size of the E2273 mockups (61 cm × 122 cm [2 ft × 4 ft]); a known quantity of water was delivered to the mockups using a reservoir/ "trickle" dispensing method; and the substrate sheathing was coated with a fluorescent dye powder that would change color upon contact with moisture.

Test mockups were constructed as follows. Each unit included a 61 cm × 122 cm (2 ft × 4 ft) sheet of 11 mm (7/16 in.) oriented strand board (OSB) sheathing. The back of the sheathing was supported by 51 mm × 102 mm (2 in. × 4 in.) studs attached in an "I" pattern (horizontal members at each end, connected by a central midrib) which left the sides open to accommodate brackets for mounting the finished mockup on a testing frame. The face of the sheathing was coated with a water-miscible fluorescent dye to provide an indication of moisture intrusion.

WRB specimens were attached to this coated sheathing with staples and then covered with a 61 cm × 122 cm (2 ft × 4 ft) sheet of 25 mm (1 in.) thick extruded polystyrene (XPS) board, which was intended to function as an exterior "faux cladding." Some mockups included the WRB alone, while others included the WRB together with plastic furring strips spaced 203 mm (8 in.) apart, in which case the WRB was fastened to the sheathing only through the furring strips. The top portion of the "faux cladding" included a projecting "hopper" (similar to the "fault slot" of the Series "A" tests) to receive the water-dispensing device described further below. The faux cladding panel /hopper was secured to the OSB using paired 51 mm (2 in.) aluminum shelf angles at each side. The remaining mockup edges were then caulked with sealant and self-adhering membrane flashing. The field area of the faux cladding was further secured through the WRB specimen to the sheathing with 51 mm (2 in.) cap nails. These cap nails were applied 203 mm (8 in.) on center with a compressed-air-driven coil nailer. The head of each cap nail was further caulked with sealant. The completed mockup was then affixed to the testing frame using the brackets. The purpose of this frame was to hold the mockup plumb and vertical and to hold the water dispensing apparatus in place at the top of the mockup during the test.

Water was applied to the top of the mockup from the "trickle" dispensing device as follows. The bottom of a 3.8 L (1 gal) plastic bucket was fitted with a brass needle valve attached to a length of plastic tubing. The lower end of this tubing was connected to a manifold made from two segments of PVC tubing joined at the middle by a "T" connector. Both PVC segments were approximately 127 mm (5 in.) long, and were drilled with 1.6 mm (1/16 in.) diameter holes set 13 mm ($\frac{1}{2}$ in.) on center. This manifold was placed at the bottom of the "hopper" in the XPS faux cladding so that the holes faced toward the exposed exterior face of the WRB specimen. This manifold was intended to ensure that water was distributed evenly across the face of the specimen, over a constant period of time.

Water was released from the "trickle" dispensing device into the mockup for 19 min. As before, the bottom of the mockup was observed for appearance of the first water droplets. After each drainage test, the WRB specimen was removed from the substrate and examined using ultraviolet light, to examine the dye-coated sheathing surface for evidence of leakage.

Results and Discussion—When used alone, both the plain and drainage-enhanced housewrap products allowed water to migrate via fastener holes to the substrate sheathing, as indicated by visible areas of fluorescent dye activation on the sheathing surface. When both types of housewraps were tested in con-

TABLE 1—*Series B/small-scale E2273 mockup results.*

Mockup Number	Test Modality (Note Sequence of Materials)	Time To First Water	Additional Observations
B.1	OBS/traditional housewrap/faux cladding	120 s	Dye observed on OSB and in catch basin
B.2	OBS/drainage enhanced housewrap/faux cladding	5 s	Dye observed on OSB and in catch basin
B.3	OBS/traditional housewrap/furring/faux cladding	Immediate	No dye observed on OSB or in catch basin
B.4	OBS/drainage enhanced housewrap/furring/faux cladding	Immediate	No dye observed on OSB or in catch basin

junction with furring strips, no dye activation occurred on the sheathing and no dye was observed in the drainage water. Therefore, water intrusion to the sheathing plane was prevented by installing the WRBs with furring. Test results are summarized in Table 1.

Summary and Conclusions

The 2006 *International Residential Building Code* requires increased use of WRB materials in construction and requires them to have some means of draining water from the building enclosure. However, this "drainage" performance requirement is not defined, and it is also not clear that current WRB products used in common design configurations will provide "a weather-resistant exterior wall envelope." Manufacturers, specifiers, and contractors are challenged to find ways to promote and use appropriate WRB materials to respond adequately to a public need. Given these factors, the author performed these studies to learn more about the "drainage efficiency" characteristics of various types of WRB materials and mechanisms (felts, housewraps, drainage wraps, drainage boards, and furring strips) as a "first step" towards developing an overall approach for the Building Enclosure.

Overall, based on tests using a working definition of "drainage efficiency" as set forth in ASTM E2273-03, it appears that traditional WRBs and housewraps do not provide a drainage capability (0 % to 9 %) to exterior walls. Drainable housewraps provide a much-improved level of such drainage (approximately 70 %), but they still retain water that can migrate through fastener holes to the underlying construction. The highest level of drainage performance (90 % and above) is obtained by using WRBs with furring, drainage mats, and profiled sheets (drainage boards).

Some exterior claddings may include an integral drainage space (e.g., vinyl siding) and, therefore, may not require an enhanced drainage approach, under certain project conditions. Others, particularly absorptive / reservoir type claddings such as stucco and manufacture stone, may require it, depending upon the project. However, "drainage" appears to be only part of the equation for success. "Drying" of exterior walls must also be considered further; recent work by others [8,9] provides useful insights on this important issue.

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Appendix A. International Residential Codes Comparison Chart

SECTION R703 – EXTERIOR COVERING (Excerpted)	
IRC 2006 PROVISIONS	IRC 2003 PROVISIONS
R703.1 General. Exterior walls shall provide the building with a weather-resistant exterior wall envelope. The exterior wall envelope shall include flashing as described in Section R703.8. The exterior wall envelope shall be designed and constructed in a manner that prevents the accumulation of water within the wall assembly by providing a water-resistant barrier behind the exterior veneer as required by Section R703.2. and a means of draining water that enters the assembly to the exterior. Protection against condensation in the exterior wall assembly shall be provided in accordance with Chapter 11 of this code. Exceptions: 1. A weather-resistant exterior wall envelope shall not be required over concrete or masonry walls designed in accordance with Chapter 6 and flashed according to Section R703.7 or R703.8. 2. Compliance with requirements for a means of drainage, and requirements of Sec. R703.2 and Sec. R703.8, shall not be required for an exterior wall envelope that has been demonstrated to resist wind-driven rain through testing of the exterior wall envelope, including joints, penetrations and intersections with dissimilar materials, in accordance with ASTM E331 under the following conditions: 2.1. Exterior wall envelope test assemblies shall include at least one opening, one control joint, one wall/eave interface and one wall sill. All tested openings and penetrations shall be representative of the intended end-use configuration. 2.2. Exterior wall envelope test assemblies shall be at least 4 feet (1219 mm) by 8 feet (1219 mm) in size. 2.3. Exterior wall assemblies shall be tested at a minimum differential	**R703.1 General.** Exterior walls shall provide the building with a weather-resistant exterior wall envelope. The exterior wall envelope shall include flashing as described in Section R703.8. The exterior wall envelope shall be designed and constructed in such a manner as to prevent the accumulation of water within the wall assembly by providing a water-resistive barrier behind the exterior veneer as required by Section R703.2

SECTION R703 – EXTERIOR COVERING (Excerpted)	
IRC 2006 PROVISIONS	**IRC 2003 PROVISIONS**
pressure of 6.24 pounds per square foot (299.Pa).. 2.4. Exterior wall envelope assemblies shall be subjected to a minimum test exposure duration of 2 hours.	
The exterior wall envelope design shall be considered to resist wind-driven rain where the results of testing indicate that water did not penetrate: control joints in the exterior wall envelope; joints at the perimeter of openings penetration; or intersections of terminations with dissimilar materials.	
R703.2 Water-Resistive Barrier. One layer of No. 15 asphalt felt, free from holes and breaks, complying with ASTM D226 for Type I felt or other approved water-resistive barrier shall be applied over studs or sheathing of all exterior walls. Such felt or material shall be applied horizontally, with the upper layer lapped over the lower layer not less than 2 inches (51 mm). Where joints occur, felt shall be lapped not less than 6 inches (152 mm). The felt or other approved material shall be continuous to the top of walls and terminated at penetrations and building appendages in a manner to meet the requirements of the exterior wall envelope as described in Section R703.1.	**R703.2 Water-resistant sheathing paper.** Asphalt-saturated felt free from holes and breaks, weighing not less than 14 pounds per 100 square feet (0.683 kg/m^2) and complying with ASTM D 226 or other approved weather-resistant material shall be applied over studs or sheathing of all exterior walls as required by Table R703-4. Such felt or material shall be applied horizontally, with the upper layer lapped over the lower layer not less than 2 inches (51 mm). Where joints occur, felt shall be lapped not less than 6 inches (152 mm).
Exception: Omission of the water-resistive barrier is permitted in the following situations: 1. In detached accessory buildings. 2. Under exterior wall finish materials as permitted in Table R703.4.	1. In detached accessory buildings. 2. Under panel siding with shiplap joints or battens. 3. Under exterior wall finish materials as permitted in Table R703.4. 4. Under paperbacked stucco lath.

Appendix B: Drainage Efficiency (Percent), Per ASTM E-2273 And Number of Seconds to "First Water"

This matrix provides results of "drainage efficiency" and "Time to First Water" (TFW) testing of E2273 mockups, together with information on mockup construction. To locate data on Mockup #2-C, e.g., follow Row 2 (left-hand column) to where it intersects Column "C." The upper figure gives the "drainage efficiency," and the lower figure gives the TFW. Refer to the text for further explanations.

Design Approach:		A	B	C	D	E	F	G	H
		1 layer WRB	2 layers WRB	1 layer WRB with ¼" (6.35 mm) plywood furring on "exterior" (front) side	1 layer WRB with ¼" (6.35. mm) foam plastic furring on "exterior" (front) side	1 layer WRB with ¾" (19 mm) plywood furring on "exterior" (front) side	1 layer WRB with ¼" (6.35 mm) foam plastic furring on "interior" (back) side	1 layer WRB with ¼" (6.35 mm) foam plastic furring aligned with each other on both sides	1 layer WRB with Drainage Mat on "exterior" (front) side
Traditional WRBs (Building Felts)									
1	#30 asphalt saturated felt	0 %							
		N/A							
2	#15 asphalt saturated felt		0 %	97.0 %	75.4 %	90.9 %	37.9 %		
			N/A	23 sec.	10 sec.	13 sec.	1,320 sec.		
Traditional WRBs (Polymer-Based Housewraps)									
3	Hwp. # 1	5.6 %		97.6 %	72.1 %	82.9 %		85.3 %	97.1 %
		1,980 sec.		15 sec.	8 sec.	9 sec.		14 sec.	25 sec.
4	Hwp. #2	9.9 %		90.5 %	82.9%	92.8 %		88.5 %	92.8 %
		1,680 sec.		9 sec.	15 sec.	12 sec.		22 sec.	23 sec.
5	Hwp. #3	11.6 %		95.4 %	77.5 %	83.3 %			92.4 %
		1,280 sec.		17 sec.	12 sec.	13 sec.			18 sec.
Drainage-Enhanced Housewraps									
6	Drainage Wrap #1	76.3 %	0 %	99.5 %	87.7 %				
		50 sec.	N/A	9 sec.	7 sec.				

Design Approach:		A	B	C	D	E	F	G	H
7	Drainage Wrap #2	69.8 %	5.1 %	97.4 %	93.4 %		77 %	99.7 %	
		94 sec.	1,200 sec.	8 sec.	15 sec.		16 sec.	3 sec.	
8	Drainage Wrap #3	90.6 %	0 %	70.9 %	83.9 %				
		360 sec.	N/A	13 sec.	11 sec.				
9	Drainage Wrap #4	62.7 %							
		180 sec.							
10	Drainage Wrap #5	55.5 %							
		240 sec.							
Profiled Sheet (Drainage Board)									
11	Drainage Board #1	97.3 %							
		16 sec.							

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