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Water Resistance and Vapor Permeance of Weather Resistive Barriers

ABSTRACT: Weather-resistive barriers (WRBs) are typically used in exterior walls of low rise frame buildings under claddings such as stucco (cement plaster), wood and wood derived products, vinyl (PVC), and masonry veneer. WRBs are primarily intended to provide resistance to water that may penetrate the outer cladding. WRBs also provide resistance to passage of air to varying extents but generally are moderately permeable to water vapor. Traditional WRB materials were limited to asphalt saturated felts and papers, but polymeric sheets have taken a growing share of the market in recent years. There are also trowel-applied and rigid board WRBs. Little information is available about the comparable properties of commercially available materials or what to consider when selecting the appropriate product for a particular application. Both building code requirements and vendors' product information are inconsistent and confusing. This paper, which is limited to the properties of water resistance and water vapor permeance, provides information that may be helpful in understanding, selecting, and using weather resistive barriers.

KEYWORDS: weather resistive barrier, sheathing membrane, housewrap, house wrap, building paper, asphalt saturated felt, asphalt saturated kraft paper, drainage wall, moisture barrier

Introduction

A critical component in the long-term performance of a membrane drainage wall is the weather resistive barrier (WRB). Although a number of terms are used to describe this building material, the term "weather resistive barrier" has been selected because it has predominated in U.S. building codes in recent decades. WRBs are integrated with flexible flashings at penetrations to provide additional water resistance and a positive connection to penetrating wall components, such as doors and windows.

Because WRBs are often the least durable weather resistive component in a wall system, their function is particularly important in maintaining the integrity of the window/wall interface. WRBs must also withstand, often for long periods of time, the rigors of exposure to sun, wind, and precipitation prior to installation of cladding. Water from leaks originating at windows and doors often results in damage only after it damages or ultimately breaches the WRB at some location near and usually below the door or window.

A drainage wall is a wall system in which cladding, such as cement plaster (stucco), wood, or wood-based siding, is intended to provide a substantial and primary barrier to water originating as precipitation. Joints, discontinuities, minor damage, or extreme weather conditions may result in limited amounts of water penetrating the cladding, and that water is intended to flow by gravity to the exterior or evaporate before damaging water-sensitive materials. Drainage to the exterior from a WRB is typically facilitated by the use of weep holes, weep screeds, or simply

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freely draining terminations at the base of walls. A WRB is typically not accessible and therefore is expected, along with associated flashings, to remain functional for the service life of the building wall system.

In the latter half of the 1900s, the materials and techniques of WRBs and flexible flashings changed little. Commonly used materials were based on papers and felts, derived from cellulose and other organic fibers, treated with asphalt. In the 1980s, polymeric "house wraps" were introduced and first used in the eastern and southern U.S. Later, polymeric self-adhering sheet materials, first marketed for waterproofing, began to be used to provide more robust penetration flashings. The construction industry embraced these new penetration flashing materials for frame construction only in the late 1990s, and within a five-year period dozens of products were introduced in the market.

The decades of the 1980s and 1990s saw an increase in construction failures and defect litigation related to water induced damage to frame buildings with notable hotspots in such places as California, British Columbia, and North Carolina. In the last three years, mold became the focus of attention. Although there are a myriad of reasons for the apparent increase in water related building damage, the increased air-tightness of buildings to achieve energy conservation is generally accepted as a major contributing factor. The historic ability of wall components wetted by precipitation or condensed water vapor to dry through air movement is no longer as effective as it was before the advent of energy efficient new construction.

Water related damage, including that related to mold and fungus, has spurred legislation, such as SB 800 (Section 895 et seq. *California Civil Code*) that defines what constitutes construction defects and provides minimum service requirements. This has reinvigorated discussion of the role of WRBs and flexible flashings in wall design and construction, including installation of components such as windows, and has placed a new burden on builders, contractors, and construction material manufacturers to provide homes free of defects.

Despite significant progress by model code organizations, industry groups, standards organizations, and the building industry media to provide updated technical information, the selection and application of materials commercially available for weather resistive barriers and flexible flashings remains a mystery for much of the design profession and construction industry, particularly as the proliferation and nature of these materials continues to increase and evolve rapidly.

Unfortunately, much of the information available is limited to self-serving product and marketing literature provided by manufacturers. Building codes and standards are generally based not on performance requirements determined by research but simply by perpetuating the properties of traditional materials or adapting to the properties of new materials.

There are limited published data that compare properties, such as tested water penetration resistance of common WRB materials, using even the often obsolete test methods accepted in codes and standards. Architects, contractors, and developers often tend to ignore incomplete and conflicting new information, falling back on traditional practices with which they are comfortable or relying on the often biased claims of vendors. Anecdotal information abounds, but reliable and technical comparisons of alternate materials and methods are woefully inadequate.

There are a number of performance properties of WRBs that should be considered in their selection. These include water resistance, water vapor permeance, air resistance, durability, compatibility with other materials, cost, installation challenges, and more. The purpose of this paper is limited to reviewing performance properties required by codes and standards and to summarizing a limited number of test results, some of which have never before been published. This information can be used by architects and specifiers to compare the expected performance of three generic types of WRBs, with respect to water resistance and water vapor permeance. The three types of WRBs include felt-based materials, paper-based materials, and polymeric materials.

Resistance to Liquid Water of New Material

The most fundamental property of a WRB is its resistance to the passage of liquid water, typically originating as precipitation. Unfortunately, test methods commonly used for water resistance were developed by the paper and textile industries for applications in such things as packaging and tarpaulins and bear little resemblance to the function that WRBs play in building wall assemblies.

Test Methods and Code Requirements

Water resistance of WRBs is commonly measured in the U.S. by two test methods that are referenced, directly or indirectly, in building codes. The two methods are AATCC Test Method 127 ("hydrostatic pressure test") or some variation of ASTM D 779 – *Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry Indicator Method* ("boat test"). The *National Building Code of Canada* does not have a minimum level of water resistance; it only requires that materials meet standards of pliability, tensile strength, and water vapor permeance. However, for materials to be voluntarily certified by the Canadian Construction Materials Centre (CCMC) [2], they must pass a third test included in *Technical Guide for Sheathing, Membrane, Breather-Type*, paragraph 6.4.5, in which a WRB is subjected to water for 2 h at a depth of 25.4 mm (1 in.) [3].

Codes used in the U.S. typically allow #15 asphalt saturated felt, conforming to ASTM D 226 *Standard Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing*, prescriptively or Grade D asphalt treated kraft paper (10 min water resistance) under some variation of ASTM D 779. ASTM D 226 covers felts both with and without perforations, but only the non-perforated type should be used as a WRB. Other materials, including polymeric housewraps, are qualified by testing and reporting under AC38 *Acceptance Criteria for Weather Resistive Barriers* [4].

Table 1 is a compilation of building code requirements for WRBs.

History and Description of the "Boat Test"

This test is performed by measuring the amount of time it takes for water to diffuse through the material and effect an indicator dye when the opposite side is in full contact with water. The 1997 *Uniform Building Code* (*UBC*) *Standard 14-1*, *Kraft Waterproof Building Paper*, is based on Federal Specification UU-B-790a (February 5, 1968). *UBC 14-1*, which was referenced in the 1997 *UBC*, *IBC* (*International Building Code*) and *IRC* (*International Residential Code*), does not describe the test protocol but simply states in a footnote "approved test methods shall be used." The "boat test" from UU-B-790a was incorporated into ASTM D 779 and is referenced in AC38 as one of the alternate tests applicable to polymeric based weather resistive barriers.

TABLE 1—*Requirements for WRB water resistance in building codes.*

Code Test Method	Asphalt Saturated Felt	Grade D (10-min) Asphalt Saturated Kraft Paper	Polymer Housewrap
*2001 California Building Code (*1997 *Uniform Building Code),* Section 1402A[2]	"asphalt saturated rag felt" is approved by prescription. No water resistance test standards are referenced.	UBC Standard 14-1 ("Approved test methods shall be used")[3] Water Resistance: Grade D (10 min)	Must be approved as alternate material subject to AC 38 *Acceptance Criteria for Weather Resistive Barriers*, (Alternate Materials – 104.11). AC 38 provides two alternate test methods (1) Section 6.4.5 of CCMC 07102, and (2) AC 38, Section 4.2. Although not explicit, it is generally understood that AC 38, Section 4.2 (AATCC Test Method 127) is typically used. In either case, tests must be conducted after weathering, including ultraviolet light exposure and wet/dry cycling.
International Building Code, Section 1404.2	D226, Type 1 (#15) is approved by prescription. No water resistance test standards are referenced.	Not listed as a prescriptive material. Must be approved as an alternate material under 104.11, typically through ICC Evaluation Service using AC38	Not listed as a prescriptive material. Must be approved as an alternate material under 104.11, typically through ICC Evaluation Service using AC38
International Residential Code, Section R703.2	D226, Type 2 (#30) is approved by prescription. No water resistance test standards are referenced. For areas enforcing the IRC, the barrier must also weigh not less than 14 lb per 100 square feet (0.683 kg/m^2)[4]	Not listed as a prescriptive material. Must be approved as alternate material under 104.11, typically through ICC Evaluation Service using AC38	Not listed as a prescriptive material. Must be approved as an alternate material under 104.11, typically through ICC Evaluation Service using AC38
National Building Code of Canada	No minimum water resistance required unless product is certified by CCMC.	No minimum water resistance required unless product is certified by CCMC.	No minimum water resistance required unless product is certified by CCNC. Polymeric house wraps are typically certified under Technical Guide for Sheathing, Membrane, Breather-Type, Masterformat Section 07193, which, under Paragrph 6.4.5must be tested to a water resistance of 2 h at a depth of 25.4 mm (1 in.) after conditioning.
NFPA 5000,[5] Section 37.3.1.2	ASTM D226, Type 1 (#15) Note: ASTM D226 does not have a water resistance test.	FS UU B 790a using UU P 31b, Method 18 Water Resistance: Grade D = 10 min	Must be approved as alternate material

[2] The *California Building Code* continues to be based on the 1997 *Uniform Building Code.*

[3] Other than "approved test methods shall be used," UBC Standard 14-1 dos not reference a specific test for weather resistance. The precursor to UBC Standard 14-1 was Federal Specification FS UU-B-790a, which used Test Method 181 from FS UU-P-31b for water resistance. Test Method 181 is similar to D 779.

[4] Since D 226 requires only 6.2 lb/100 ft^2 (303 g/m^2) for Type 1 (#15), only Type II (#30) would be allowed. This should be reviewed and perhaps reconsidered by the ICC for consistency with the *IBC* and custom and practice in the building industry.

[5] 37.3.1.2: Barrier shall be a minimum of one layer of building paper meeting Federal Specification UU B 790a, Specification for Building Paper, Vegetable Fiber, Kraft, Waterproofed, Water Repellant, for kraft waterproof building paper, or No. 15 asphalt saturated felt complying with Type I, felt in accordance with ASTM D 226 *Standard Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing*.

History and Description of the "Hydrostatic Pressure Test"

The "hydrostatic pressure test," "water column test," or, technically, *AATCC Test Method 127*, is listed in AC38 as an alternate test for polymeric-based materials. This test measures the hydrostatic pressure at which water can be forced through a sample of material. House wraps are typically much more vapor permeable than sheathing papers and felts but generally have a better resistance to movement of liquid water under pressure. As a result, polymeric products do not perform well in the boat test because the high vapor permeability allows for quick movement of vapor through the membrane. Manufacturers of these types of membranes use a water column test. This involves sealing a sample of membrane to the base of a hollow column. Water is then poured into the column, and the height of water over time is measured until water is observed on the dry side of the membrane. The pressure at penetration is recorded. Spunbonded olefin membranes generally perform better than building papers in this test because of the small pores in the membrane and the better water saturated strength of the membrane. Other house wrap products, such as perforated polyethylene membranes, usually fall somewhere between sheathing papers and spunbonded olefin membranes in terms of vapor permeability and resistance to liquid water [5]. The properties of these products will vary with the size and number of holes that are perforated though the base sheet. Resistance to liquid water will usually decrease as the vapor permeance increases.

History and Description of the "Water Ponding Test"

The water ponding test is described in CCMC *Technical Guide for Sheathing, Membrane, Breather-Type*, Masterformat Section 07102 (Technical Update July 7, 1993), Section 6.4.5, in which a cylindrical bowl of the sample material is filled with 25.4 mm (1.0 in.) of water and observed for 2 h. To pass the test, no seepage can be observed below the sample. The Guide is intended for use in evaluating "breather-type sheathing membranes, which are polyethylene or polypropylene-based, woven or non-woven."[6] Specimens are to undergo a UV exposure test and heat aging prior to testing (Sections 6.2.3 and 6.2.4). The results shown in Table 2 are for new, unconditioned material.

Performance Tests

Table 2 compares results of water resistance tests on three representative samples of new material. Similar tests on conditioned materials are not available, but anecdotal information abounds.

Summary of Results

The boat test water penetration resistance time for #15 felt was over six times that of "60-min" asphalt saturated kraft paper. The relatively poor performance of the polymeric house wrap is not unexpected for reasons previously described.

In the hydrostatic head test, for a single layer of material, the house wrap outperformed the #15 felt by 309 % and outperformed the "60-min" asphalt saturated kraft paper by 174 %. Contrary to the results of the "boat test," the "60-min" asphalt saturated kraft paper outperformed the #15 felt by 49 %.

Adding a second layer of material increased the hydrostatic water resistance by 75.4 % for #15 felt, 44.0 % for "60-min" asphalt saturated kraft paper, and 50.5 % for house wrap.

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[6] Polypropylene and polypropylene are subclasses of a broad class of chemicals called olefins.

TABLE 2—*Comparable water resistance of three WRB materials using AATCC test method 127-1998 and ASTM D 779* – Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry Indicator Method.

Test Method	ASTM D226 # 15 Felt (Type 1)	60-min, Asphalt Saturated Kraft Paper[7]	Polymer Housewrap (Spun-bonded polyethylene fiber construction)
AATCC Test Method 127-1998[8] (one layer of material) Pressure at Water Penetration cm of H_2O, lbf/in^2 (psi) and Pa	60.9 cm 0.87 lbf/in^2 5998 Pa	90.9 cm 1.29 lbf/in^2 8894 Pa	249.2 cm[9] 3.55 lbf/in^2 24476 Pa
AATCC Test Method 127-1998[10] (two layers of material) Pressure at Water Penetration cm of H_2O cm of H_2O, lbf/in^2 (psi) and Pa	106.8 cm 1.52 lbf/in^2 10480 Pa	130.9 cm 1.86 lbf/in^2 12824 Pa	375.0 cm 5.34 lbf/in^2 36818 Pa
ASTM D779[11] Water Penetration Time (lowest Side Average)[12]	6 h, 13 min, 10 s	1 hr, 3 min, 20 s	9 min, 33 s
CCMC Technical Guide for Sheathing, Membrane, Breather-Type, Masterformat Section 07102, Section 6.4.5[13]	Pass	Pass	Pass

Conclusions

In a type of test where pressure is not a factor, asphalt saturated felt significantly outperformed asphalt saturated kraft paper. With high pressures, asphalt saturated kraft paper slightly outperforms asphalt saturated felt. This may be because kraft paper has a tighter matrix than felt, thus performing better under pressure. Felt, however, has more asphalt, thus resisting migration of water longer under low pressure. With more asphalt and better performance at low pressures, felt may be a better choice than paper.

It is well accepted that unperforated polymer WRBs perform well under higher pressure compared to cellulose-based WRBs. However, the pressure at which even the least water resistant WRB fails the hydrostatic test (0.87 lbf/in^2) is equivalent to 125 lbf/ft^2, the force of a 200 mph wind. Most low-rise residential windows are designed to withstand a water penetration pressure equivalent to a wind speed of 30–50 mph. A 50 mph wind speed is equivalent to

[7] Although Grade D asphalt saturated paper with (10-min water resistance minimum requirement) is the minimum standard in several codes, Grade D 60 Minute (60-min water resistance minimum requirement) was chosen for testing because it better represents current construction industry practice.

[8] Tests by Intertek Labtest, 70 Diamond Road, Springfield, NJ 07081, Test Report 68456, May 30, 2003, 973/346-5500, fax 973/379-5232. Three samples from one roll were tested.

[9] The manufacturer advertises the Water Penetration Resistance of the material tested as 210 cm of H_2O. Although AATCC Test Method 127 does not have a weathering requirement, AC38 does have an ultraviolet light exposure weathering pretest requirement for house wraps.

[10] Ibid.

[11] Tests by Testing-Calibration-Consulting (TCC), 760 East Francis Street, Unit L, Ontario, CA 9176, Test Report 03-840, April 23, 2003, 909/947-7701, fax 909/947-7707, for Fenestration Testing Laboratory, 1516 South Campus Avenue, Ontario, CA 91761, 909/923-6260, fax 909/923-6262. Five samples from the same roll were tested each side, for a total of 10 tests.

[12] "Lowest side average" means the average test values from the side of the sample that had the lowest water resistance. Tests are run on each side of five samples.

[13] Test by Intertek ETL Semko (Interetk Testing Services NA Ltd.) 3210 American Drive, Mississauga, Ontario, Canada L4V 1B3, 905/678-7820, fax 905/678-7131, Report 3055345-1, February 26, 2004. Ten samples from one roll were tested.

approximately 6.25 lbf/ft^2, 0.04 lbf/in^2 (299 Pa), and 1.20 in. (30.48 cm) of H_2O. Relatively high performance of polymeric WRBs under high hydrostatic pressures may be impressive but is not necessarily indicative of a property required to fulfill their intended function.

I reviewed Fisette's[14] hydrostatic head tests with WRB. I note that he chose a 3.5 in. head because he said it is equivalent to 70 mph wind speed, which he thought was reasonable [6]. My calculations show that a 3.5 in. head is equivalent to about 18 lbf/ft^2, or about 85 mph wind speed. Whether at 70 mph or 85 mph, this is unreasonably high. A 70 mph wind is equivalent to 12.26 lbf/ft^2 (587 Pa). Design pressures for low-rise buildings in most of the U.S. are in the range of 20–40 lbf/ft^2 (960–1920 Pa), and the corresponding 15 % Water Resistance Test Pressures for windows and doors are in the range 3.00–6.00 lbf/ft^2 (144–287 Pa) [7]. The corresponding Water Resistance Test Pressure for the 25.4 mm of H_2O in the water ponding test would be 5.20 lbf/ft^2 (248 Pa), well within the design range of most windows used in low-rise construction.

There appears to be no compelling reason to design a concealed WRB, which is, at best, the second layer of defense against windblown rain, to a higher performance level than a window, which is the first and only defense against wind blown rain.

Resistance to Liquid Water – Aged or Conditioned Material

There is no test information in the literature about comparative water resistance of WRBs after prolonged exposure to water, ultraviolet light, or to wet dry cycling. Under AC38, weathering by ultraviolet light exposure and wet/dry cycling is required of polymeric WRBs if they are tested for water resistance using AATCC Test Method 127 or Section 6.4.5 of CCMC 07102. Polymeric WRB manufacturers typically limit exposure of their products prior to cladding, with one leading manufacturer limiting exposure to four months. No conditioning is required if water-resistance tests are conducted in accordance with ASTM D 779.

There is limited anecdotal information. According to Lstiburek, "In areas that get a lot of rain, even two layers of building paper can be overcome by regular soakings. I've seen building paper rot, even if you have two layers … Grade D paper rots faster than roofing felt. The best paper for a wall is a roofing felt." Wesley Page agrees that Grade D paper cannot withstand repeated wetting: "Grade D building paper will fail completely if it gets wet," says Page. "It just disintegrates and disappears." Any paper or felt will be less likely to rot if it is installed behind an air space that permits drainage [7]. According to Klimas, "Felt paper's UV resistance is not good, and it tends to wrinkle and rip in the wind over time [7]."

My own experience mirrors that of Lstiburek and Page that asphalt saturated felt remains more robust than asphalt impregnated paper under conditions of prolonged wetting.

Water Vapor Permeance of New Material

Conventional wisdom, lately being increasingly debated, is that it is typically important for a WRB to be water vapor permeable to allow drying from the interior of a wall to the exterior in order to compensate for any moisture in the wall cavity. Water can exist in a wall cavity from any number of sources including initial construction moisture, condensation of water vapor within a wall assembly, or from a breach in the WRB.

[14] Paul Fisette is director of the Building Materials Technology and Management Program at the University of Massachusetts in Amherst, MA: http://www.umass.edu/bmatwt.

Test Methods and Code Requirements

In North America, the accepted tests for the measurement of *permeance* and *water vapor transmission rate* (WVT) are in ASTM E 96 *Standard Test Methods for Water Vapor Transmission of Materials.* Permeance[15] is the accepted measurement of the performance of a WRB for passage of water vapor. In the U.S., permeance has been typically expressed in perms. 1 perm = grain/(ft^2•h)(in Hg). In metrics, permeance is measured in g/(s•m^2•Pa) or ng/(s•m^2•Pa), and 1 perm is equal to 5.72×10^{-8} g/(s•m^2).

Permeance is often confused with *permeability*,[16] which is permeance per unit thickness, or with *water vapor transmission rate* (WVT),[17] measured in grains/(h•ft^2) and (g/h•m^2), which does not include unit vapor pressure difference.

To add even more confusion, E 96 includes two basic methods and several procedures for testing and reporting. According to E 96, "Agreement should not be expected between results obtained by different methods."

Despite the fact that permeance, and not WVT, is the accepted measure of vapor permeance, both AC38 and UBC Standard 14-1 require a minimum average WVT of 35 g/(m^2·24 h) measured by ASTM E 96 Desiccant Method. The *National Building Code of Canada* requires permeance of $\geq$170 ng/9Pa·s m^2). Without more test information, the data are mutually inconvertible without making some assumptions regarding vapor pressure.

Because of common misuse of terminology and the fact that competing WRBs are typically tested for either WVT or permeance, and one or the other is reported, performance comparisons are difficult. In fact, there are so many problems with comparability that the current set of standards and requirements for water vapor permeance of WRBs is almost meaningless. There needs to be standardization of test methods, and test results should be reported in graphic form to indicate a range reflecting varying hygrothermal conditions. See *Moisture Control in Buildings* [9] for a detailed discussion of the challenges of defining vapor permeance for WRBs.

Performance Tests

No original test data for asphalt saturated felt are available; however, Treschel shows 320 ng/(s•m^2•Pa) (5.6 perms) using the desiccant method and 57 ng/(s•m^2•Pa) (1.0 perms) using the water method [9]

The CMHC *Wood Frame Envelopes in the Coastal Climate of British Columbia* shows "breather-type sheathing paper with a water vapor permeance of 2.96–24.39 perms (170–1400 ng/(s•m^2•Pa)) [10].

A leading manufacturer of a spunbonded olefin housewrap publishes a specification showing a range of 1496–1670 ng/(s•m^2•Pa) (26 perms) for similar product lines using E 96, Method B.[18]

The code requirements for allowable water vapor transmission or permeance are as follows:

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[15] E 96, quoted from C 168 *Terminology Relating to Thermal Insulating Materials*, defines water vapor permeance as "the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions."

[16] E 96, quoted from C 168 *Terminology Relating to Thermal Insulating Materials* defines water vapor permeance as "the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions."

[17] E 96, quoted from C 168 *Terminology Relating to Thermal Insulating Materials* defines water vapor transmission rate as "the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity."

[18] There is no Method B described in E 96. Procedure B describes the Water Method at 73.4°F (23°C).

TABLE 3—*Tests or standards for permeance in building codes.*

Code Test Method	Asphalt Saturated Felt	Grade D (10-min) Asphalt Saturated Kraft Paper	Polymer Housewrap
2001 California Building Code (1997 Uniform Building Code), Section 1402A[19] (Prescriptive) UBC Standard 14-1 ("Approved test methods shall be used")[20]	"asphalt saturated rag felt" is approved by prescription. No permeance requirements are referenced	Average WVT, ($g/m^2 \cdot 24h$), Grade D: 35 minimum[21]	Must be approved as alternate material subject to AC 38 *Acceptance Criteria for Weather Resistive Barriers*, (Alternate Materials – 104.11). AC 38, table 1, requires the following WVT in $g/(m^2 \cdot 24h)$ when conducted by E 96, Desiccant Method: Grade A: maximum 4 Grade B: maximum 6 Grade D: minimum 35
International Building Code, Section 1404.2	D226, Type I (#15) is approved by prescription. No permeance test standards are referenced.	Not listed as a prescriptive material. Must be approved as an alternate material under 104.11, typically through ICC Evaluation Service using AC38	Not listed as a prescriptive material. Must be approved as an alternate material under 104.11, typically through ICC Evaluation Service using AC38
International Residential Code, Section R703.2	D226, Type 2 (#30) is approved by prescription. No permeance standards are referenced.	Not listed as a prescriptive material. Must be approved as an alternate material under 104.11, typically through ICC Evaluation Service using AC38	Not listed as a prescriptive material. Must be approved as an alternate material under 104.11, typically through ICC Evaluation Service using AC38
National Building Code of Canada CAN2-51.32-M77, *Sheathing Membrane, Breather Type*, (E 96, Procedure A, Desiccant Method at 73.4°F (23°C)) Same as in *Technical Guide for Sheathing, Membrane, Breather-Type*, 6.4.2)	New: $\geq$ 170 ng/(Pa·s m^2) and $\leq$ 1400 ng/(Pa·s m^2) Aged: $\geq$ 2900 ng/(Pa·s m^2)	New: $\geq$ 170 ng/(Pa·s m^2) and $\leq$ 1400 ng/(Pa·s m^2) Aged: $\geq$ 2900 ng/(Pa·s m^2)	New: $\geq$ 170 ng/(Pa·s m^2) and $\leq$ 1400 ng/(Pa·s m^2) Aged: $\geq$ 2900 ng/(Pa·s m^2)
NFPA 5000[22]	"asphalt saturated rag felt" is approved by prescription. No permeance standards are referenced.	Average WVT, ($g/m^2 \cdot 24h$), Grade D, 35 minimum, tested by FS UU B 790a using UU P 31b, Method 181	Average WVT, ($g/m^2 \cdot 24h$), Grade D, 35 minimum, tested by FS UU B 790a using UU P 31b, Method 181

[19] The *California Building Code* continues to be based on the 1997 *Uniform Building Code.*

[20] Other than "approved test methods shall be used," UBC Standard 14-1 dos not reference a specific test for weather resistance. The precursor to UBC Standard 14-1 was Federal Specification FS UU-B-790a, which used Test Method 181 from FS UU-P-31b for water resistance. Test Method 181 is similar to D779.

[21] According to Theresa A. Weston, Ph.D., WVT of 35 ($g/m^2 \cdot 24h$) is a reasonable equivalent to 5 perms. (Theresa A Weston, DuPont Nonwovens, P.O. Box 27001, Richmond, VA 23261, 804/383-4031, email: Theresa.A.Weston@usa.dupont.com).

In AC38, there is no requirement for permeance; however, there is a requirement for maximum or minimum water vapor transmission, referencing E 96, Desiccant Method. Unfortunately, the determination of water vapor transmission is only an intermediate step in the calculation of permeance as required by the "Report" section of E 96. Water Vapor Transmission is a material performance measurement that requires the addition of the vapor pressure difference in the test chamber to calculate permeance, which is the accepted measurement of the performance of a weather resistive barrier membrane for passage of water vapor.

Special Code Requirements for Use in Cement Plaster (Stucco) Claddings

The “Exterior Wall Covering” chapters of both the 2003 *International Building Code* (Section 1402.2) and the 2003 *California Building Code* (Section 1402.1) list asphalt saturated felt prescriptively as an approved WRB. However, the “Gypsum Board and Plaster” chapter of the *International Building Code* requires a “weather-resistant vapor-permeable barrier with a performance[23] at least equivalent to two layers of Grade D paper” over wood based sheathing, and the *California Building Code* (Section 2506.04) requires a WRB that “shall include two layers of Grade D paper.”

The origin and theory behind this requirement is described in the 1997 *Handbook to the Uniform Building Code*:

> 2506.4 Weather-resistive barriers. The code requires a weather-resistive barrier to be installed behind exterior plaster for the reasons discussed in the previous provisions of Section 1402. Furthermore, the code requires that when the barrier is applied over wood-base sheathing such as plywood, for example, the barrier shall be two layers of Grade D paper. This requirement is based on the observed problems where one layer of a typical Type 15 felt is applied over wood sheathing. The wood sheathing eventually exhibits dry rot because moisture penetrates to the sheathing. Cracking is created in the plaster due to movement of the sheathing caused by alternate expansion and contraction. Field experience has shown that where two layers of building paper are used, penetration of moisture to the sheathing is considerably decreased, as is the cracking of the plaster due to movement of the sheathing caused by wet and dry cycles. <u>The Grade D paper is specified because it has the proper water vapor permeability to prevent entrapment of moisture between the paper and the sheathing</u> [underlining by author]. [8]

In the author’s opinion, the preceding statement is based on anecdotal sources rather than credible studies, particularly since there are different types of Grade D papers with substantial differences in permeance, and the information available indicates that asphalt saturated felt falls at least within the lower range of permeance required by the *California building Code* and *NFPA 5000*. Furthermore, the appropriate range of permeance for a WRB under any specific service condition is still very much a subject of debate among experts.

Water Vapor Permeance of Conditioned Material

The permance of a WRB varies with relative humidity, temperature, and vapor pressure [9]. Saturated materials typically perform differently than dry materials. Wet dry cycling, as required

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[22] 37.3.1.2: Barrier shall be a minimum of one layer of building paper meeting Federal Specification UU B 790a, *Specification for Building Paper, Vegetable Fiber, Kraft, Waterproofed, Water Repellant*, for kraft waterproof building paper, or No. 15 asphalt saturated felt complying with Type I, felt in accordance with ASTM D 226 *Standard Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing*.

[23] Some building officials interpret “equivalency” as comparable water resistance, while others interpret it as comparable permeance.

in CAN2-51.32-M77, also changes the permeance of WRBs. Establishing the hypothetical service condition under which the permeance of a WRB would be most critical is a challenge that has yet to be met.

History and Description of Weather Resistive Barrier Materials

Asphalt Saturated Felt

There continues to be substantial confusion between two similar waterproofing materials composed of organic materials produced in similar ways and perhaps diverging from a common predecessor. There is a tendency to refer to asphalt saturated felt and asphalt saturated kraft paper interchangeably, using such common terms as “building paper,” “tarpaper,” “felt,” etc., although they are two very distinct products.

The first known use in the U.S. of organic felt in roofing reportedly occurred in 1844 in Newark, NJ, a seaport, where a method of using pine tar impregnated paper and wood pitch was copied from ship construction and used for roofing buildings. Papermaking and felting are similar processes and are both old arts involving the working of fibers together by a combination of mechanical means, chemical action, moisture, and heat. What started out as roofing paper developed into “rag” felt and gradually emerged as “organic” felt. These products must be sufficiently “open” to have space between fibers to permit maximum absorption of waterproofing asphalt. The primary ingredient, cloth rags, became significantly less useful following the introduction of “wash and wear” textiles [11].

Saturation [with asphalt] is achieved in the saturator by passing the sheet rapidly under and over a series of rolls which repeatedly dip the felt into a vat of molten bitumen. Moisture and air are expelled, and bitumen takes their places in the porous felt. The consistency and composition of the bitumen together with the properties of the dry felt affect the rate of saturation. Since saturation is not complete, the resulting felt still can absorb moisture and is vapor permeable. The vapor permeance and water absorption of saturated felt can be greatly reduced by coating it with mineral-stabilized bitumen [12].

Saturated wood-fiber felts can absorb water up to 80 % of their weight when immersed, and this produces expansion up to 2 % parallel to and 1.5 % perpendicular to the fiber or machine direction of the felt. Also, as felts dry there is an accompanying shrinkage, which can be greater than the original expansion. When exposed to water and air, organic fibers are subject to rot and fungal attack, and roots of vegetation may grow into them. [12].

Originally, the weight of felts was based on 480 sq ft, the typical felt ream [12]. Currently, the weight is based on a roofing “square,” or 100 sq ft. Klimas reports that “roof ply felt is 27-lb grade (unsaturated) [12].” That would be equivalent to 5.6 lb per square, just 0.04 lb more than the current requirement of ASTM D 226. ASTM D 226 requires a minimum weight of 5.2 lb for desaturated #15 felt and a weight of the saturant of 6.2 lb for a total of 11.5 lb. In 1979, the UBC Standard 32-1 required the saturant to not be less than 1.4 times the dry felt weight, so 5.2 lb dry felt, when saturated, would be 12.48 lb per 100 sq ft. It is widely claimed that #15 asphalt saturated felt historically weighed 15 lb and that the pound sign (#) was moved from the right to the left of what was originally the weight, to change “15#” to “#15” or “No. 15” as the weight diminished. We have seen no credible documentation that the original weight of this product was 15 lb, but as can be seen from the following building code extracts, the weight has, apparently, diminished over the last 40 years.

The 1964 *Uniform Building Code,* Section 1707(a) required "building paper" described therein as "asphalt saturated felt free from holes and breaks and weighing not less than 14 pounds per one hundred square feet (100 sq. ft.) or approved waterproof paper."

By 1973, the *Uniform Building Code*, Section 1707(a) had bifurcated the asphalt saturated sheet products into *UBC Standard No. 17-1* for "Kraft waterproof building paper" and *UBC Standard 32-1* for "asphalt saturated rag felt." UBC Standard 32-1 required a desaturated felt weight of not less than 5.2 lb per 100 sq ft for Type 15 felt and a saturated weight of not less than 1.4 times the weight of the unsaturated moisture free felt, resulting in a finish weight not less than 12.48 lb per 100 sq ft.

The 1997 *Uniform Building Code* and the *California Building Code* (based on the 1997 *UBC*) continued to reference *UBC Standard 14-1 for* kraft waterproof building paper but have dropped the reference to *UBC Standard 32-1* for asphalt-saturated rag felt, although the material is still included in 1402(a) as an allowable weather resistive barrier. The 2003 *International Building Code* (1404.2) describes "A minimum of one layer of No. 15 asphalt felt, complying with ASTM D 226 for Type 1 [commonly called No. 15] felt…"

The last (1999) *BOCA National Building Code* stated: "1405.3.6 Water-resistive barrier: A minimum of one layer of No. 15 asphalt felt complying with ASTM D226 as listed in Chapter 35, for Type I felt [13]…"

A relatively new standard for asphalt saturated organic felt is ASTM D 4869-02 *Standard Specification for Asphalt-Saturated Organic Felt Underlayment Used in Steep Slope Roofing.* Unlike D 226, this specification includes a water resistance test ("liquid water transmission test") that involves a 4-h exposure to a shower without any evidence of wetness on the underside.

Products conforming to both ASTM D 226 and D 4869, as well as products that conform to neither, are commercially available.

Potential Advantages of Asphalt Saturated Felt

- Long history of successful use under normal exposure conditions.
- Explicitly conforms to several model codes.
- Low material cost.
- Long-term durability possibly superior to paper-based materials.

Potential Disadvantages

- Minimal performance test data available for use as a WRB.
- Comparatively high permeance may result in wall cavity condensation under certain service conditions.
- Low resistance to tearing and breaking.
- Low resistance to bending.
- Vulnerable to deterioration after periodic or long-term exposure to water, especially when combined with exposure to air or UV.
- Exposure to surfactants may adversely affect resistance to water penetration.
- May not conform to some building codes for use with cement plaster over wood based sheathing.

Asphalt Saturated Kraft Paper

The term *kraft* paper is broadly used to describe all types of sulfate papers, although it is primarily descriptive of the basic grades of unbleached sulfate papers where strength is the chief factor, and cleanliness and color are secondary. Kraft pulp is pulp cooked by the alkaline liquor consisting essentially of a mixture of caustic soda and sodium sulfide. The make-up chemical is traditionally sodium sulfate, which is reduced to the sulfide in the chemical recovery process; hence the alternative designation, sulfate pulp.

Building paper, as opposed to asphalt saturated felt, was first manufactured in the 1950s.[24] In the last 50 years, asphalt saturated kraft paper has eclipsed felt as an organic, asphalt treated WRB. It remains the WRB of choice in many parts of the U.S., particularly California and the western states.

Demand for increased durability has resulted in the introduction of "30-minute" and "60-minute" asphalt saturated kraft papers with water resistance increased over the 10 min required for once popular Grade D papers having 10 min water resistance, still the standard in most U.S. building codes.

Potential Advantage of Asphalt Saturated Kraft Paper

- Long history of successful use under normal exposure conditions.
- Explicitly conforms to several model codes.
- Low material cost.
- More performance test data available, when used as a WRB, than for felt-based materials.
- Better resistance to bending damage than felt-based materials.
- Comparatively lower permeance, compared to felt-based materials, may reduce chances of wall cavity condensation.

Potential Disadvantages of Asphalt Saturated Kraft Paper

- Low resistance to tearing.
- Highly vulnerable to deterioration after periodic or long-term exposure to water, especially when combined with exposure to air or UV.
- When used with cement plaster, single layer applications of Grade D paper do not drain as well as double applications, can stick to plaster, and are difficult to repair post-construction, particularly when applied as "paper-backed lath" and used without sheathing.

Polymer Sheets

The term "weather resistive barrier," as used in the building codes, was originally understood to mean "water resistant barrier." Tests, when referenced, were originally limited to water vapor permeance and water resistance.

The energy crisis of the early 1970s spawned a number of building energy conservation techniques and materials, including what are commonly known as "house wraps," or more commonly, "housewraps." One product was described as an "energy-saving air infiltration barrier." House wraps were originally marketed for their energy saving properties but tested for water resistance by their manufacturers to obtain equivalency recommendations from building code organizations for use as weather resistive barriers required by codes.

[24] Leonard Dorin, Consultant to Fortifiber, 941 Mountain View Drive, Lafayette, CA 94549-372 925-962-05408, ldorin@aol.com.

House wraps typically are thin, lightweight fabrics made of polyolefin fibers or extruded polyethylene films that are spun, woven, laminated, or fiber reinforced. Some have fiber properties that allow diffusion of water vapor, and others require mechanically punched micro-perforations to provide the desired level of water vapor permeance.

The air barrier functionality of housewraps is intended primarily to block random air movement through building cavities. If the air barrier is to perform its intended role, it must meet a number of requirements: continuity, structural integrity, air impermeability, and durability. An air barrier may consist of a single material or two or more materials, which, when assembled together, make up an air impermeable, structurally adequate barrier. Moderate water vapor permeance has also come to be an accepted desirable functionality of air barriers. The theory is that the air resistance functionality limits passage of potentially damaging volumes of airborne water vapor into walls but promotes drying by allowing passage of smaller amounts of water vapor to the exterior.

Many common construction materials, such as structural wood panels, gypsum board, foam board, and even WRBs and paint can function as air barriers, but joints, laps, and discontinuities with the same and different materials compromise the integrity of the air resistance of the whole building. Flexible sheet materials in comparatively large sizes with taped seams largely solve the integrity problem.

Model codes in the United States have not yet incorporated requirements for air barriers, but the *National Building Code of Canada* has required air barriers since 1986, and the *Massachusetts Energy Code* (780 CMR) states, "1304.3.1 Air Barriers: The building envelope shall be designed and constructed with a continuous air barrier to control air leakage into, or out of, the conditioned space." ASTM E 1677, *Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls* was first approved in 1995 but has not been incorporated into any model codes.

Potential Advantage of Polymeric Sheets

- High resistance to tearing and breaking.
- Manufactured in large sheets – joints are minimized.
- Will not deteriorate with long exposure to water.
- Air barrier functionality.
- High water vapor permeance.

Potential Disadvantages of Polymeric Sheets

- Relatively expensive material cost.
- May deteriorate after long-term exposure to UV.
- Surfactants can affect water resistance.
- May retard evaporation of excess water in wall cavities.
- There is some controversy about the water penetration resistance of micro-perforated sheets.

Conclusions

All of the three most common types of WRBs used in North America have some history of satisfactory performance when appropriately used under conditions of conventional construction with exposure to normal weather conditions. None was developed specifically for the purpose of serving as a WRB in building wall systems, and all were adapted from some previous use or from a product looking for an application.

Codes and standards related to WRBs were developed not as a result of evaluation of the functional requirements for WRBs, but instead from institutionalizing the properties of existing materials that have been used traditionally and from adapting to the properties of new materials. Information about the optimal properties of a WRB has not been developed, and there is little reliable information available that compares the critical properties of available and competing WRB products. Marketing and tradition appear to have played a major role in shaping perceptions of WRBs by both the public and building industry professionals.

There is a critical need to develop and test building models that subject WRBs to conditions that replicate those in actual service and to develop standards that reflect actual service needs.

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[2] Canadian Construction Materials Centre, Institute for Research in Construction, National Research Council Canada, Montreal Road, Building M-24, Ottawa, Ontario K1A) R6, 613/993-6189, fax 613/952-0268.

[3] The CGSB offers a Certification Program for Breather Type Sheathing Membrane based on standard CAN/CGSB-51.32-M77 -*Sheathing, Membrane, Breather Type*. For information, contact Judy Baltare, Canadian General Standards Board, Conformity Assessment Officer, Certification Services - Products and Services,819)-956-1236, Fax: (819) 956-0395; Email: Judy.Baltare@pwgsc.gc.ca.

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