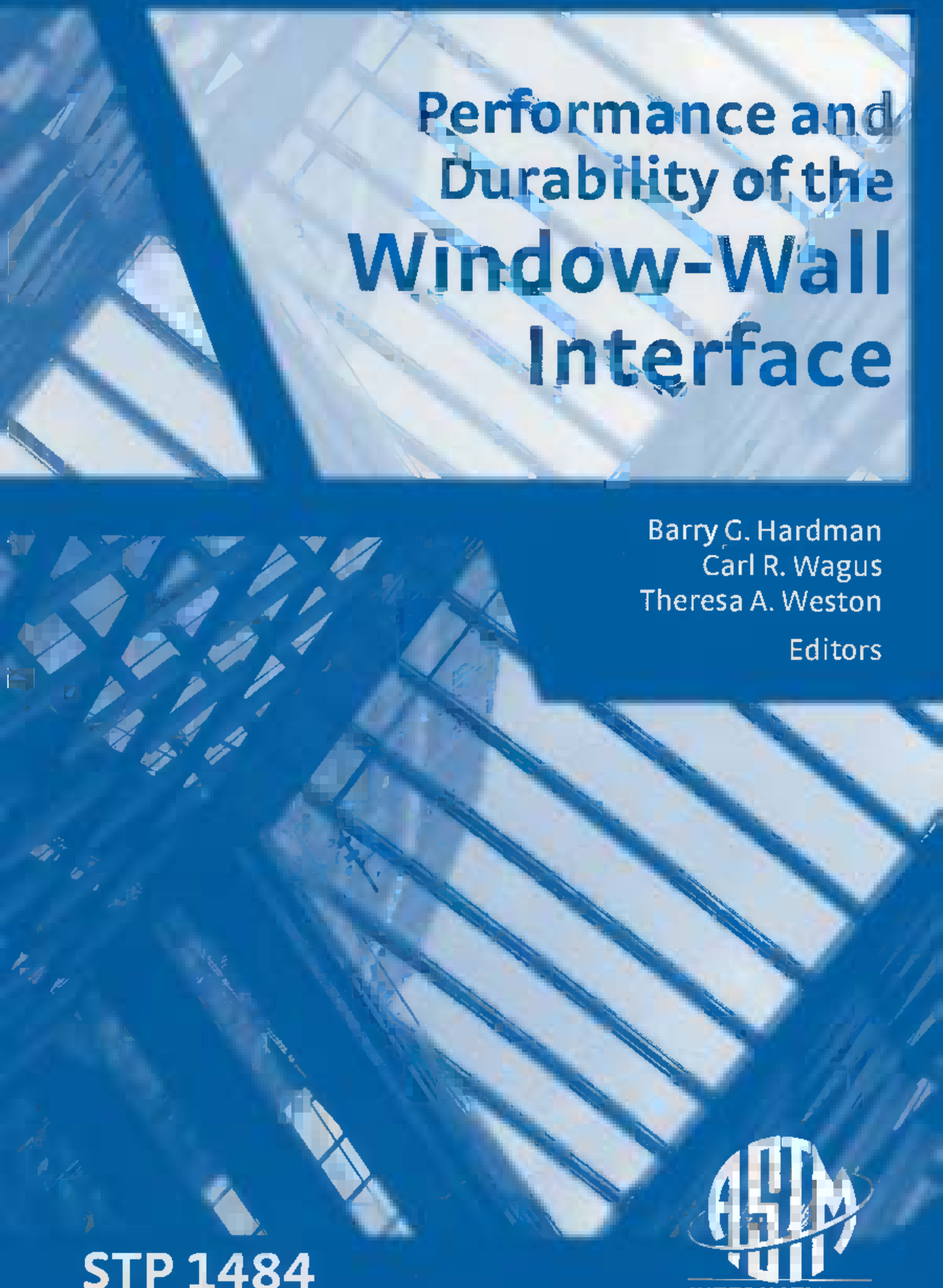
Performance and Durability of the Window-Wall Interface



Barry G. Hardman
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Editors

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Barry G. Hardman, Carl R. Wagus, and Theresa A. Weston, editors

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Peer Review Policy

Each paper published in this volume was evaluated by two peer reviewers and at least one editor. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM International Committee on Publications.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of the peer reviewers. In keeping with long-standing publication practices, ASTM International maintains the anonymity of the peer reviewers. The ASTM International Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM International.

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Foreword

This publication, *Performance and Durability of the Window-Wall Interface*, includes peer reviewed papers presented at the ASTM E06 Symposium by this same name in April of 2004. The symposium, held in Salt Lake City, Utah on April 18, 2004, focused on gathering much-needed window-wall interface information, which was not previously available through the private sector. The papers submitted reveal product testing and the testing of installation methods and techniques. The symposium chairman was Barry G. Hardman from the National Building Science Corporation, and the symposium co-chairs were Carl R. Wagus with Pittco Architectural Metals, and Theresa A. Weston with DuPont Nonwovens.

Contents

Overview

This standard technical publication represents peer-reviewed white papers presented during the forum entitled "Performance and Durability of the Window-Wall Interface", held in Salt Lake City on April 18, 2004. This is a first attempt to gather much-needed window-wall interface information that has been previously unavailable through the private sector. The white papers included in this STP give a broad picture of current techniques and technology to solve an otherwise difficult integration problem facing building construction practitioners.

During the late 1980s and early 1990s, and prompted by a need to save energy, many organizations were formed, including NFRC. NFRC took on the task of rating windows for thermal performance, but it became apparent that installation into the envelope affected the performance.

The changes in materials and techniques during the past few decades have produced some problems that appear to be newly observed by the building industry. Those problems appear to be generated from moisture and liquid water entering the walls through a variety of interfaces surrounding fenestration installations.

The E06.51.11 task group developed *E 2112 Standard Practice for Installation of Exterior Windows, Doors, and Skylights*. Once E 2112 was developed, it became apparent that there was little or no publicly available data on housewrap or flashings, and since the integration of the fenestration and the envelope is paramount, our task group has shifted gears to investigate and make available all the data that is important, to enable the user to make choices.

STP 1484 offers viewpoints and testimony from the private sector, which includes new research, exhaustive testing, and the creation of installation standards that attempt to identify installation methods and construction sequencing, to integrate a variety of fenestration products into a variety of wall claddings. Interface issues include:

- Integration of windows or doors with their related interfaces–flashings, sealants, claddings, and membranes, just to mention a few.
- Considerations of weather, exposure, job site conditions;
- Changing of installation methods based on the constant innovation of changing materials from the 1950s or post-World War II through the present;
- Compatibility or incompatibility of adjacent and integrated materials;
- A variety of separate trades who work on the window-wall interface area without coordination with each other;
- The roles of the architects, builders, and the various trades responsible for the installation of these fenestration products.

Many of the submitted papers reveal product testing and the testing of installation methods and techniques. In some cases, the reader will be introduced to the importance of drying in walls and the role that permeability plays in the selection of materials. There are papers that supply detailed information on the ability or inability of self-adhered materials to maintain their original adhesion properties and their long-term serviceability and durability.

Readers can obtain vital information that will help them write specifications, create or interpret standards, evaluate materials for product selection, or recommend changes to the building codes.

As mentioned earlier, this is a first symposium in this area, and it is the intent of this task group, ASTM E06.51.11 Fenestration Installation, to present a second symposium in Tampa, Florida in October, 2007, entitled "Up Against the Wall." Ultimately, we would like to achieve a matrix of information, based on peer-reviewed papers with published test data, that will allow the user to compare and select installation methods and materials for performance under different conditions; this data will be useful to the architect, specifier, installer, and building owner. We encourage testing and publication of data on alternate installation methods and new materials.

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Symposium Chairman and Editor

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Pittco Architectural Metals
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MATERIALS

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Water Resistance and Durability of Weather-Resistive Barriers

ABSTRACT: Weather resistive barriers function as the second line of defense against water that has intruded past a building's cladding. Despite its importance, however, the evaluation of weather-resistive barrier water resistance performance is not conducted in a consistent manner across product types. Several different test methods that include vastly different water exposure techniques are used. Because of the variance in test methods and rating systems, the selection of optimal weather resistive barrier for a specific project can be difficult. Complicating matters further, the water resistance of weather resistive barriers is almost always reported on as-received materials, with little if any information provided on how the water resistance will change during the construction period or in service. This paper presents data comparing the water resistance of weather resistive barriers measured by both standard methods and by a small-scale water spray test. Additionally, the change in water resistance performance due to direct environmental exposure is discussed.

KEYWORDS: water resistance, weather resistive barriers, sheathing membranes, drainage plane

Introduction

Weather-resistive barriers (WRBs), sometimes referred to as sheathing membranes, or water barriers are a key part of the water management system of building walls. These materials provide secondary protection to the sheathing and wall structure by shielding these components from rain water which may be driven through the exterior cladding. Therefore, knowledge of the resistance to liquid water transmission of a weather resistive barrier is important to the assessment of its suitability. Unfortunately the industry has no standard method of testing water resistance of weather-resistive barriers. The matter is further complicated because WRBs are designed to be vapor permeable to enable the wall to dry small amounts of penetrant water, and some of the industry test methods for water resistance do not distinguish between liquid and vapor transmission. Additionally, durability of weather resistive barriers and knowledge of how their water resistance changes with either exposure during construction or service life is for the most part ignored by codes and standards. This paper presents a review of water resistance measurements of WRBs and includes some results from a small scale water spray test. Additionally, a review of the effect of environmental exposure on the water resistance of WRBs is presented. Results of testing showing the degradation of water resistance by mechanical abrasion and disruption, as well as exposure to UV and thermal aging, are discussed.

Water Resistance of Weather-Resistive Barriers

Current Standards and Test Methods for Water Resistance

Although a key performance criteria, there is no generally accepted method of measuring water resistance. Several test method standards exist. Most are suitable only to weather-resistive barriers with specific material composition. In the United States the International Code Council recognizes weather-resistive barriers through an acceptance criterion [1]. This criterion recognizes three different test methods; two of which are based on penetration under hydrostatic head and the other based on a combination of liquid diffusion, vapor diffusion, and absorption known colloquially as the "boat test." (Table 1)

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TABLE 1—*Water resistance requirements of ICC-ES Acceptance Criteria AC38.*

Weather resistive barrier material composition	Test methods: Basic performance	Test methods: "60 Min Grade D" performance
Felt-based	No water resistance test requirements—Conformance with ASTM D226 is required.	
Paper-based	ASTM D779—10 min	ASTM D779—60 min
Polymer-based (building wraps and housewraps)	CCMC 07102 or AATCC-127 at 55 cm for 5 h	AATCC-127 at 55 cm for 5 h

These tests are consistent with test data reported by manufacturers. A review of each test method including representative test data follows.

ASTM-D779 Standard Test Method for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry Indicator Method—This test method was developed to test papers and paper-based materials. The results are reported in water transudation time. More specifically "the time interval from the instant of contact of the test specimen with water until the rate of change in the color of the indicator is at a maximum" is reported. The indicator composition is critical to the value measured and was identified during the development of the method as a key issue with the method repeatability and reproducibility [2]. The indicator does not distinguish between liquid and vapor as reported in Section 4: Significance and use of this method "For test times up to approximately 30 s, liquid transudation rate is dominant and this test method can be considered to measure this property. As test times exceed 30 s, the influence of vapor-transmission rate increases and this test method cannot be regarded as a valid measure of liquid resistance (sizing)." Test results showing the dominance of vapor transmission over water resistance in this test have been reported. Specifically, several studies have shown that this test method is highly dependent on the water temperature indicating that vapor transport is the dominant mode of moisture transport. The test results were reported to vary by 4 % for each degree Fahrenheit of test water variation from 70°F [2]. Test results for asphalted papers were shown to vary by a factor of 5 when tested at 100°F versus 73°F [3]. Researchers have concluded that this method is inappropriate for evaluation of materials, and should only be used for quality control [4].

This method, although not generally used for nonpaper-based materials, was used to test polymeric-based weather-resistive barriers. In particular because of its sensitivity to vapor diffusion it is unsuitable for use with moderate and high permeability polymer based WRBs. Previously reported results show that some perforated polymeric weather resistive barriers can show water penetration using ASTM D779 in as little as 30 s and in general less than 10 minutes [5,6]. Table 2 shows results from ASTM D779 for several nonperforated spun-bonded polyolefin (SBPO) housewraps. The materials show a wide range of transudation times. The times vary with both the vapor permeability and the hydrostatic head of the materials.

ASTM D779 measurements of these types of materials can also be extremely variable as can be seen in the distribution of test results for SBPO #4 in Fig. 1. The individual sample measurements are not normally distributed and transudation time varies from 141 to >480 min.

Hydrostatic Pressure Test (AATCC-127)—This method was designed for testing "heavy, closely woven fabrics that are expected to be used in contact with water" [7]. It involves exposing a sample to an increasing head of water and determining a "breakthrough" pressure at which water penetrates the sample. This method has the benefit of only measuring liquid water transfer, but it has been criticized for not being relevant to actual construction performance because of the high water pressures tested [4].

It is typical for manufacturers to report the breakthrough pressure. Table 3 shows the breakthrough pressures of several types of weather-resistive barriers measured using AATCC-127.

The code acceptance criteria, however, contains a pass/fail criteria based on time to breakthrough under a 55 cm hydrostatic head instead of the instantaneous breakthrough pressure. The time and pressure

TABLE 2—*ASTM D779 results for four SBPO housewraps.*

	SBPO #1	SBPO #2	SBPO #3	SBPO #4
ASTM D779 (minutes)[a]	19.6	23.8	149	304
Hydrostatic head (cm at failure)[b]	>210	>210	>210	>280
Vapor permeability (perms)[b]	58	50	26	28

[a]Average of ten measurements.

[b]Reported in manufacturer's literature.

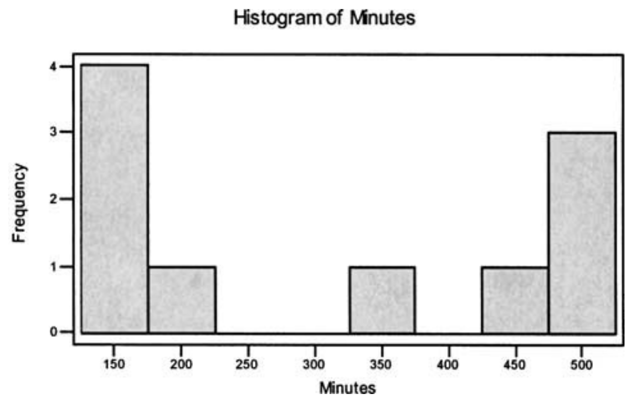

FIG. 1—*Distribution of individual ASTM D779 measurements on SBPO #4.*

response are strongly inter-related for absorbent weather-resistive barriers such as building papers and felts. Figure 2 shows the results of testing with asphalt impregnated building papers and felts at different pressures for the time of breakthrough. Time to failure at 75 cm hydrostatic head ranged from instantaneous failure to 6 min failure time. While at 55 cm hydrostatic head the failure time ranged from 12 to 68 min. Felt products had a much higher sensitivity than building papers, most likely due to their greater thickness and mass being able to retain more water.

CCMC 07102 Water Resistance Test—This test is reported as pass/fail criteria to 2.54 cm hydrostatic head held for 2 h [8]. This test presents the lowest challenge level of any of the tests in the (ICC) acceptance criteria [1]. A lower challenge level was selected in response to comments that the AC-38 modified AATCC-127 criteria was too stringent based on normal wind speeds and pressures.

System Test Methods—Outside of the building code acceptance and manufacturer quality control arena, weather-resistive barriers are also tested as part of wall systems. Wall systems are commonly tested by applying a water spray to the surface of a specimen. One example of such a test is used in ASTM E1677 Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls, in which ASTM E331 Test Method for Water Penetration of Exterior Windows, Curtain Walls, and

TABLE 3—*Hydrostatic Head (AATCC-127) of several types of weather-resistive barriers.*

Weather-resistive barrier type	Hydrostatic head (cm)
Perforated polymer-based	10 to 27
Nonperforated polymer-based (SBPO)	>210 to >280
Nonperforated polymer-based (film laminate)	130 to >180
Paper-based (10 Min Grade D)	65 to 99
Paper-based (60 Min Grade D)	67 to 103
Felt-based	59 to 80

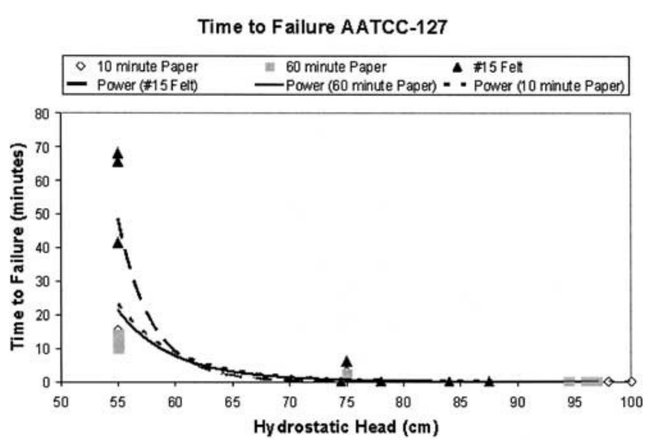

FIG. 2—*Time-pressure response of building paper and felt to hydrostatic head level.*

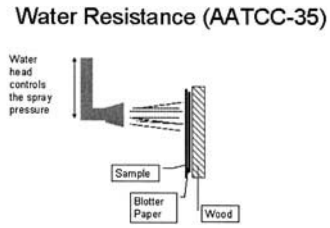

FIG. 3—*AATCC35 apparatus.*

Doors by Uniform Static Air Pressure Difference is used under specific conditions to challenge the installed air retarder. A spray rack is calibrated to deliver 3.4 L/m^{2*}min (5 U.S. $gal/ft^{2*}h$), while a 0.11 in. H_2O (27 Pa) pressure difference (equivalent wind speed of approximately 15 mph) is applied across the specimen. The passing criteria is defined as no water entering during a 15-min. test period.

Spray testing is also specified for roofing underlayments (the roof structure equivalent of a weather-resistive barrier) in ASTM D4869 Standard Specification for Asphalt-Saturated Organic Felt Shingle Underlayment Used in Roofing. In this standard a water spray calibrated to supply 40 to 42 gal/h (42 to 44 cm^2/s) is directly applied against a backed underlayment which is tilted at a 20° angle. An area of approximately 10 to 12 in. is impinged by the spray. The passing criterion is no visible water passage in 4 h.

Proposed Test Method–Small Scale Spray Test (AATCC-35)

A water spray based test which can be conducted on small, approximately 1 ft^2 (0.1 m^2), specimens would be useful for the evaluation of weather-resistive barriers. By searching other industries, a suitable small scale spray test, AATCC-35 Test Method for Water Resistance: Rain Test, was found [9]. AATCC-35 was originally developed for textile fabrics, and was designed to measure the resistance of fabrics to the penetration of water by impact. Water impact penetration is directly applicable for the weather resistive barrier during the construction phase when it is directly exposed and has the benefit of being consistent with the philosophy of the tests conducted to evaluate roof underlayments.

The basic test setup is shown in Fig. 3. The test specimen, backed by a blotter paper and a rigid board or holder, is sprayed for 5 min under controlled conditions. The blotter is weighed before and after the spraying and the amount of water which penetrated the sample to the blotter measured by difference. To get a complete picture of the resistance of a fabric a range of spray intensities are used. The specified sample size is 8 in. by 8 in. (20.3 cm by 20.3 cm). The sample is backed by a blotter paper that is 6 in. by 6 in. (15.2 cm by 15.2 cm). Modifications of the time duration and spray conditions would be needed to adopt this test as a weather-resistive barrier standard. To investigate the applicability of this test, however, a series of tests were conducted on several different weather-resistive barriers under different conditions. For some of the tests a modified test setup was used.

Water Resistance Testing Based on AATCC-35

Building Paper and Felt

Building paper and felt are the traditional weather-resistive barrier materials. The performance of 10 min Grade D Building paper, 60 min Grade D building paper, and #15 felt was evaluated using the standard AATCC-35 method. The only variation from the published method was that it was conducted for longer time duration than the standard 5 min and that the weather resistive barriers were weighed before and after the test to measure the moisture absorption of the barrier in addition to the moisture which had penetrated. Two spray intensities were conducted: 2 ft (61 cm) of water pressure head and 3.5 ft (107 cm) of water pressure head applied to the nozzle. Three specimens were run at each condition. Figure 4 shows the response of Grade D building paper with a 2 ft (61 cm) column height. The response of Grade D paper is typical of all the papers and felts. Because they are absorbent, the moisture content in the paper rises quite rapidly, while no significant water is transferred to the blotter paper. After the paper has become wet, in this case about 30 min, water begins to be transferred through the paper to the blotter. Raising the intensity

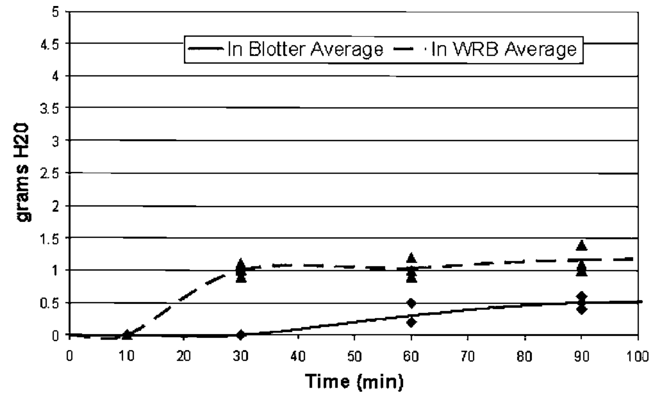

FIG. 4—*AATCC35 measurements of Grade D building paper.*

of the test causes the paper or felt to gain moisture more quickly and to absorb a larger amount. Figure 5 shows the water absorption of the 10 min Grade D paper, 60 minute Grade D paper, and #15 felt at both intensity levels. Because the spray test can be used as a measure of weather-resistive barrier water absorption in addition to moisture transudation, it offers an advantage over other water resistance test methods. A weather-resistive barrier's water absorption characteristics are important to the wall's overall moisture management. The absorption of water by building felt was noted to retard wall drying in one laboratory study of wall moisture management [10].

Perforated and Nonperforated Polymer-based Weather-resistive Barriers—Polymeric-based weather-resistive barriers do not absorb water and therefore do not have any initial period before water transmission occurs. Figure 6 shows the response of four polymeric-based housewraps to the AATCC-35 test at the 2 ft intensity level. Three of the housewraps are perforated products and one of the products is a nonperforated SBPO product. The perforated products have significantly more water transmission than the non-

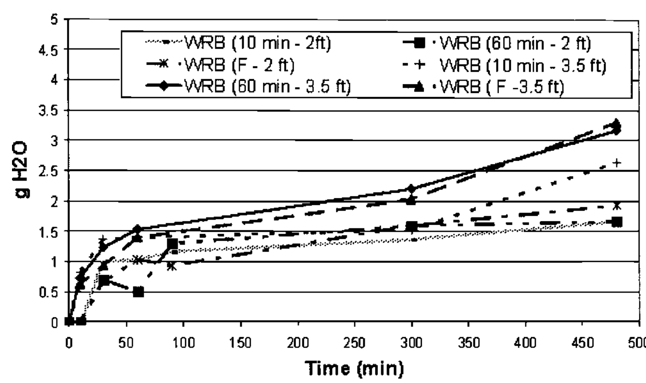

FIG. 5—*Water absorption of building papers and felts during AATCC35.*

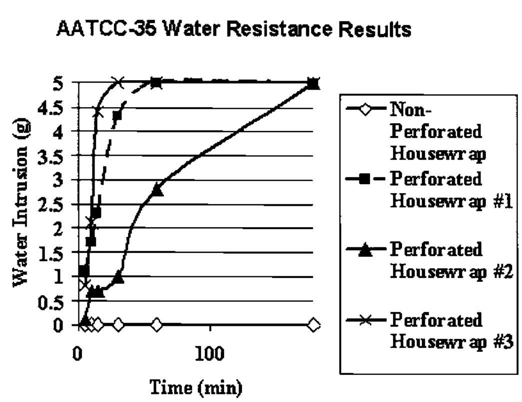

FIG. 6—*AATCC35 measurements of polymeric-based weather-resistive barriers.*

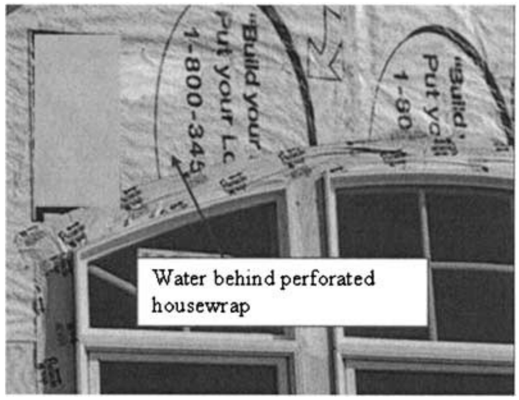

FIG. 7—*Field photograph showing rain water that has penetrated through a perforated polymeric weather-resistive barrier during construction.*

perforated product or the building papers or felts. This is consistent with the higher hydrostatic head of nonperforated weather-resistive barriers compared to that of perforated weather-resistive barriers reported earlier in Table 3. This also agrees with field experience that rain easily penetrates perforated weather-resistive barriers during construction, an example of which is shown in Fig. 7. Results from AATCC35 testing of various types of weather-resistive barriers are shown for two intensity levels in Table 4.

Effect of Fasteners on Water Resistance—Additional testing was conducted on perforated and non-perforated weather resistive barriers and the effect of fasteners on the water resistance using a modified version of AATCC-35. The modifications included enclosing the spray tester in a clear box, reducing the distance from the spray nozzle to the sample face, controlling intensity with a pump instead of a physical column of water, and changes in sample size. Enclosing the spray tester in a box was to improve safety and housekeeping but it will also increase the relative humidity that the sample sees during test. The reduction of distance between the spray nozzle and the sample will increase the intensity of the spray impact on the sample and therefore the severity of the test. These changes in the test have an unknown effect on the test data, so data from the different test sets should only be compared qualitatively. Figure 8 shows a picture of the modified test setup.

It has been noted in the trade that fasteners, especially staples, are expected to reduce the water resistance of weather-resistive barriers. The objective of this test was to examine the effect of two common

TABLE 4—*AATCC35 measurements for several types of weather-resistive barriers.*

Weather-resistive barrier type	g H_2O (60 min duration, 2 ft column)	g H_2O (480 min duration, 3.5 ft column)
Grade D paper (10 and 60 min)	0.3 to 0.6	7.9 to 13.5
#15 Felt	0.1	1.4
Perforated polymeric	2.8 to >5	Not tested
Nonperforated polymeric	0 to 0.3	0.8 to 1.9

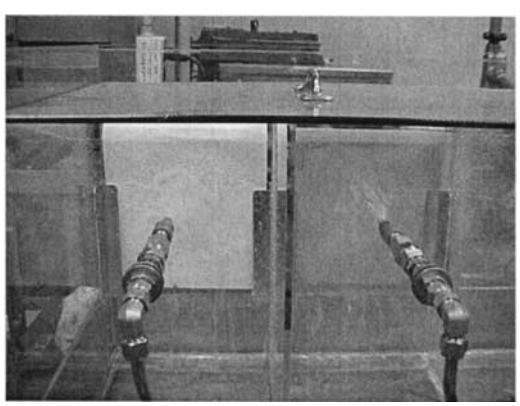

FIG. 8—*Modified AATCC35 spray tester.*

TABLE 5—*Fastener test samples.*

Test sample	Weather resistive barrier	Fastener
1-Z	Perforated housewrap	None
1-S	Perforated housewrap	Staple
1-CN	Perforated housewrap	Cap nail
2-Z	Nonperforated (SBPO) Housewrap	None
2-S	Nonperforated (SBPO) Housewrap	Staple
2-CN	Nonperforated (SBPO) Housewrap	Cap nail

fasteners, staples and cap nails, in the context of the range of performance of weather-resistive barriers. The spray test was a suitable test because the sample is mounted on a rigid backing to which the fastener could be attached. Table 5 shows the samples run in the test.

Figure 9 shows the sample configuration in which a single fastener is installed through the weather-resistive barrier, blotter, and rigid backing (sheathing). The sample represents a fastener density of one fastener/0.56 sq ft. The test results shown in Fig. 10 agree with earlier AATCC35 testing showing that perforated weather-resistive barriers allow more water passage than nonperforated weather-resistive barriers. In this test, perforated weather-resistive barriers allowed 90 times more water to penetrate compared to nonperforated weather-resistive barriers. Staples decreased the water resistance of the weather-resistive barriers, but the nonperforated samples with the staple still only allowed 14 % of the amount of water intrusion that was allowed by the perforated product without a staple. Cap nails did not significantly reduce the water resistance of the weather-resistive barriers.

Durability of Weather-Resistive Barrier Water Resistance

Durability of weather-resistive barriers is even more poorly standardized than water resistance. Few if any tests or criteria are present in codes and standards. During construction and the service life of a building, WRBs are subjected to environmental conditions that can cause reduction in material properties, including water resistance. The exposure during construction is higher intensity but of much shorter duration than that during the service life of the wall system. Materials are seldom tested after exposures and so this is relatively uncharted ground. The key environmental loads that can affect material properties are mechanical stresses, such as imposed by wind forces, building movement, lack of compatibility with other materials, UV/thermal exposure, and cyclic wetting and drying. A review of the effects of these environmental

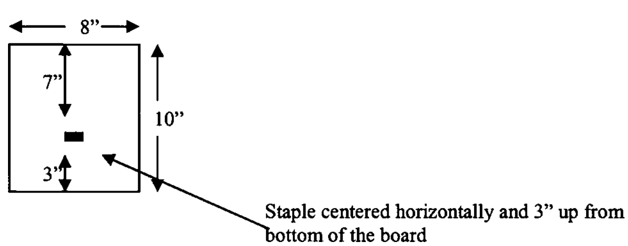

FIG. 9—*Fastener test specimen.*

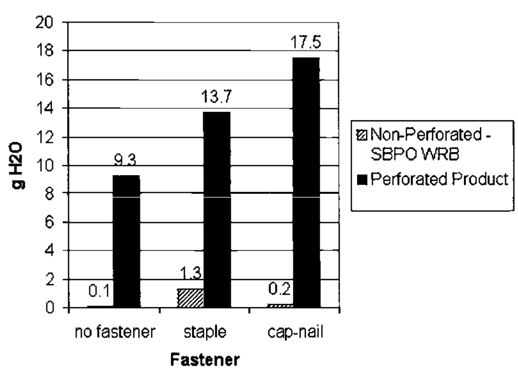

FIG. 10—*AATCC35 fastener test.*

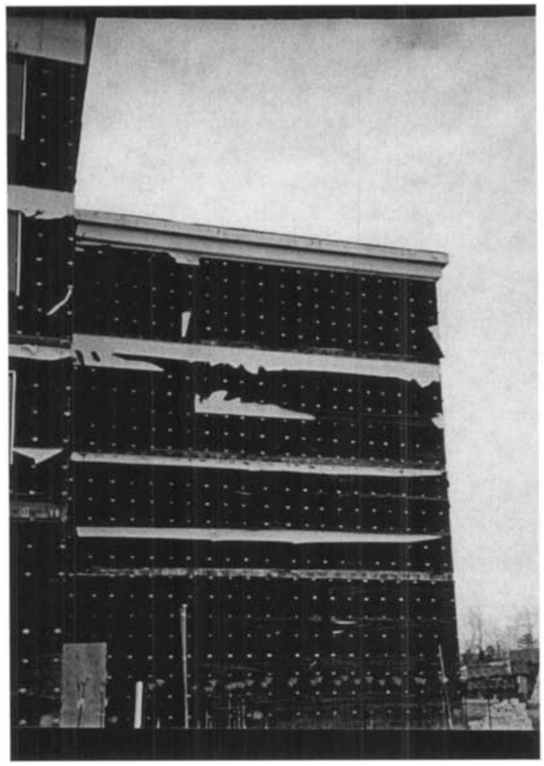

FIG. 11—*Wind damage to felt weather resistive barrier.*

loads on weather-resistive barrier water resistance was conducted. As the material composition of a weather-resistive barrier will determine its vulnerability to specific environmental factors, focused testing was conducted to illustrate the significance of environmental exposure on weather-resistive barrier water resistance.

Large Scale Damage During Construction

Tearing or ripping of weather-resistive barriers during construction has been known to occur. An example of large scale tearing is shown in Fig. 11. Obviously large holes and tears eliminate weather-resistive barrier continuity and therefore the water performance of the barrier. Codes require minimum tensile strengths on materials, but this type of damage is highly dependent on installation and cannot be determined by any material test. Use of cap nails rather than staples for attachment and taping seams are both useful in reducing weather-resistive barrier damage during the construction phase. Some system tests have wind load durability as part of the test. ASTM E1677 contains a structural integrity requirement utilizing ASTM E330 Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Uniform Static Air Pressure Differences. The air retarder system is required to withstand sustained minimum pressure of 2 in. H_2O (500 Pa) (equivalent wind speed of approximately 65 mph or 29 m/s) for 1 h. The CCMC Technical Guide for Air Barrier Systems has a stiffer structural performance comprised of a series of pressure cycles with pressures up to 1200 Pa.

Small Scale Damage Due to Mechanical Exposure—Although less obvious than the large scale ripping and tearing, mechanical forces which cause stretching or abrasion can affect material properties, including water resistance. This is especially important when the weather-resistive barrier is a laminated membrane. Laminated weather-resistive barriers usually have a film layer, which provides the barrier properties for the material, and a support layer. The film layer can be monolithic, microporous, or perforated and is usually thin and relatively fragile. The support layer can be woven fabric or nonwoven scrim. The film layer determines the water resistance of the material. In many cases, the film can be damaged or delaminated during construction resulting in loss of water resistance. Figures 12–18 show examples from field investigations of damage to laminated weather-resistive barriers.

A specific example of damage due to a laminate material is when the material is stretched. The support

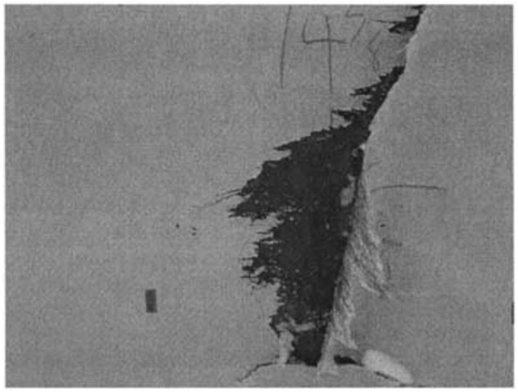

FIG. 12—*Weather resistive barrier delamination at tear.*

material is able to withstand a greater level of stress than the film and the film begins to crack. Figures 19 and 20 show scanning electron micrographs of a laminated housewrap which has been stretched half of its break elongation. Cracks and fissures in the barrier film as well as the initial steps in delamination are clearly visible. Cracking and delamination resulting in loss of water resistance can be the result of simply creasing or wrinkling some laminated film weather-resistive barriers.

Abrasion is also an issue with fragile film barriers. To test the resistance of several weather-resisitive

FIG. 13—*Abrasive damage to weather resistive barrier from slap stapler.*

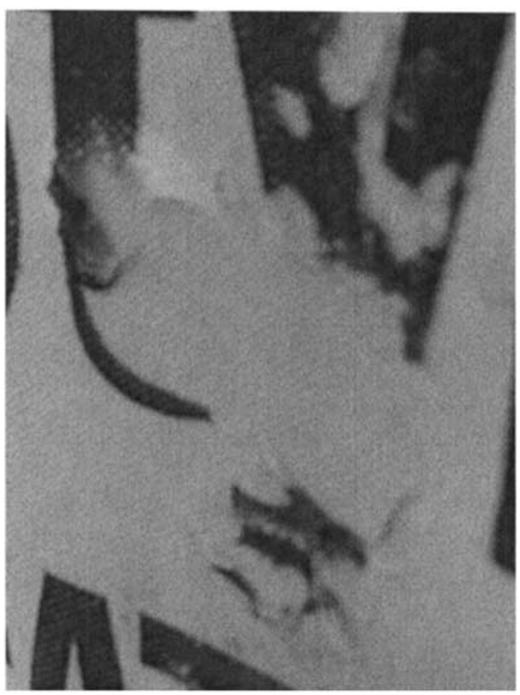

FIG. 14—*Weather resistive barrier film damage.*

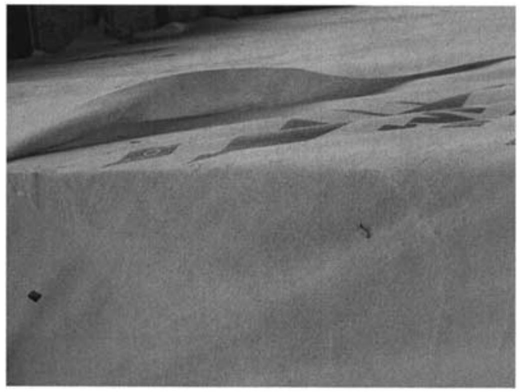

FIG. 15—*Abrasive damage and delamination of film-based weather resisitive barrier.*

barriers to abrasion, ASTM D3511 Standard Test Method for Pilling Resistance and Other Related Surface Changes of Textile Fabrics, Brush Pilling Tester Method was used to abraid the samples. The water resistance was measured by hydrostatic head before and after abrasion. The results in Fig. 21 show significant loss in water resistance in several of the film products, whereas the SBPO which is not dependent on a fragile film maintains its water resistance.

Ultra-Violet Exposure and Aging

Ultra-violet radiation and aging have been identified as a durability concern. Materials are subject to degradation and oxidation, and if they contain volatile components can become embrittled as these components are lost. The ICC-ES Acceptance Criteria for Weather-Resistive Barriers requires the following

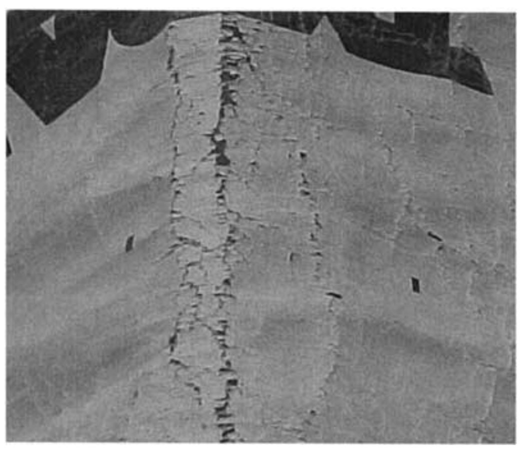

FIG. 16—*Film-based weather resistive barrier with film cracking at corner.*

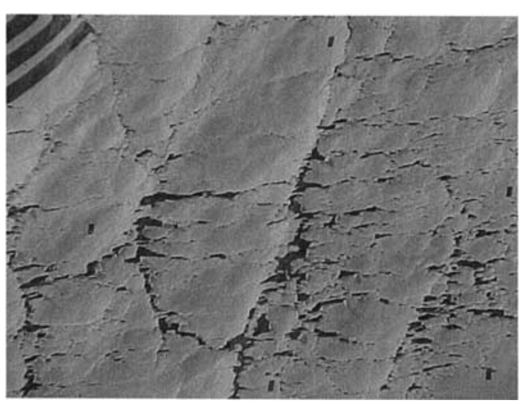

FIG. 17—*Film-based weather resistive barrier with film cracking and delaminating.*

FIG. 18—*Cracked and delaminated housewrap.*

UV exposure and accelerated aging procedure [1]. Samples are exposed to ultraviolet sun lamps for a total of 210 h at a rate of 10 h per day for 21 days. The exposure temperature for the samples was between 135 and 140°F. Immediately upon completion of the ultraviolet exposure; test specimens are subjected to 25 accelerated aging cycles:

- Oven drying at 120°F for 3 h with all surfaces exposed.
- Immersion in room temperature water for three hours with all surfaces exposed.
- After removal from the water, specimens are blotted dry before air drying for 18 h at a temperature of 75°F+/−5°F.

This procedure, as well as real time exposure to UV radiation, was used to evaluate the effect of UV radiation on the water resistance of weather-resistive barriers. Table 6 shows the response of asphalt impregnated building papers and felts as well as nonperforated (SBPO) housewraps to UV exposure. Water resistance before and after exposure was monitored using the ICBO hydrostatic head criteria of time to failure at 55 cm hydrohead. Significant loss of water resistance occurs with all the building papers and felts, while the SBPO housewraps exhibit no significant reduction in water resistance.

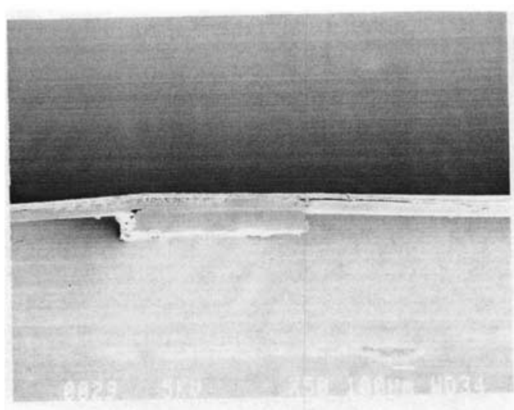

FIG. 19—*Scanning electron micrograph of partially delaminated weather resistive barrier.*

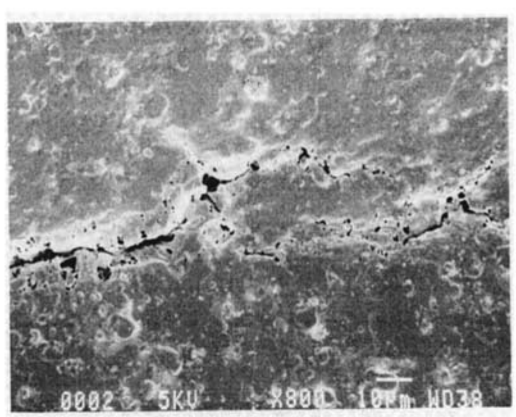

FIG. 20—*Cracking of film from stretching weather-resistive barrier.*

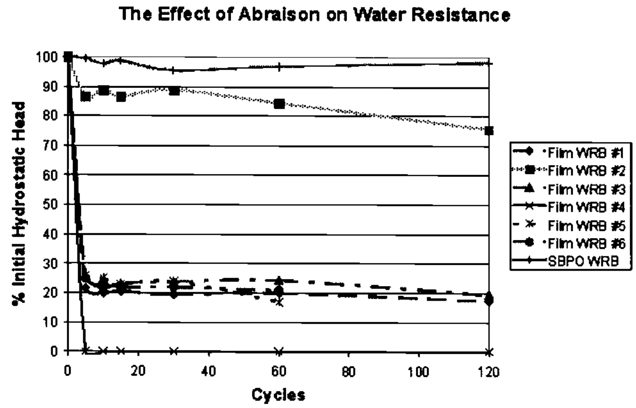

FIG. 21—*Loss of water resistance due to abrasion.*

Degradation in water resistance is also demonstrated in a test in which several weather-resistive barriers were exposed vertically outside in Richmond, Virginia for two weeks. Samples were exposed to UV radiation, diurnal temperature and humidity cycling, and some rain events. The modified AATCC35 water spray test was used to monitor changes in the water resistance of the weather-resistive barriers. The results show that the exposure resulted in significant reductions in building paper and felt water resistance (see Fig. 22). Scanning electron microscopy (Fig. 23) of building felt shows loss of asphalt as well as cracking of the asphalt. Previous research has noted a reduction in liquid flow through building papers which have been aged by real-time atmospheric exposure [11].

Weather-resistive barriers only experience significant exposure to ultraviolet light during construction. Most manufacturers of polymeric-based housewraps provide recommendations for the length of time their weather-resistive barrier can remain uncovered. Guidelines range from one month to one year. There is no uniform standard, however, to support these guidelines. Measurements of UV intensity of vertical surfaces at a real-time exposure facility for the months of July through December are shown in Table 7.

TABLE 6—*UV (ICBO Criteria) aging of weather-resistive barriers.*

	Time to failure (minutes) at 55 cm (AATCC127)[a]	
	As received	After UV exposure and accelerated aging
10 min Grade D Building Paper	13.6	8.0
60 min Grade D Building Paper	12.6	0.1
#15 Felt	58.4	8.2
SBPO #1	>300 min	>300 min
SBPO #2	>300 min	>300 min
SBPO #3	>300 min	>300 min
SBPO #4	>300 min	>300 min

[a]Average of three measurements.

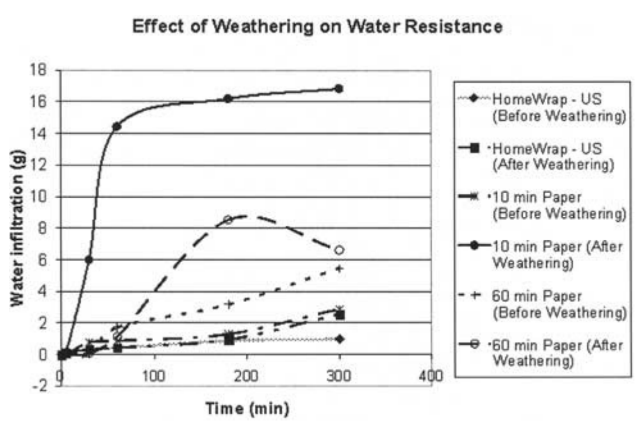

FIG. 22—*AATCC35 results of weather-resistive barriers before and after exposure.*

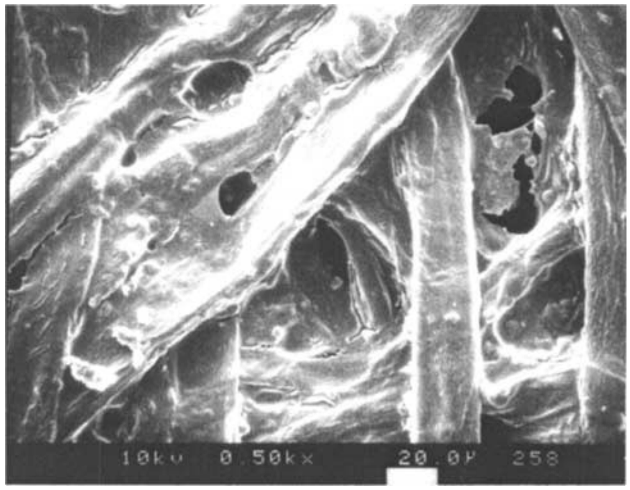

FIG. 23—*Scanning electron micrograph of exposed felt.*

Twenty-two mega-joules per square meter is the average amount of UV radiation seen in one month and could be used as a gage by which to standardize the real time exposure of several weather-resistive barriers.

The effect of UV exposure on polymeric-based weather-resistive barriers was evaluated using real-time exposure. The exposure level of the samples was monitored and the water resistance was measured by hydrostatic head per AATCC-127. The results in Fig. 24 show that film based materials are particularly vulnerable to loss of water resistance due to UV exposure. Scanning electron micrographs of the film-based products show that UV radiation causes embrittlement and cracking of the barrier film first on a microscopic level which ultimately leads to visible degradation of the film layer (see Fig. 25). It is important to note that significant loss of water resistance occurs during the microscopic cracking period before damage is clearly visible.

Cyclic Wetting and Drying—Cyclic wetting and drying as well as long term wetting have been sited as degrading asphalt cellulose based materials. Field studies have noted building paper rotting and disintegrating from long-term exposure to water [12–15]. Supporting these findings from the field is a laboratory study that shows that building papers and felts show a greater potential for mold growth than polymer-based weather-resistive barriers [16].

TABLE 7—*Monthly UV exposure of vertical surfaces.*

Q-Lab weathering research service—Arizona site						
Date	July 1999	August 1999	September 1999	October 1999	November 1999	December 1999
45′	34.57	34.72	33.49	33.09	25.83	19.71
Vertical Orientation[a]	23.13	23.23	22.40	22.14	17.28	13.19

[a]Calculated from average exposure relationship of 0.669 between 90′ (vertical) and 45′ orientation.

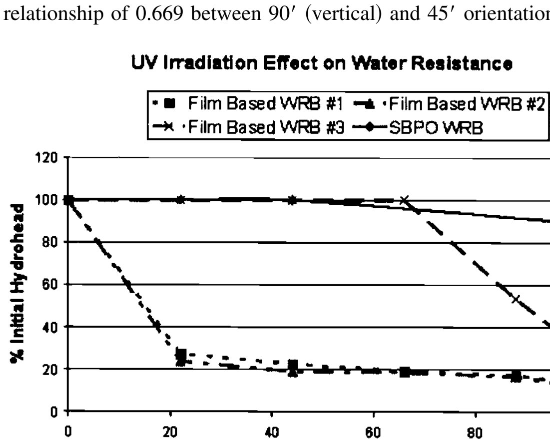

FIG. 24—*Loss of water resistance after UV exposure.*

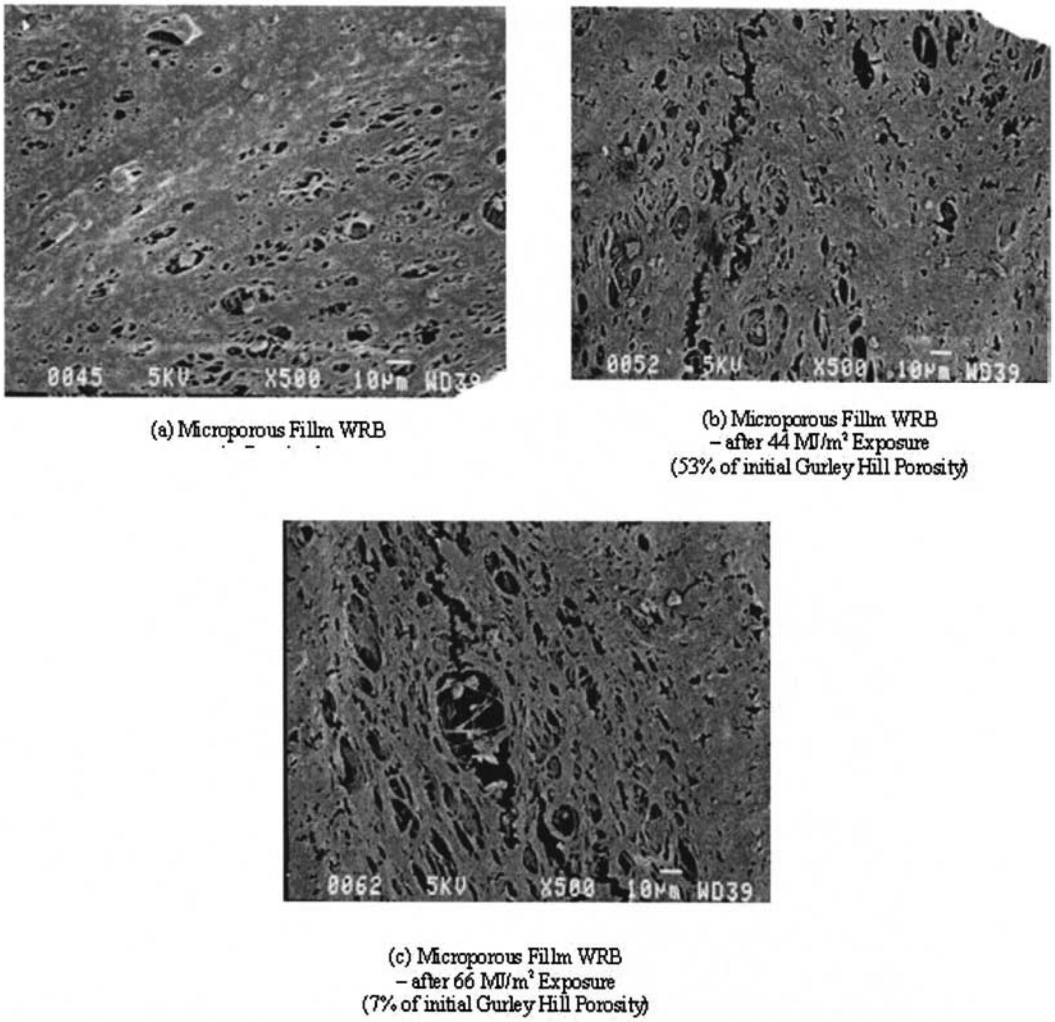

FIG. 25—*Film degradation from UV exposure.*

When building papers and felts are exposed to water or even high humidity they will wrinkle putting stresses on fasteners. Figure 26 shows ripping at a staple attaching building paper to a stud which occurred during laboratory testing including water spray exposure and thermal cycling. Cyclic wetting and drying have little to no effect on polymeric-based weather resistive barriers as they do not generally absorb water.

Loss of Water Resistance because of Exposures to Surfactants—There has been speculation in the trade about the loss of weather-resistive barrier water resistance due to surfactant exposure including wood extracts from cedar and detergents. No standard test method exists to evaluate this situation. Exposure is

FIG. 26—*Ripping at staple occurring during moisture and thermal cycling of building paper.*

TABLE 8—*Summary of water resistance testing.*

Weather-resistive barrier type	ASTM D779 (Boat Test) min	AATCC-127 (hydrostatic head) cm	AATCC35 (60 min, 2 ft. column intensity) g H_2O	AATCC35 (480 min, 3.5 ft. Column intensity) g H_2O
Perforated Polymer-Based	0.5 to 10	10 to 27	2.8 to >5	not tested
Non-Perforated Polymer-Based (SBPO)	19.6 to 304	>210 to >280	0 to 0.3	0.8 to 1.9
Non-Perforated Polymer-Based (Film Laminate)	Not tested	130 to >180	Not tested	Not tested
Paper-Based	10 to 60	65 to 103	0.3 to .6	7.9 to 13.5
Felt-Based	not tested	59 to 80	0.1	1.4

highly situational and it is difficult to imagine a single criterion will be developed. Two research studies have been published. In one test the several weather resistive barriers were exposed to cedar extract liquids and then had their water resistance measured via AATCC-127 hydrostatic head. The results showed exposure to the liquid cedar extract had no effect on the water resistance after removal from the solution. Drying and subsequently depositing the extract on the weather-resistive barriers, however, did result in loss of water resistance across all types (felt, SBPO, film, and perforated) of weather-resistive barrier [16]. The SBPO housewraps in this study exhibited the highest water resistance either before or after the cedar extractive deposition. The other study utilized a 3 1/2 in. column of water containing various surfactant solutions [17]. Perforated housewraps were eliminated from the study because they failed this column test under water with no surfactants added. The results showed the initial water resistance with nonperforated (SBPO and film) WRBs did not leak any water from the column. The second best performer was felt losing about 30 % of the column water over the two hour test period. When a soap solution was used in place of water the nonperforated housewraps both lost about 10 % of the column height in 2 h. When a cedar solution was used the nonperforated wraps lost approximately 3 % in the 2 h.

Conclusions and Recommendations

This paper presents a review of factors influencing the water resistance of weather-resistive barriers. There is a wide range in water resistance of weather-resistive barriers and wide range of water resistance measurement methods. Table 8 summarizes the water resistance of the major kind of products by each of the major test methods, including results from a small scale spray test which was investigated in this study. Perforated polymeric weather-resistive barriers show lowest water resistance on all tests.

There is a strong need to develop a more standardized evaluation method which can be applied across the different types of weather resistive barriers. AATCC-35 is a water spray test that is suitable for the evaluation of small samples. It is an attractive method because it simulates rain exposure and is especially resonant with exposures during construction. The small scale spray test has the additional advantage that it can be used to characterize water absorption of weather-resistive barriers in addition to water transmission. AATCC35 should be evaluated and further developed as a method for evaluation weather resistive barriers.

The water resistance of weather resistive barriers can be reduced by a number of environmental exposures.

- Laminated film products are the most sensitive showing significant reduction in water resistance from abrasion, mechanical handling, UV radiation, and thermal exposure.
- Building papers and felts depend on their asphalt component for water resistance and loss of the asphalt due to volatilization or leaching produces a loss in water resistance. Building papers and felts exhibit significant loss of water resistance from UV exposure, and are deteriorated by continual exposure to water.

Test methods should be developed to standardize the evaluation of weather-resistive barriers to UV exposure, thermal exposure, long term wetting, and mechanical handling. Water resistance should be evaluated after exposure in addition to being measured on new materials.

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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^2·24h), 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^2·24h) 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^2·24h), Grade D, 35 minimum, tested by FS UU B 790a using UU P 31b, Method 181	Average WVT, (g/m^2·24h), 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^2·24h) 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.

References

[1] AATCC *Test Method 127*, American Association of Textile Chemists and Colorists (AATCC), PO Box 12215, Research Triangle Park, NC 27709, 919-549-8141, FAX: 919-549-8933, www.aatcc.org.

[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.

[4] AC38 Acceptance Criteria for Weather-Resistive Barriers, Published by ICC Evaluation Service, 5360 Workman Mill Road, Whittier, California 90601, 562/699-0543, Fax: 562/695-4694, www.icc-es.org.

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Adhesive Characterization & Durability of Self-Adhered Flashings

ABSTRACT: Self-adhered flashing products can very effectively maintain a durable moisture-tight seal at the window-wall interface, which is highly vulnerable to moisture intrusion. However, it is essential that these products be installed under conditions where adequate adhesion to the substrate is achieved. Also, the self-adhered flashing products must have thermal durability and dimensional stability to maintain their performance at the high temperatures that can exist behind siding. This study gives a preliminary adhesion characterization assessment of six self-adhered flashing products, three with modified-asphalt based adhesives and three with butyl based adhesives, onto several common building substrates and installed at a range of temperatures, including moist and dusty conditions. What is found is that the butyl based adhesive systems have a broader window of installation surface conditions and temperatures where "adequate adhesion" is achieved without the use of a primer than the modified-asphalt based adhesive products. Also, a thermal aging study shows that the butyl based adhesive products are more thermally stable than the modified-asphalt based products at typical temperatures behind siding. Also, film topsheets are more prone to deformation and curling after thermal aging than nonwovens composite or foil laminate based topsheets.

KEYWORDS: construction, water management, flashing, sealants, windows, buildings, durability, adhesives

Introduction

Moisture problems in buildings can arise from several sources, but the window-wall interface has been shown to be one of the most critical factors for water intrusion. In a recent report by RDH Building Engineering Limited in Canada [1], a wide variety of window types and assemblies were tested for leakage, using six potential leakage paths for water intrusion. Although water leakage was found to some extent in all of the leakage paths, the "through window to wall interface to adjacent wall assembly" leakage path was the most prevalent for all of the window types tested and had a high risk of consequential damage to the building. The causes for this are many, but improper flashing installation and over-reliance on building sealants were noted consistently as contributing effects in this report. In addition, the Durability by Design guideline published by the Partnership of Advancing Technology in Housing (PATH) reports that "most leakage problems are related to improper or insufficient flashing details or the absence of flashing" [2].

The use of self-adhered flashing products is becoming more widespread as the installation and performance advantages over building sealants and non-adhered flashing products are realized. The PATH Durability by Design guideline noted above states that "caulks and sealants are generally not a suitable substitute for flashing." Recent studies have shown that, if properly installed, self-adhered flashing products are highly effective in protecting the window-wall

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interface for various windows shapes and designs [3,4]. These studies also showed that the butyl adhesive based self-adhered flashing products tested maintained an effective moisture seal through accelerated environmental exposure and when installed under cold and hot conditions.

Thus, the water-tight seal and installation ease provided by self-adhered flashings offer significant advantages over non-adhered/mechanically fastened flashing products and building sealants. However, self-adhered flashings products have not yet been broadly accepted into Codes and Standards, due to valid concerns. Specifically, the adhesive bond, which is essential for the self-adhered flashing to maintain a moisture seal, is not universally sufficient for the various types of self-adhered flashing products on various building substrates, particularly under adverse installation conditions, such as on wet, cold, and dusty surfaces. Also, adhesion to different types of sheathing materials and weather-resistive barriers has not been well characterized for the different types of flashing materials. There is no standard for minimum adhesion and/or performance for self-adhered flashing products that will provide guidance to the industry on how to properly use these products, although this is currently under development by an American Architectural Manufacturers Association (AAMA) task group. This study reports adhesive characteristics for common self-adhered flashing products under a range of installation conditions and substrates for both butyl and modified asphalt based adhesive systems. Also, conditions where a primer is necessary to achieve an 'adequate' bond will be evaluated.

In addition to adhesion, another primary concern with the use of self-adhered flashing products is the durability of these products after extended environmental exposure. It has been shown that there are significant differences in the performance of self-adhered flashing products, particularly in terms of resistance to heat and UV exposure. A recent study compared the UV aging performance of common modified-asphalt adhesive based products to butyl adhesive based products, as well as the adhesive durability of these products after exposure to water per the American Architectural Manufacturers Association (AAMA) Voluntary Specifications and Test Methods for Sealants (AAMA 800) adhesion durability test [5]. This study showed that the physical integrity after UV aging and the adhesion retention after moisture exposure for the butyl based products were superior to the modified-asphalt based products. However, while it is clear that UV resistance for the self-adhered products is necessary for the period between the installation of the window and siding, another key concern is how these products perform *after* the siding is installed. In this case, the self-adhered products are not visible, but are still essential to maintain a water-tight seal at the window-wall interface. Temperatures behind siding on a warm (29ºC/85ºF), sunny day can easily exceed 70ºC (158ºF) – will the self-adhered flashing still be effective after long periods of time under this exposure? In a review of commercially available self-adhered flashing products, it was noted that during hot weather exposure, butyl products are preferred to modified-asphalt based products, which can ooze at high temperatures [6]. This study presents illustrations on the condition of these products after typical heat exposure.

Product Testing

Background

Self-adhered flashing products are broadly utilized in building construction to provide a moisture seal between joints, such as at the window-wall interface. Therefore, these products are expected to sufficiently adhere to a wide variety of substrates, such that a durable moisture seal is maintained for the life of the joint. As noted above, no Standard has yet been established to define adequate adhesion and durability for self-adhered flashings. We have generated data to help initiate this discussion and to identify a rough framework where self-adhered flashings provide an adequate seal without the help of a primer (which adds substantial cost in both installation costs and materials) and where they do not. It is important to note, however, that the term 'adequate seal' has yet to be validated with end use testing. This study also presents the conditions of self-adhered flashing products after thermal aging exposure, to illustrate product durability under common conditions in use.

Self-adhered flashing products generally consist of three specific components: 1) the adhesive, 2) the topsheet, and 3) the release paper. The function of the adhesive is to provide the moisture seal between the window-wall interface over the life of the joint. In general, self-adhered flashing adhesives are of two types: modified-asphalt/bitumen based and butyl adhesive based. The top sheet's function is to give integrity to the finished flashing product, provide dimensional stability under temperature extremes, and protect the adhesive from the effects of UV exposure in sunlight. It also protects against handling damage and tearing during installation. Dimensional stability is clearly needed to prevent channels from forming during service that can lead to leaks. There is a wide variety of topsheets available, but these can be generally categorized as film, foil based laminate, or multicomponent nonwoven laminate. The release film is used to protect the adhesive before installation and prevent blocking when packaged and stored in a rolled form.

In this study, we have chosen representative flashing products with both modified-asphalt and butyl adhesive systems. Modified-asphalt samples in the Adhesive Characterization study all had film topsheets, but the butyl adhesive samples had a variety of topsheet systems as indicated in Table 1.

The product testing portion of this report is divided into two parts: Adhesive Characterization and Thermal Exposure. The same self-adhered flashing products are used in both studies, except that a film/foil laminate topsheet replaces one of the film topsheet modified-asphalt samples in the Thermal Exposure study to illustrate the effect of this type of topsheet.

Adhesive Characterization

Experimental Method—To give a broad representation of self-adhered flashing products for adhesion characterization, six different self-adhered flashing products were chosen for this study. Three of the products have modified-asphalt based adhesives, and three have butyl adhesives. These products, along with topsheet type, are summarized in Table 1.

TABLE 1—*Self-adhered flashing products used in adhesion study.*

Sample ID#	Adhesive System	Top Sheet
A-1	Modified asphalt	Film
A-2	Modified asphalt	Film
A-3	Modified asphalt	Film
B-1	Butyl	Elastomeric nonwoven composite
B-2	Butyl	Nonwovens composite
B-3	Butyl	Film

These products were tested for adhesion performance on substrates commonly found in building materials and various installation conditions. The building sheathing materials used in this study are oriented strand board (OSB), concrete block, painted steel, and fiberglass coated sheathing board. Adhesion to polyvinylchloride (PVC) strips was also tested to simulate a common material used for window flanges. It is also very common for self-adhered flashing products to be applied directly to building paper or house wraps (“Weather-Resistant Barriers”). However, peel adhesive values of self-adhered flashing to these substrates can be misleading, because the failure mode is often due to tearing or delamination of the WRB or building paper rather than adhesive or cohesive failure of the flashing adhesive. Thus, these products were not included in this initial study.

The adhesion tests were run for all substrates at three different temperatures to simulate the range of installation conditions that are commonly employed. In the case of OSB board, various methods for wetting the substrate were done to simulate a “wet” surface. Also, a “dusty” OSB surface was tested for all self-adhered flashing products, to simulate potential “real-life” conditions found in the building industry. Table 2 summarizes the substrates and conditions; more details of substrate and sample preparation and test methods are given below.

Flashing Sample Preparation—Peel adhesion measurement of individual samples was done per ASTM D 3330 F standard for 90º peel adhesion. Samples were prepared using a 1 kg (2.5 lb) roller that was rolled back and forth across each specimen (1 cycle) at 30 cm/min. One notable exception was that the roller had the hard steel face without the rubber coating, which is found to give better lamination with the flashing in prior studies. A two roller fixture (per ASTM D 3167) was used to maintain a constant peel angle over the length of the sample. The flashing products were cut into 25 mm (1 in) × 200 mm (8 in.) strips for testing with the 20 cm in the roll (machine) direction except for sample B1, where the 200 mm was in the width (cross) direction to minimize stretching during peel. Sample B1 is designed to elongate up to 150 % in the machine direction, so testing in the cross direction provides results consistent with the other products. Each test condition represents five replicate samples.

TABLE 2—*Substrate and installation conditions for adhesive characterization tests.*

Substrate	Installation Temperatures Tested (ºC)	Moisture Level (other than dry)	Primed surface	Dusty
Oriented Strand Board (OSB)	-4, 27, 38	1) equilibrated to 15 % moisture content 2) spray/misted for 1 h 3) spray/misted for 1 h, then wiped with dry towel	1) at -4ºC 2) at 27ºC after spray/misted and wiped	At 27ºC/dry surface only
Concrete Block	-4, 27, 38	Not tested	1) at -4ºC 2) at 27ºC	Not tested
PVC	-4, 27, 38	Not tested	Not tested	Not tested
Steel with rust-proof paint	-4, 27, 38	Not tested	Not tested	Not tested
Fiberglass coated sheathing board	-4, 27, 38	Not tested	1) at -4ºC 2) at 27ºC 3) at 38ºC	Not tested

Substrate Preparation—The substrates used in this study were cut from larger samples, sheets or blocks, into test strips. The flashing samples were then applied to the substrates for adhesion testing. "Type 1" PVC strips were cut from 600 mm × 1200 mm × 3 mm sheets on a shear to 30 mm × 200 mm test strips. The surface was wiped free of any dust or dirt prior to laminating. Cold roll steel 1.6 mm thick was cut on a shear to 30 mm × 200 mm strips. These were solvent washed with acetone and dried. Samples were corrosion treated with "Rustoleum," flat black, industrial grade, spray paint. Construction grade concrete block was purchased from a brickyard as nominal 50 mm × 200 mm × 400 mm blocks. These were sliced, using a waterjet, into nominal 32 mm × 200 mm strips for testing. Concrete was primed for testing using 3M HS90 spray adhesive; 5 min (10 at -4ºC) were allowed for the primer to cure prior to laminating. Nominal 12.5 mm OSB was purchased from Home Depot. This was cut into ~30 mm × 200 mm test strips with the 200 mm strip in the 2400 mm board direction. The samples were cut on a standard table saw, and pieces with excessive printing or splashes of edge paint were avoided. The samples were adhered to the 'smooth' side of the OSB. Samples were primed as above with 3M HS90. Densglass Gold® fiberglass faced sheathing produced by Georgia Pacific was purchased from a contractor supply yard. Each sheet was cut into 8 squares for shipping using a panel saw and subsequently cut using a table saw into nominal 30 mm × 200 mm test strips with the 200 mm strip in the 2400 mm sheet direction. All samples were made using the outside (yellow) surface.

Samples of both substrate and flashing for testing at room temperature were conditioned at 27ºC, 50 % RH lab for at least 2 weeks prior to testing. A concrete block was cut wet and was dried for one month, ensuring equilibrium with the 27ºC, 50 % RH environment. Samples for testing at -4ºC or 38ºC were made by conditioning the substrate material (already conditioned to 27ºC, 50 % RH) in a chamber at test temperature with high air flow for about a day (at least overnight). They were then laminated with flashing that was conditioned to room temperature and then returned to the chamber for 24 h prior to testing.

OSB test strips were conditioned a number of ways reflecting real-life conditions:

Rain Misted—Samples were exposed to a light drizzle for 1 h at an outside temperature of about 18ºC. After wetting, samples were warmed to room temperature, then laminated and stored at room temperature for 24 h. The same degree of wetting could be achieved without the cooperation of the weather by misting the samples with a mister for several seconds every 10 min over 1 h. This visually provided the same amount of water beaded on the surface and a similar amount of water pickup. Most of the test items were prepared during a day-long light steady drizzle, but a few were satisfactorily prepared in the lab.

Rain Misted and Wiped—Some of the above samples were blotted with a paper towel prior to lamination. Note that in some cases the rain beaded on the coating on the OSB, but the blotting pushed some water into the surface.

Rain Misted, Wiped, and Primed—Some of the above samples were sprayed with 3M HS 90 and allowed 5–10 min to cure prior to lamination.

Equilibrated to ~15 % Moisture—By trial and error, it was determined that this weight gain could be reproducibly achieved in a humidity chamber with 38–40ºC temperature and 90–95 % RH. Weight gains were found to be stable from about 40 to over 100 h; samples were typically given 48–72 h exposure. After exposure, samples were cooled to room temperature, then laminated. Laminated samples were sealed in a film bag and stored at room temperature for 24 h. Note: soaking OSB in water to get 15 % pickup led to excessive delamination of the surface strands and water pickup in the many voids. Using hot humid exposure eliminated these problems.

Dusty OSB—These samples were prepared by shaking the set of 5 specimens in a 5 gal trash bag about 20 % full of saw dust, collected below a table saw. The specimens we shaken for 1 min, then removed, tapped together a few times to remove large pieces, and laid on a table test side up. The samples had a considerable amount of dust on them. A can of "Dust-Off" compressed "air" was used with the nozzle tube to lightly blow off the test surface. The surface was visually dust free after this process, although all of the pores and groves contained dust. The samples were then applied to the substrate and stored at room temperature for 24 h and then tested for peel adhesion.

Definition of Minimum "Adequate" Adhesion—As stated previously, there is no established standard to define an "adequate" adhesion value that corresponds to a sufficient bond between a self-adhered flashing and a substrate. In this study, a "minimum hurdle" of 4 N/cm (2.2 lb_f/in.) is utilized as "adequate" adhesion to a substrate. This was based on two factors. First, there was a subjective evaluation of the force it takes to pull the flashing from the substrate, whereas 4 N/cm were determined to provide sufficient "resistance" for what was deemed a "good bond." Secondly, adhesive failure can be characterized through four general mechanisms: 1) interfacial/adhesive failure, where the adhesive peels "cleanly" from the substrate, leaving no adhesive on the substrate surface; 2) cohesive failure, where the adhesive itself tears apart, leaving some adhesive on the substrate surface; 3) topsheet failure, where the bond between the topsheet and the adhesive fails, leaving all or most of the adhesive on the substrate surface; and 4) substrate failure, where the adhesive pulls off portions of the substrate surface. In many cases the mode of failure is a combination of these mechanisms. However, in general, samples that failed either cohesively or by topsheet failure had strong adhesion to the substrate (enough to tear the adhesive apart or the bond to the topsheet). Conversely, samples that had interfacial adhesive failure generally had a relatively weak bond to the substrate. Samples that exhibited substrate failure were of mixed strength, depending on the degree of bonding of the substrate surface (in general, weak). Peel adhesion values on samples that showed 100 % interfacial failure were generally below 4 N/cm, which is another rationalization for this 'minimum adhesion hurdle' of 4 N/cm.

Adhesive Characterization Test Results

The average peel load is used as the comparative "peel strength" of each sample, which is the average of 5 replications. One exception to using the average peel load was for -4ºC on painted steel and PVC sheet. This condition exhibited brittle interfacial failure that resulted in intermittent loading, and results were reported through an 'average of peaks' method. This failure mode results when the fracture propagates faster than the specimen is loaded.

Adhesion to Dry OSB—Oriented Strand Board (OSB) is one of the most common building substrates used today in residential construction. Self-adhered flashing products are often bonded directly to the OSB sheathing. However, there are many different manufacturers of OSB that produce a wide range of product, which have widely different surface characteristics. In this test, the same standard OSB product was used for all self-adhered flashing materials for consistency in the surface characteristics. Variability also exists from the non-uniformity of the surface. The size and orientation of the wood strands varies constantly across and along the OSB. Peel data were collected and averaged over about 150 mm (5 replicates at 30 mm each) to account for these properties.

Test results on dry OSB are indicated on Fig. 1. Data are shown at -4ºC, -4ºC with primer applied, 27ºC, and 38 C for the six self-adhered flashing products tested. All products installed under cold condition (-4ºC) on dry, unprimed OSB showed interfacial "adhesive" failure with very low peel adhesion values (less than 2 N/cm). However, when the OSB surface is primed, all of the flashing products gave very strong peel adhesion values, with many showing topsheet lamination failures, which means the adhesive stuck to the OSB better than to the topsheet. Thus, it is clear that installing self-adhered flashings on OSB at this low temperature requires a primer application, which enhances the adhesion more than adequately for all products (at least for the primer used in this study).

The peel adhesion values on dry OSB at 27ºC have differential results. In this case, two of the modified-asphalt based flashing products did not have adequate adhesion, whereas all of the butyl based adhesives were above 8.0 N/cm, demonstrating some cohesive failures. Thus, this is a case where the use of a butyl based adhesive gives adequate adhesion to OSB without a primer, whereas most of the modified-asphalt based adhesives need a primer for adequate adhesion. A similar result is seen at 38ºC on dry OSB, with all butyl based products having adequate adhesion, but the modified-asphalt based products are barely adequate.

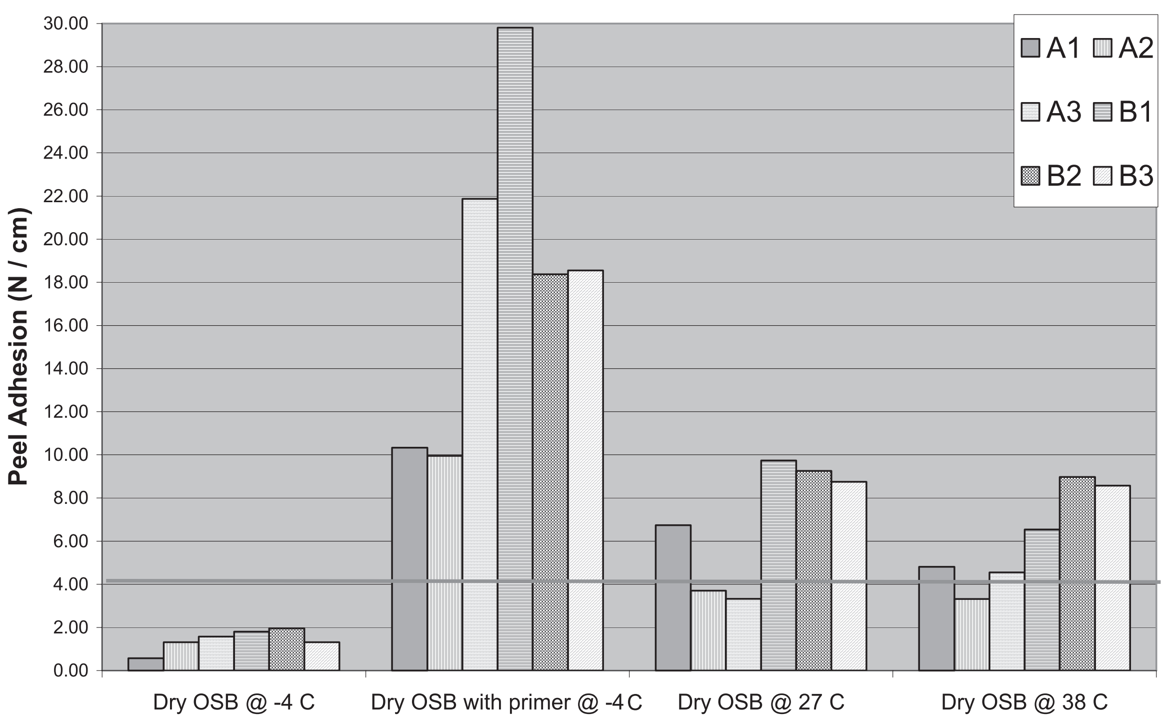

FIG. 1—*Adhesive of self-adhered flashing products to dry OSB.*

Adhesion to Wet and Dusty OSB—It is often the case that windows and flashing products are installed under non-ideal conditions, particularly to wet or dusty surfaces. Therefore, peel adhesion tests were run under simulated wet and dusty conditions onto OSB for the six self-adhered flashing products in this study. The results are shown on Fig. 2.

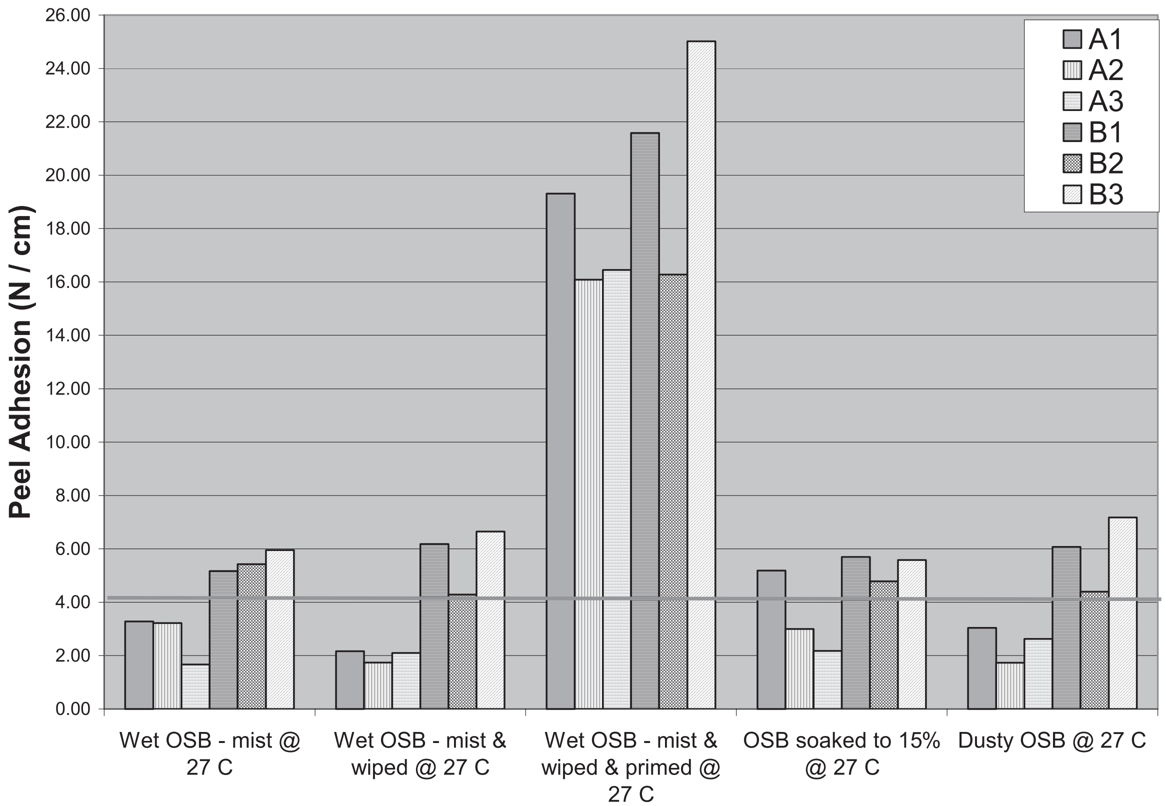

FIG. 2—*Adhesion of self-adhered flashing products to wet and dusty OSB surfaces.*

The data indicate that the adhesion of the modified-asphalt based flashing products to misted and equilibrated 15 % moisture content OSB (with only one exception for the 15 % OSB) were well below the level of 'adequate adhesion' with clean, interfacial peels. However, all of the butyl adhesive based products were above the 4 N/cm adhesion hurdle. The failure mechanism for the butyl adhesives, in many cases, is pulling 'splinters' off of the face of the OSB board, which is a "substrate failure" mechanism, as described above.

Note that for all flashing samples, the addition of primer to the wet OSB surface produced very strong adhesion. Thus, on unprimed wet OSB surfaces, the butyl adhesive samples performed better than the modified-asphalt samples. But in all cases, the addition of primer made the adhesion very sufficient.

Results for dusty OSB surface are very similar to the wet OSB surface. The modified-asphalt based samples did not have adequate adhesion, with values around 2 N/cm, whereas the butyl based flashing products were all above 4 N/cm, and two were above 6 N/cm. Thus, once again the butyl based adhesives proved adequate without the use of a primer, but the modified-asphalt based products did not. The failure mechanism for all samples is primarily interfacial adhesive, although the adhesive did appear "dusty," which is by definition some substrate failure.

However, the butyl based products exhibited more substantial "surface failure" with some OSB splinters pulled from the surface. Although this was not tested, it is fully expected that addition of a primer to the dusty OSB surface would have resulted in excellent adhesion for all flashing products, with results comparable to primed OSB on a dry surface.

Adhesion to Concrete Block—Concrete block construction is common in commercial buildings as well as in residential construction in hurricane prone locations. Self-adhered flashing products are used on concrete block walls to create a moisture seal at the window-wall interface and to protect the wood buck insert in the opening. Peel adhesion was tested for the six self-adhered flashing products on concrete block; data are shown on Fig. 3.

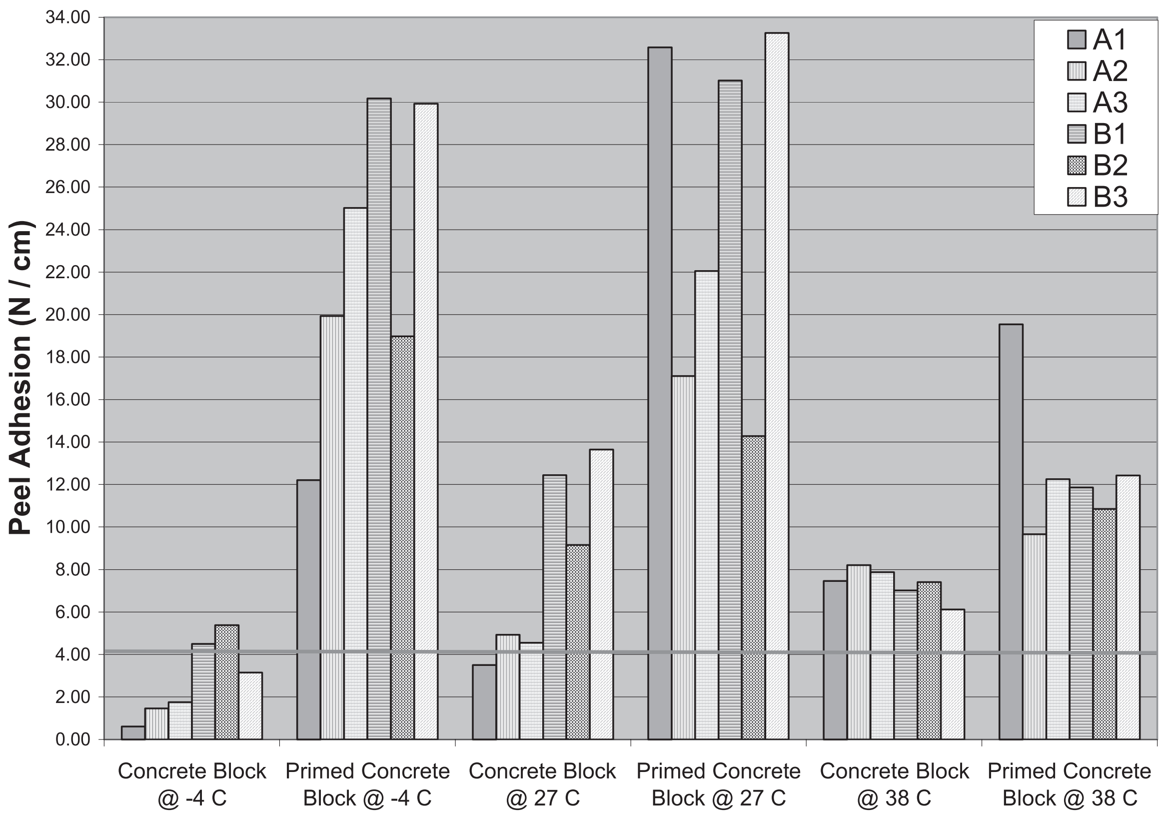

FIG. 3—*Self-adhered flashing adhesion to Concrete Block at various temperatures.*

The concrete block adhesion tests were run at three temperatures: -4º, 27º, and 38ºC, both on bare block and with primer added at all temperatures. The low temperature data show very low adhesion values for the modified-asphalt based products, all below 2 N/cm with interfacial adhesion failure, whereas two of the butyl based products have barely "adequate" adhesion with just over 4 N/cm. When a primer is added, however, all flashing products have excellent adhesion with topsheet or cohesive failure mechanisms. A similar result is seen at 27ºC. Here, the modified-asphalt based samples are 'barely adequate,' with about 4 N/cm peel adhesion and a mixed interfacial/surface ("dust") failure mechanism. However, the butyl based products were quite good, with adhesion values over 8 N/cm without primer. Once again, when primer is used, all products showed excellent adhesion. At 38ºC, all flashing products showed adequate adhesion to concrete block, without primer, with very little differentiation between them.

Adhesion to PVC and Painted Steel—As noted above, rigid PVC is commonly used as flange material on windows. Steel coated with rust-proof paint is a common building material in commercial construction. Adhesion data for self-adhered flashing products on PVC and painted steel are indicated on Fig. 4. Tests were run at all three temperatures, but in this case no primer was used. The results for painted steel are different than what has been observed for the other substrates tested thus far, particularly at low temperature (-4ºC). In this case, the modified-asphalt based adhesive samples have generally higher adhesion values than the butyl adhesive based products, with only one of the butyl based products having "adequate" adhesion. At higher temperatures, however, the products are less differentiated, and all have very sufficient adhesion values.

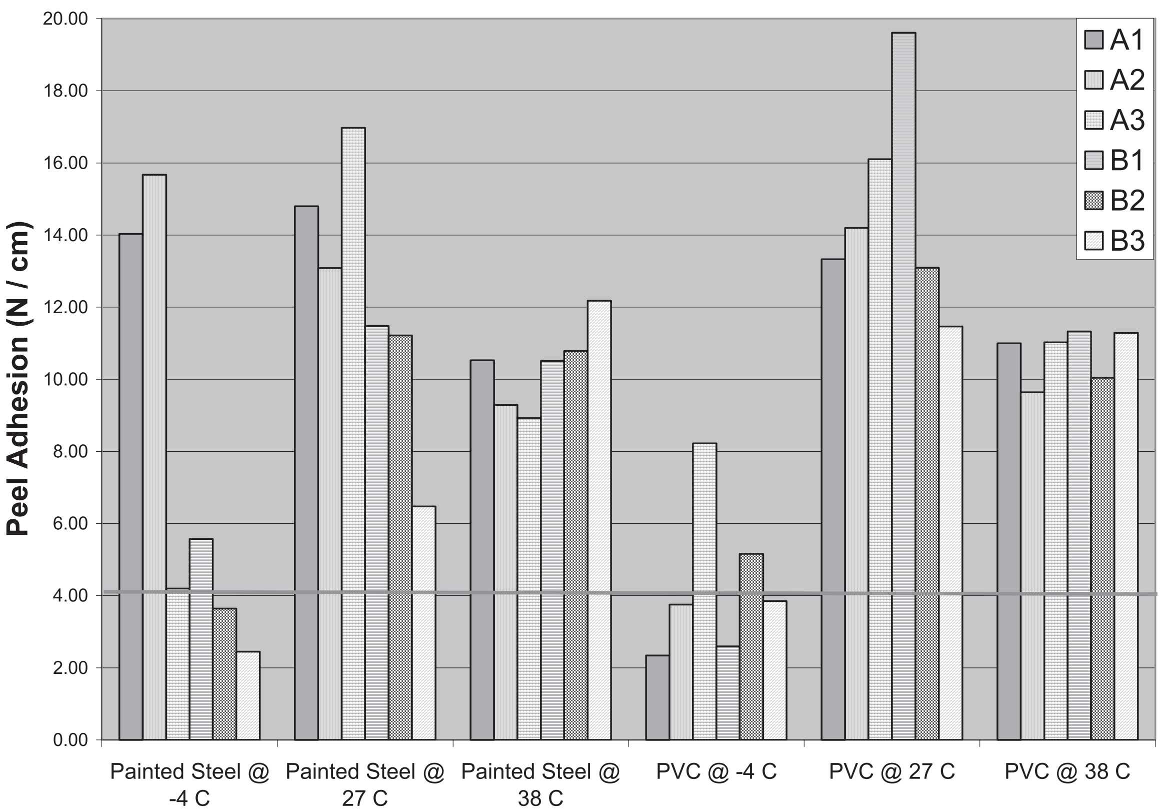

FIG. 4—*Adhesion of self-adhered flashing products to rigid PVC strips and painted steel.*

The adhesion to rigid PVC strips at low temperature (-4ºC) have mixed results, with some products showing adequate adhesion, while others did not. It is important to note that at this condition, the samples show "stick-slip" failure mode, which is brittle interfacial failure that results in intermittent loading. Thus, the data are reported through an 'average of peaks' method. This failure mode results when the fracture propagates faster than the specimen is loaded. This is also the case on painted steel samples at low temperature. However, two of the asphalt-based products did appear to have superior adhesion at low temperatures to painted steel, but due to the 'stick-slip' failure mechanism, this may be somewhat distorted. The adhesion results for PVC at higher temperatures (27ºC and 38ºC) have very good adhesion for all samples, both with modified-asphalt and butyl adhesives.

Thus, it can be generally concluded that the self-adhered flashing products have good adhesion to PVC and painted steel without the use of primer, particularly when applied at temperatures above freezing.

Adhesion to Fiberglass Coated Sheathing—Fiberglass coated gypsum sheathing board is commonly used in commercial construction. This sheathing presents special challenges for self-adhered flashing products, as well as other adhesive products, due to the loosely bonded fiberglass, which readily pulls away from the surface, causing a "sheathing failure" mechanism at low peel force. Figure 5 illustrates this effect for the self-adhered flashing substrates on fiberglass sheathing board. At all temperatures tested, the peel adhesion values for the unprimed surface are low, with 'sheathing failure' the dominate mechanism, although at the highest temperatures (38ºC), some butyl adhesive products are "barely adequate." Fibers from the fiberglass sheathing are visible on the surface of the adhesive as it is pulled away from the board. On the other hand, if the fiberglass surface is bonded with the spray adhesive primer, then the surface is much more resistant to delamination, and the peel adhesion values are very high. This phenomenon was seen for all products at all temperatures tested.

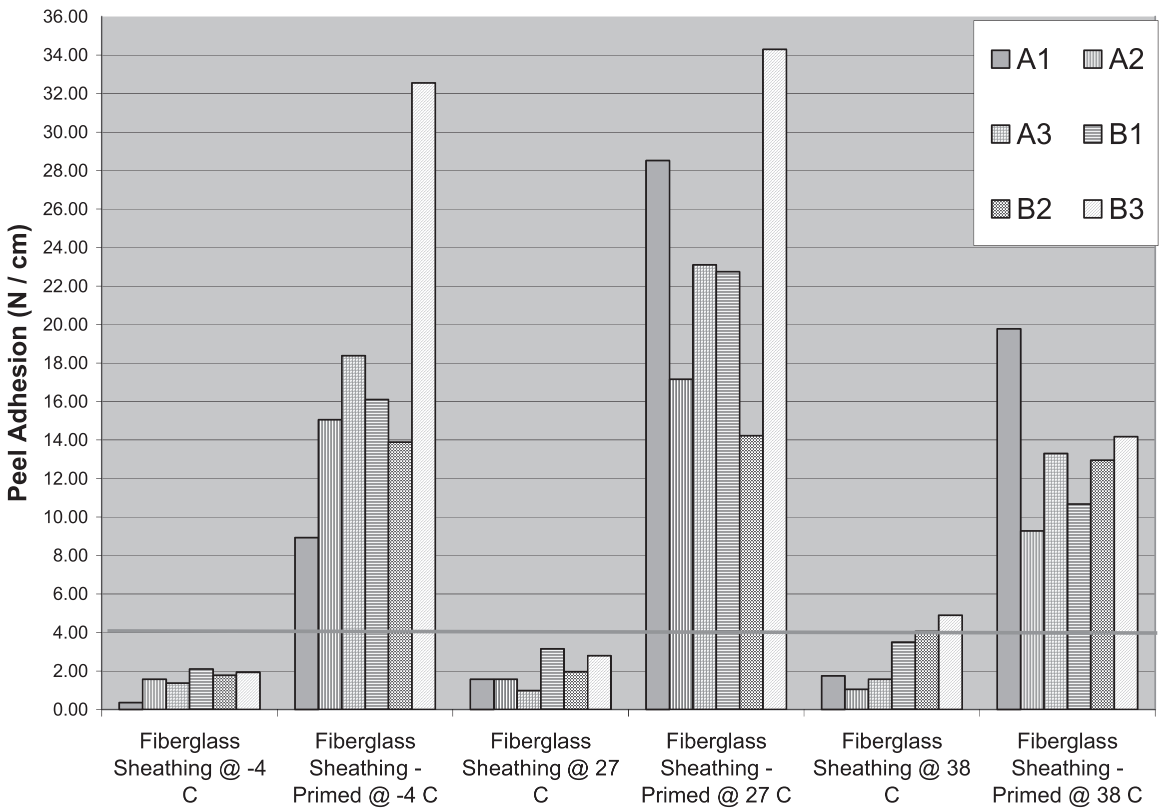

FIG. 5—*Adhesion of self-adhered flashings to fiberglass sheathing board.*

Thermal Aging Tests

Temperatures behind a wall with grey colored, cedar siding on a sunny 29ºC day in California were measured to be 77ºC (170ºF) and can thus easily exceed 80–85ºC on very hot days (above 30ºC). Therefore, self-adhered flashing products must be thermally and dimensionally stable at these temperatures over long exposure times. This is an essential, but 'hidden,' characteristic of self-adhered flashings, since once the siding is installed, they are no longer visible.

Experimental Method—Self-adhered flashing samples were applied to bare OSB sheathing and OSB wrapped with spun bond polyolefin housewrap in preparation for thermal aging. The products tested were the same as those in the *Adhesion Characterization* test description above, with the one exception that one of the modified asphalt-based adhesive products (A1) was replaced with a modified-asphalt adhesive product that has a foil laminate topsheet. This was done to illustrate the effect of the topsheet on the thermal aging performance of the laminate. Thermal aging was done in a standard air circulating oven at 70ºC (158ºF) for 14 days to simulate heat exposure behind siding on a wall.

Thermal Aging Test Results—The six self-adhered flashing products before thermal aging exposure are shown on Fig. 6 (on OSB) and Fig. 7 (on spun bond polyolefin housewrap). The three products on the left are butyl based adhesive flashing products; the three products on the right are modified asphalt-based adhesive products (A1 is replaced with a foil laminate topsheet). The products were then heat aged in an air circulating oven at 70ºC (158ºF) for 14 days; results on bare OSB are shown on Fig. 8. The effect is quite dramatic. Note how the topsheets of two of the modified-asphalt base products, particularly the one in the center, have curled back and exposed the modified-asphalt adhesive, which in the middle sample has oozed and exposed bare OSB in spots. The product with the foil laminate, however, has remained dimensionally stable, indicating that the topsheet (the other two samples had film topsheet) has a significant effect on stability. For the three butyl-adhesive based samples (on the left), no curl back of the topsheet is noted. However, the sample with the film topsheet has formed 'wrinkles,' under which are open channels for water intrusion. This effect is better illustrated on Fig. 9, which provides a side view of the three butyl-adhesive based samples. The nonwoven composite samples, however, do not have any "channeling," and therefore demonstrate enhanced dimensional stability after this heat exposure compared to film topsheets. This again demonstrates the importance of a durable topsheet on the self-adhered flashing laminate.

The self-adhered flashing products heat aged on spun bond film housewrap wrapped on OSB are shown on Fig. 10. In this case, the topsheet curl back effect is also evident for the modified-asphalt adhesives with film topsheets, although less dramatic than on bare OSB. Once again, the foil based topsheet is more stable through this heat aging. An effect not shown as clearly on the bare OSB, however, is the oozing of the modified-asphalt based adhesive into the housewrap sample, as seen by the dark stains around all of the modified-asphalt samples. A close-up illustration of this leaching and oozing of the modified-asphalt adhesive samples is shown on Fig. 11. This is a result of leachable components in this type of adhesive system migrating into the film, which not only stains the substrate, but also suggests the possibility of a deterioration (drying out) of the adhesive over time. The three butyl adhesive samples (on the left) did not show any curl back or adhesive "leaching." The butyl sample with the film based topsheet once again "wrinkled" after the heat exposure, but did not form open channels on the housewrap as it did on the bare OSB, likely due to enhanced adhesion to the housewrap as well as the flexible nature of the substrate. The butyl samples with nonwoven composite based topsheets are once again stable (no curl back, wrinkles, or leaching) through this heat exposure.

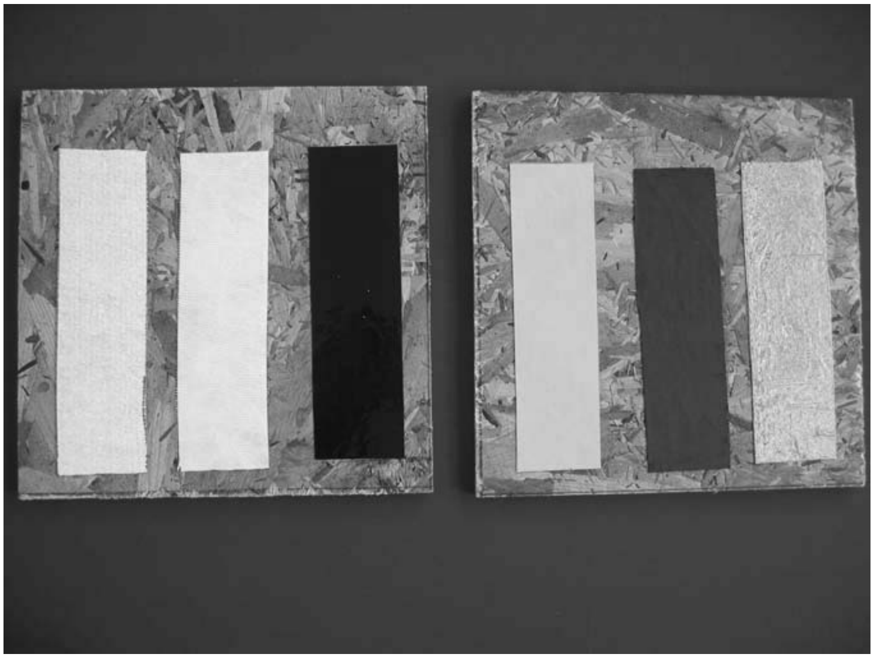

FIG. 6—*Self-adhered flashing samples on OSB before thermal aging; three butyl based adhesive samples are on the left, and three asphalt based adhesive samples are on the right.*

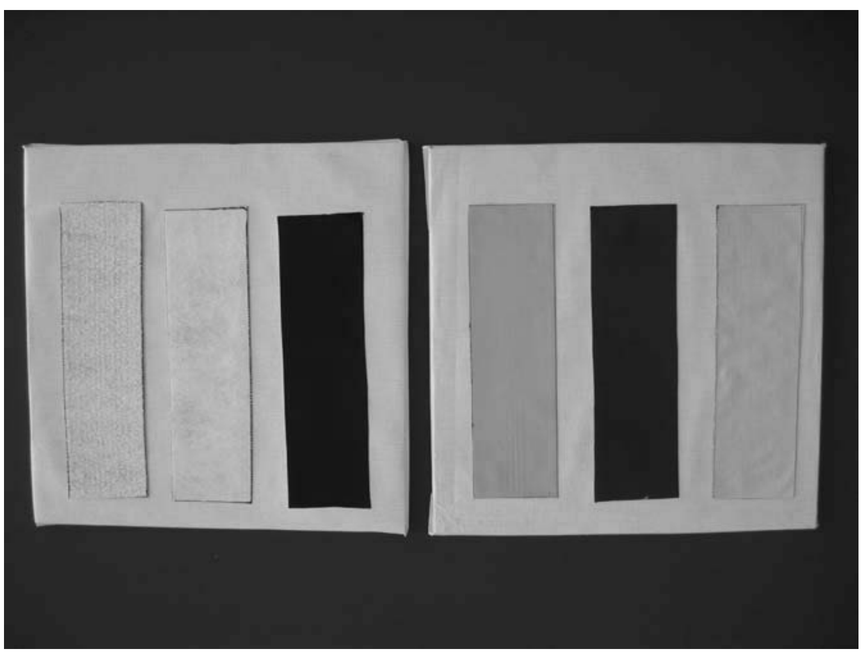

FIG. 7—*Self-adhered flashing products on spun bond polyolefin housewrap before thermal aging; three butyl based adhesive samples are on the left, and three asphalt based adhesive samples are on the right.*

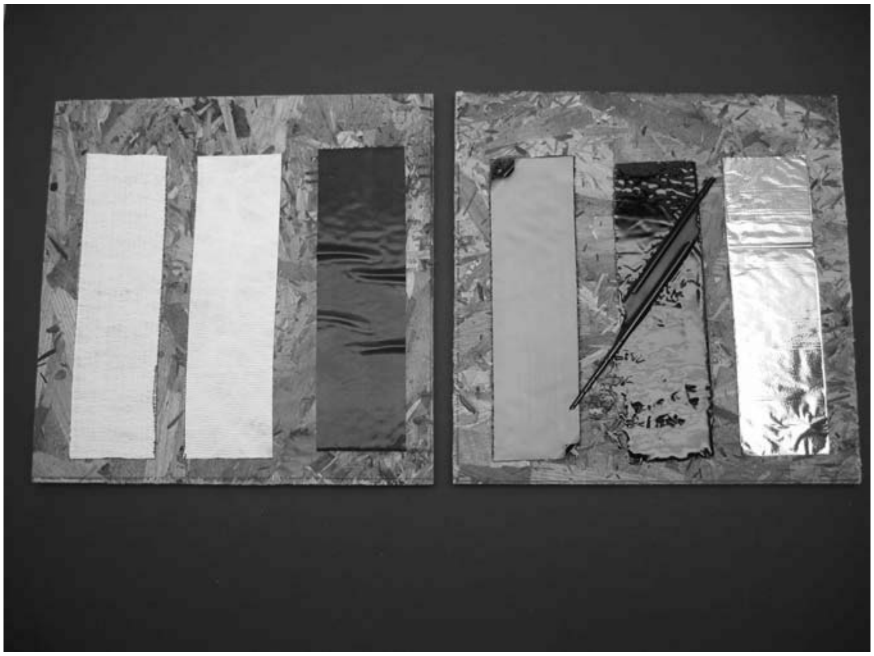

FIG. 8—*Self-adhered flashing samples on OSB after thermal aging at 70ºC for 14 days; three butyl based adhesive samples are on the left, and three asphalt based adhesive samples are on the right.*

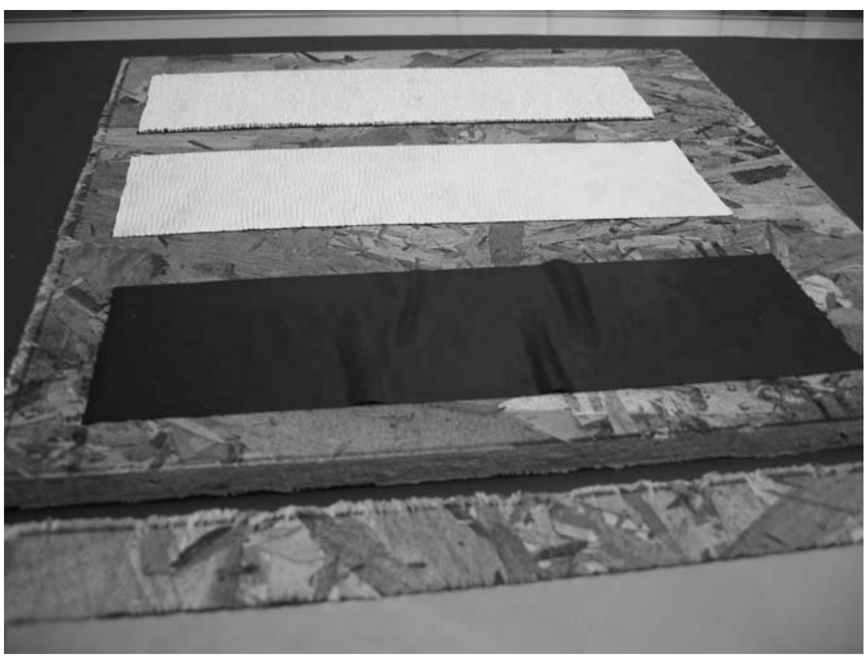

FIG. 9—*Side-view of butyl-based adhesive products after thermal aging.*

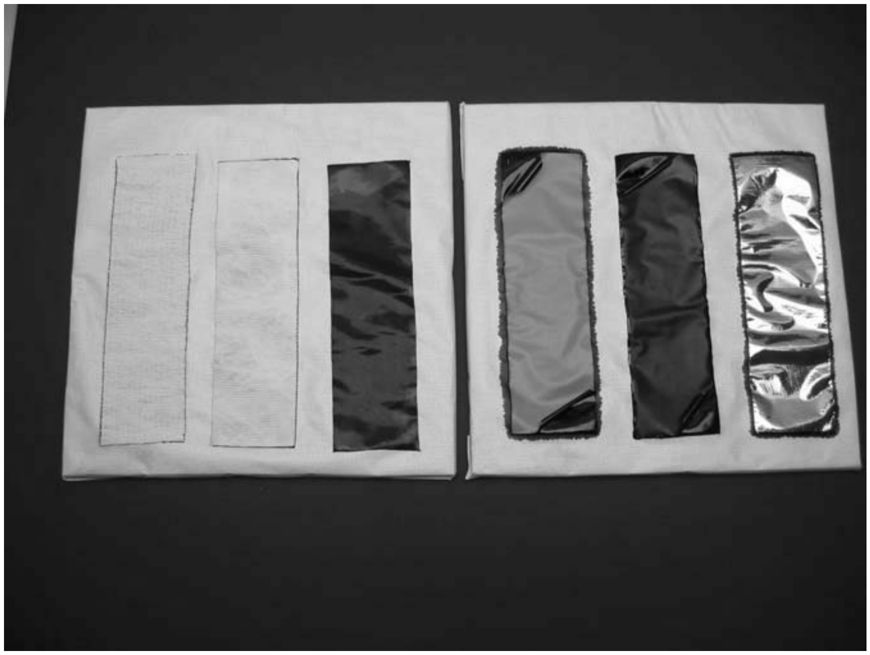

FIG. 10—*Self-adhered flashing samples on OSB wrapped with housewrap after thermal aging at 70ºC for 14 days; three butyl based adhesive samples are on the left, and three asphalt based adhesive samples are on the right.*

FIG. 11—*Close-up of staining by modified-asphalt adhesive products after 70ºC heat aging.*

Summary and Conclusions

Adhesion Characterization Summary—Data presented in this study provide an assessment of the adhesion characteristics of typical self-adhered flashing products installed to a variety of common substrates at a range of temperatures and on a moist and dusty surface. What is shown is that the butyl samples provide adequate adhesion without relying on primer for a wider range of installation conditions than the asphalt samples. The butyl samples have higher adhesion to wet/dusty OSB, clean OSB, and concrete block when tested at a common installation temperature of 27ºC, whereas all modified-asphalt products require a primer. The testing did not determine where this butyl adhesion level falls off with decreasing temperature. At cold installation temperatures below freezing, all products required a spray primer to reach adequate adhesion. All products adhered well to PVC strips and painted steel without the use of a primer. For all conditions and products, the use of a primer dramatically improved the adhesion performance. This is only a preliminary assessment, and much work is still needed to fully characterize the breadth of exposures and conditions found in the field.

Thermal Aging Summary—The thermal aging performance measured at 70ºC for 14 days shows a dramatic difference between the self-adhered flashing products on both OSB and housewrap surfaces. In this case, it was shown that the type of topsheet can also impact the thermal aging performance. In general, the film topsheets have a tendency to pucker, deform, and curl back at this temperature exposure, causing potential routes for moisture intrusions. However, the nonwoven composite laminates and foil topsheets are more dimensionally stable after exposure to these temperatures. The butyl-adhesive based products are also shown to be more thermally stable under these conditions, while the asphalt adhesive based products are shown to ooze and stain the substrate to which they are adhered.

Overall Conclusions—This study gives evidence that the use of self-adhered flashing products requires careful consideration for the installation conditions, the temperature exposures, and the types of substrates that are involved. It is clear that while butyl based adhesive products are generally more expensive than modified-asphalt based products, they provide a broader window of installation conditions (cold, wet, dusty surfaces) where an 'adequate' level of adhesion to the substrate is realized without the use of a primer. Also, the butyl adhesive based products are generally more thermally stable (do not ooze or stain) at temperatures commonly realized on warm days behind siding. The type of topsheet also contributes to thermal stability, as the film topsheets are not as dimensionally stable at these exposures as the nonwovens laminate or film/foil based topsheets. With all of these considerations, self-adhered flashing products can be successfully utilized to provide a durable moisture seal at the window-wall interface.

Acknowledgments

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INSTALLATION

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Designing and Specifying Self-Adhering Flashings for the Window-Wall Interface

ABSTRACT: Self-adhering flashings provide a flexible and durable material that conforms to various wall planes, particularly those occurring in recessed wall openings. New flashing methods for the window-wall interface are available for this material. These new methods for designers are illustrated with step-by-step installation details for recessed windows, flush wall openings, recessed sills, and sill pan flashings. Considerations for flashing the window-wall interface are presented. A guide specification for self-adhering flashings is included for specifiers.

KEYWORDS: Detailing, Specification, Weather-Resistant Barrier (WRB), Self-Adhering Flashing (SAF), Recessed Opening, Sill Pan Flashing, Window Head Flashing

Introduction

During the last 20 years, innovative building contractors concerned with the durability of traditional window flashing products have used flexible, self-adhering, sheet waterproofing membranes around wall openings for windows, doors, and other penetrations. These materials were borrowed from the roof membrane industry and introduced as wall flashings. Only within the last 10 years have the manufacturers of these products recognized the use of their products as wall flashings. And only recently have manufacturers of self-adhering flashings begun to develop instructions for their use as window flashings. Still, the state of information available to designers and specifiers is incomplete but growing.

Self-adhering flashings typically are 40 mils thick with thinner 20 & 25 mil products also used. The widths used for flashing window opening perimeters are generally 4, 6, 9, and 12-in. wide. Flashing widths wider than 9-in. may become unwieldy to handle with field conditions. Lengths of utilized flashings vary with the window opening size and the number of workers installing the product.

In 2001, ASTM E 2112 recognized self-adhering flashings for the window-wall interface, but it did not illustrate a specific flashing method based on the product's unique features of flexibility and continuous adhesion. This paper is intended to extend the body of information available to assist designers and specifiers desiring to use self-adhering flashings for windows and recessed openings at the window-wall interface.

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Focus and Scope

This paper will cover the use of self-adhering flashings around recessed wall openings at the window-wall interface. It will also include a method for creating a sill pan flashing, as well as a new method for flashing flush wall openings.

The information for designers will outline issues to consider when using self-adhering flashings, techniques for detailing, example flashing sequence diagrams for a flush wall opening, a sill pan flashing, and a recessed window opening. The details presented in this paper should generally be consistent with current construction practice and comply with most flashing manufacturers' recommendations, except where the author introduces other suggestions as personal opinion.

Specifiers will be introduced to the issues to consider for product and installation specifications. A guide specification for self-adhering flashings is presented that addresses window flashings and can be used for other wall flashing applications.

This paper is not a comprehensive treatise on the subject of flashing or just a case study review. It is a compilation and summation of suggestions representing the experience from many projects intended for an audience of design professionals and specifiers for use as a general reference.

I. DESIGN CONSIDERATIONS

This paper assumes that the designer is generally familiar the subject of weather-proofing systems for buildings and has an understanding of the issues contained in ASTM E 241 and E 1825.

A. Major weather-proofing concerns at the window-wall interface using self-adhering flashings for window openings include:

- Head flashing at windows and recessed openings
- Flashing & sealant bridges between the window frame and the weather-resistant barrier
- Sloped sill substrates
- Minimization and placement of penetrating fasteners
- Sill pan flashings

A.1 Head Flashing

A separate metal (or plastic) head flashing is recommended to control moisture weeping down the wall above window openings and directing drainage to the exterior or around the window. There can be head flashing both above the window frame and also at the head of recessed openings.

A.1.1 Recessed Opening Head—Recessed heads function the same as the edge of soffits and require a separate drip flashing to prevent moisture from being allowed to seep back into the recessed soffit area. Moisture that seeps back into the recess is delayed in draining down the wall and exposes flashing, weather-barrier laps, and fastener penetrations to an increased risk of water entry. Stucco wall finishes require soffit drips at the edges of walls and along the heads of recessed openings. Other exterior wall finishes benefit with the use of head flashings at recessed openings.

A.1.2 Window Head Flashing—Separate flashings over window heads should be considered when the profile of the frame does not provided free moisture flow over the outside edge of the frame. Obstructed drainage at the head of the window frame can direct water to susceptible window and flashing corners and can permit accumulated water to back up the wall and breach the upper edge of the window frame directing water behind the wall's weather-barrier system.

A.2 Flashing and Sealant Acts as a Bridge Between Window Frame and the Weather-Resistant Barrier (WRB)

Flashing with or without sealant creates a waterproof perimeter extension of the window frame integrated with the WRB. Continuity of the materials is essential to prevent water intrusion. A self-adhering flashing (SAF) along with sealant is used to "bridge" the gap between the window and the WRB at the rough opening. The self-adhering flashing can lap and adhere to both the substrate and the WRB. The window frame is then sealed to the SAF or adhered with additional strips of SAF lapping the frame and completing the "bridge." Integral fin window frames are commonly flashed with SAF. Block (non-fin) frames offer a challenge to obtain sufficient surface to adhere SAF.

A.2.1 Sloped Sill—Recessed window openings greater than 6 in. in depth require a sloped substrate under the SAF to provide drainage. Sills less than 6 in. deep can perform with a flat membrane if there are no fasteners through the sill flashing. All laps and seams at flat membrane sills must be fully bonded. A sloped sill prevents moisture from accumulating and being retained against imperfections in the flashing installation.

A.2.2 Minimization and Placement of Penetrating Fasteners—Fasteners penetrating the SAF are a place of potential water entry. *Do not rely on the marketing language in manufacturers' brochures.* There is as yet no recognized standard for "self-sealing" around fasteners. The only closely relevant standard is ASTM D 1970 (developed for roof eave underlayment membranes) that tests a laboratory-installed smooth roofing nail driven at 90° into a solid substrate with a 5-in. head of constantly cool water for a 72-h period. However, building walls use field-installed fasteners such as screws, staples, and ring-shank nails driven at angles which sometimes miss framing ("shiners"). Outside the lab, it is risky to depend on self-adhering flashing to seal around fastener penetrations, in the opinion of the author. The placement and number of the eventual fasteners through an SAF should be anticipated and included in the flashing design. Fasteners should be kept away from critical sill and head corners where laps and seams in the WRB or SAF occur. Heads of fasteners can sometimes be sealed at the penetration through the SAF when fasteners cannot be avoided.

A.2.3 Sills—Recessed sills collect and retain moisture more than any other location except for a roof. Eliminate fasteners through the sill flashing where possible. Or, if it is necessary to fasten through the sill flashing, provide a sloped sill substrate, and plan the location of fasteners avoiding penetrations too close to sill corners. The risks of fastener penetrations can be addressed with the use of thicker (40 mil) sill flashing, layout of an additional strip of flashing membrane at the penetrating hole, and sealing around the fastener. The depth of the recess can affect the flashing technique used. Recessed sills can be made from a single width of flashing. Sill depths of greater than 6-in. made with lapped strips of SAF can be as effective as sills. Narrow depth sill pan flashings under windows may be more practical if made from soldered sheet metal.

A.2.4 Heads—The use of separate head flashing or soffit edge drip at recessed openings makes the use of fasteners at heads less risky. But, if a head flashing or soffit drip is not used, fasteners through the SAF at recessed heads become critical to plan in design and monitor during installation. A similar flashing technique like that applied to the recessed sill should be implemented at the recessed head opening.

A.2.5 Sill Pan Flashing—Recessed window openings should have sill flashing at the opening. A sill pan under the window sill frame should also be considered. Self-adhering flashings can be used to create the sill pan flashing under windows and sill flashing at recessed openings.

B. Design guides & graphic techniques for detailing self-adhering flashings at the window-wall interface include:

B.1 Corner Conditions

Analyze and design the opening conditions at the corners of head and sill. Designers typically do not provide isometric (3-dimensional) flashing details. But it is essential to analyze and think through the flashing requirements at critical junctures, terminations, penetrations, and window openings, even if isometric details are not provided in the construction documents. If the details do not show it, the specs should state it.

B.2 Distinguish Materials

Show the weather-barrier, flashings, and bedding sealants distinctly in the details. Architectural details should emphasize flashing materials by graphically separating material indications as drawn lines clearly distinguished from other materials also shown as lines. The detail scale should be large enough to illustrate layered materials.

B.3 A Smooth Drainage Plane

The design of the wall's weather-proofing system should place the substrate supporting the WRB and SAF in the same plane. Where changes in the weather-proofing plane occur, the transition should be gradual to accommodate material and installation limits. Keep adequate space at corners and room around the perimeter of windows to allow for construction tolerances, the build-up of lapped materials, and the flashing installation. Keep the drainage plane continuous.

B.4 Continuity of Wall Trim

Maintain the continuity of horizontal and vertical building trim and accessories. Trim around window openings and wall components, such as stucco accessories, should be evaluated regarding their impact on the performance of window flashings. Head trim without a head flashing can direct water behind the WRB into the wall system. Stucco accessories that terminate at window opening corners can direct increased water toward critical flashing areas. Flashing should be durable at locations where trim may increase water entry. Terminations of trim should be sealed at the surface to limit water entry into the wall assembly.

C. Example Details

The Appendices contain special details developed to use self-adhering flashings. They presume steel or wood frame construction with an exterior wall sheathing to provide support for the flashings and WRB. The details are shown with a nail-fin window, but the basic principle will apply to no-fin (block frame) windows as well. The details anticipate an exterior wall finish of Portland cement plaster but can work with wood siding as well as other cladding materials. Not every opening will be flashed the same way. Different opening widths, heights, and depths will require adjustment of the flashing design. There can be variations in flashing shapes, profiles, and configurations used to fabricate a sill pan. There are variations in the installation sequence likely to occur between projects and materials.

C.1 Sill Pan Flashing

The flexible and adhesive properties of self-adhering flashings are used to create a rear leg turn-up, side dams, inside corners, outside corners, and pinhole patches. See Fig. 1 and Appendix 1.

C.2 Flush Wall Flashing

In this paper, a new flashing technique called Method C uses self-adhering flashings and supplements the flashing Methods A, A1, B, and B1 described in ASTM E 2112. The integral window fin is sandwiched between strips of self-adhering flashing at the jambs and head. This method is also suitable for flashing horizontal and vertical mulled window units. See Fig. 2 and Appendix 2.

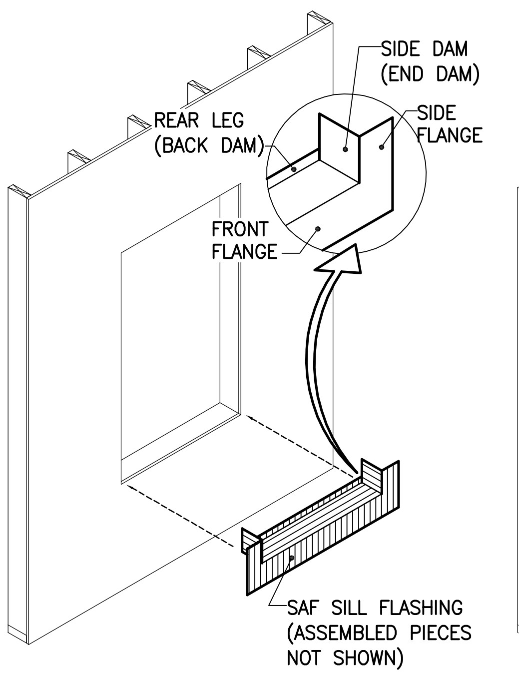


FIG. 1—*SAF sill pan flashing.*

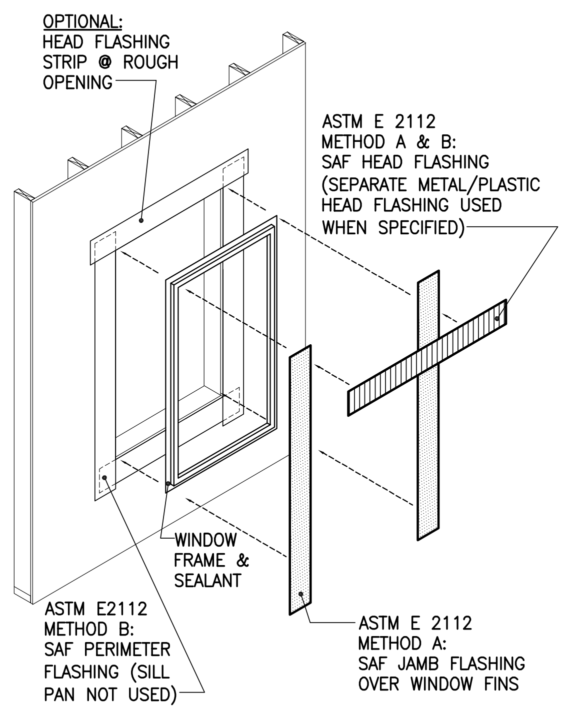


FIG. 2—*SAF flush window opening flashing Method C = (Method A + Method B).*

C.3 Recessed Window Flashing

The self-adhering flashing is used to create a complete flashing system for a recessed opening that includes the sill flashing and window flashing Method C. See Fig. 3 and Appendix 3.

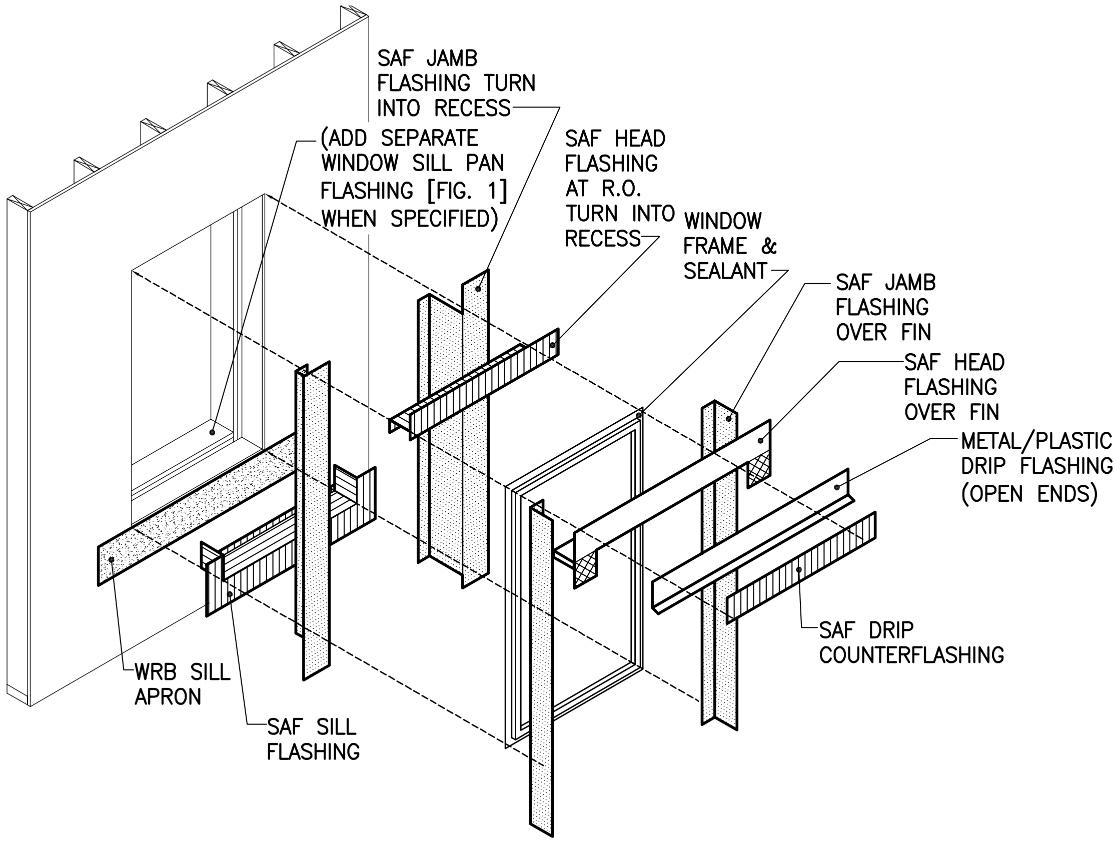


FIG. 3—*SAF recessed window opening flashing – Method C.*

II. SPECIFICATION CONSIDERATIONS

A. Industry standards are currently being developed by AAMA for the required physical property criteria of self-adhering materials used as flashings. AAMA, ASTM, and other organizations will also be developing installation standards. In the meantime, this paper intends to present useful information for designers and specifiers. The following are items to consider when specifying self-adhering flashing.

- Adhesion
- Thickness
- Laps & Seams
- Inside/Outside Corners & Pinhole Patches
- Adhesive Selection
- Protection
- Mock-up

- Inspection
- Testing
- Trade Coordination

A.1 Adhesion

If the self-adhering flashing is merely used in place of traditional flashing products and procedures, then adhesion is not critical. In all other applications, adhesion is an important product characteristic. Adhesion values are different among product manufacturers and among products of a single manufacturer. Lap adhesion of the flashing to itself is important, but most available products stick well to themselves. The flashing also needs to stick to various substrates. Flashing needs to adhere to the window frame when it is part of the flashing system. Most product manufacturers have tested their product adhesion to various materials, such as wood and steel. Product research may be needed to verify adhesion values for specific project materials, such as paper-based and polymer-based weather-barriers, OSB, fiberglass-faced sheathing, aluminum, or vinyl window frames. Beware that the chemical composition and surface films from manufacturing vary with different vinyls used in window frames and can impact adhesion. All self-adhering products do not adhere as well to wet or damp substrates. Wet and damp substrates should be avoided. Primers will increase adhesion to most substrates.

A.2 Thickness

Self-adhering products are generally available between 40 mils and 20 mils in thickness. The thicker product will be more durable and have a greater tendency to seal around fastener penetrations. The 40 mil thickness material should be used at critical sill conditions, for example. The thinner products are useful where flashing laps can build up the overall thickness such as at corners that can interfere with the installation of windows and other products. The 20 or 25 mil products are well suited for counterflashing other flashings, such as metal head flashings.

A.3 Laps and Seams

Product manufacturers recommend minimum laps of their product when lapped to itself. This ranges from 2–3 in. The author recommends specifying laps of 4–6 in. unless using a hand roller at laps and seams when lesser laps can be adequate. Using a solid hand roller at laps and seams ensures that minimum laps of less than 3 in. are flat and tight. Air is pushed out at rolled laps so more of the adhesive material sticks. A question occurs about how much lap is sufficient at porous substrates and at window frames with only 3/4 to 1-1/2 in. of fin available. This issue is currently being discussed in the industry. It is the author's experience that the integral fins on window frames are smooth and solid, providing a good base for flashing adhesion. Good adhesion performance requires the frame to be clean, dry, and without any surface films. Adhesion to weather-barriers should have wider laps. Six-inch laps are prudent for vertical and horizontal conditions, but 2-in. laps for horizontal laps are the minimum for non-adhesive materials, such as building paper. A primer on substrates and a hand-roller will improve adhesion at laps and seams.

A.4 Inside/Outside Corners and Pinhole Patches

Self-adhering membrane flashings can be used to fabricate inside and outside corners at wall recesses. Inside corners can be made with one piece folded or 2 pieces including a pinhole patch. Outside corners can be variously made with 3 pieces including a pinhole patch. The pinhole patch is a small piece of SAF used to close the open joint ("pinhole") where flashings are not lapped. Pinhole patches can have various shapes, but a circle of about 3 in. in diameter distributes the stresses of conforming to corners more uniformly around the edge than square-shaped patches. See Fig. 4. The edges of pinhole patches should be hand-rolled flat and tight.

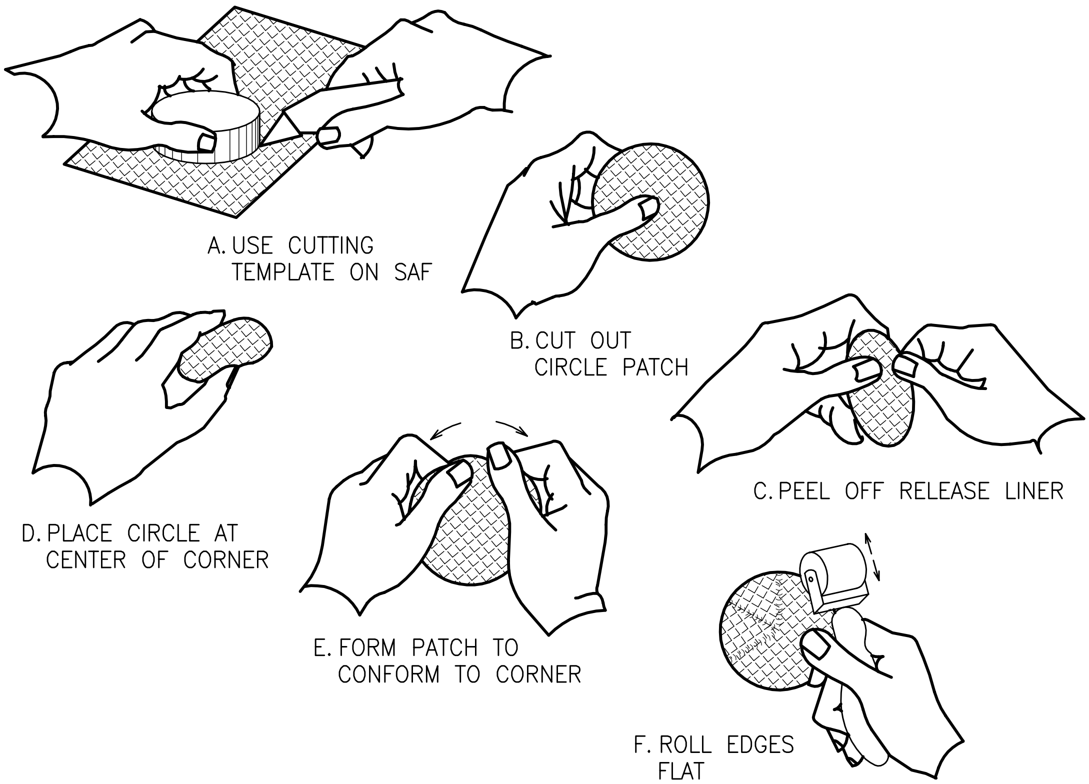


FIG. 4—*SAF circle patch for corner conditions.*

A.5 Adhesive Selection

Generally, there are two types of adhesive material used as the basis of currently available self-adhering flashings – butyl and rubberized asphalt. Not all products are equal. Look at the manufacturer's values for adhesion as a start. Then compare other physical properties, such as the service temperature range or weather exposure limits. For example, butyl flashings can tolerate higher service temperatures than rubberized asphalt under exposed sheet metal sill flashings. Rubberized asphalt flashings are generally less expensive than butyl flashings.

A.6 Protection

The self-adhering flashings are durable materials, but can be subject to damage during installation and construction until covered by other materials.

A.6.1 Physical Damage—The SAF is subject to damage from cuts and punctures during and after installation. Flashings at sills are particularly exposed to abuse from traffic of materials and personnel in and out of window openings during prolonged construction. Damaged flashings can be replaced or repaired with patches of new SAF over cuts and sealant compatible with the SAF at punctures. Roll edges of patches.

A.6.2 Weather Exposure—All the SAF products are subject to deterioration from prolonged exposure to sun, heat, and weather. All products will begin to lose adhesion at the edges where porous substrates are left exposed to rain and dampness. Even foil-faced flashings, which can be exposed for extended periods, are not intended for permanent weather exposure. All self-adhering flashings have various recommended limits to exposure ranging from 30 days to 6 months. Covering the exposed flashings temporarily during construction with the weather-barrier or installing shade cloth on scaffolding will help protect the flashings from exposure.

A.7 Mock-up

Including a flashing mock-up requirement in the specifications is an important consideration in building construction. The mock-up process is an opportunity to verify that the flashing system design and materials will work in practice. It also gives the opportunity for the general contractor and subcontractors to review their work scope and determine the installation sequence and resolve trade coordination issues.

If the weather-proofing design for the project is not complete with fully developed details as shown in the examples in this paper, then the mock-up becomes the essential milestone event to work out the design issues before construction progresses past the time for optimum design choices.

A.8 Inspection

It is critical to verify the consistency and adequacy of the flashing installation at the window-wall interface. Inspection of the flashing installation should be part of the expected duty of the contractor’s foreman and field superintendent. The AAMA IM-TM has useful checklists for quality control during installation.

The author further recommends that a third party verify the integrity of the installation, as well. This can be done as a “structural observation” by the project’s design professional who is confident in his or her knowledge of weather-proofing systems. It can also be done by a waterproofing consultant or a qualified “special inspector.”

A.9 Water Testing

The adequacy of the self-adhering flashing system is determined by its successful performance in preventing water intrusion and directing moisture drainage to the building exterior. Field testing of the design and installation of the flashing helps ensure expected performance. Water testing is often part of the field verification of window performance. The field testing procedures used for window testing can also be used for the window-wall interface with some modification. The field test standard ASTM E 1105 is used to test windows’ water resistance. Self-adhering flashings and the completed wall assembly can be included in the window testing program. The calibrated spray rack can be used at zero water pressure or at a negative pressure specified by the building designer. The designer should also specify test duration. After water intrusion has been verified by an E 1105 test, the AAMA 501.2 standard using a calibrated spray nozzle can test the window-wall interface to pinpoint specific water entry locations or water leakage paths. The testing of window flashings should be coordinated with the testing planned for the window and wall assemblies.

Other testing can include a separate test for a recessed wall sill flashing and a window sill pan flashing. The window sill pan flashing (if included in the design) can be tested with the window frame as part of the AAMA Standard 502, "Method A, Optional Water Test," by plugging the window sill weep holes, filling the window sill track with water, and observing for leaks during a minimum 15-min period. The recessed sill opening flashing can be tested by damming the outside sill edge, filling the sill area with water, and observing for leaks.

A.10 Trade Coordination

The flashing design may lead to certain sequences of material application that require coordination of two or more subcontractors. The specification should alert the general contractor to consider trade coordination. The mock-up is an opportunity to work out these trade coordination issues. The various trades involved in flashing, window installation, and wall construction can provide feedback that may lead to a change in the flashing design or modification of the installation sequence. For any particular job, the design, material selection, and flashing installation method is subject to change based on the experience, preferences, trade jurisdiction practices, and contractual arrangements of the trades involved.

B. Guide Specification

The Appendix contains a guide specification developed for self-adhering flashings used for window flashings, as well as for general flashing applications. The specification is specifically developed for self-adhering flashings where current practice usually places this product in Section 07650 Flexible Flashings. The *Construction Specifications Institute* (CSI) MasterFormat number 07660 Self-Adhering Flashing is suggested to be used to separately identify this product specification. See Appendix 4.

This guide specification example is not intended to be used for any building project without editing by the responsible design professional. It is presented as a guide for specifiers using professional judgment to evaluate its use for a particular purpose. It is certain that the current state of industry knowledge is evolving, and this specification will need to change to remain applicable.

Conclusion

New flashing methods and a guide specification for self-adhering flashings are available with this paper that can be used as interim references until consensus industry standards are developed. The details shown in this paper optimize the unique features of durability, flexibility, and uniform sealing capability for this flashing product. The details are presented in a format that illustrates a complete flashing installation integrated with the weather-resistant barrier at the window-wall interface.

Acknowledgments

The development of self-adhering sill pan flashing and recessed window flashing details in this paper has been the result of productive collaborations with contractors and subcontractors during actual construction projects. This paper would not have been developed or taken the perspective of graphically presenting an orderly flashing method without the contributions of several outstanding field superintendents. The author is especially thankful to the following individuals:

- Doug Lankenau, Jeff Hicks Construction, Mill Valley, CA. Doug introduced the author to SAF materials and procedures for installing perimeter window flashing in 1991. He also has been aware of the importance of material compatibility and adhesion between flashings, sealants, and weather-resistant barriers.
- Chuck Carpenter, formerly with Oliver & Co., Richmond, CA. Chuck demonstrated the benefit of a well-managed collaboration between designer and flashing installers. He helped produce the SAF flashing technique developed for recessed ledges at stucco walls in 1998.
- Chris High, Fairview General Contractors, Moraga, CA. Chris introduced the author to the idea of field-cut circle patches of SAF to address pinhole corner conditions with field fabrication of multi-layer SAF flashings in 1999.

The guide specification in this paper is modified from the sample specification contained in the Polyken "Flashing Tapes" manual as Section 07650 Flexible Flashings. The concept for the Method C flashing technique is also contained in the Polyken "Flashing Tapes" manual as "Method SAF." The comprehensive design and detailing of this Method C has also been developed by Chris Decareau, AIA, Simpson Gumpertz & Heger, Inc., San Francisco, CA.

The opinions, recommendations, and details presented in this paper are those of the author and do not necessarily represent the views of SGH, ASTM, AAMA, or other organizations cited.

Useful References for Designers and Specifiers

[1] AAMA IM-TM - "Installation Masters" Training Manual, AAMA, Schaumburg, UL, 2000. This manual was developed by AAMA based on the available draft of ASTM Standard E 2112. It also contains general information and techniques not contained in E 2112. It is directed to installers, but there are useful guidelines for designers, specifiers, and inspectors.

[2] AAMA 501.2 - Field Check of Metal Curtain Walls for Water Leakage. A hand-held, calibrated spray nozzle test is often used for quality control of non-operable windows and diagnostic surveys. There is yet no industry consensus for procedures for using the AAMA nozzle for quality control of operable windows, testing newly completed wall assemblies, or predicting potential leak sources where no leak history is present. However, it is a reproducible test method that can be a useful tool for experienced and knowledgeable inspectors.

[3] AAMA 502 - Voluntary Specification for Field Testing of Windows and Sliding Glass Doors. "Test Method A, Optional Sill Dam Test." The sill track test (typically applies to operable windows) used at window sill corners can also be used to test sill pan flashings. AAMA 502 also contains Test Method B. This spray rack test includes the window-wall

interface and follows the procedures of ASTM E 1105. Note there are differences between the 1990 edition and 2002 edition regarding the number of samples tested, what constitutes a “leak,” using full test pressure versus 2/3 test pressure and the height of water in the sill track for the sill dam test. The designer/specifier should consider these differences in interpreting test results.

[4] ASTM D 1970 - Specification for Self-Adhering Polymer Modified Bituminous Sheet Materials Used as Steep Roofing Underlayment for Ice Dam Protection. This contains the fastener “self-sealing” test that most SAF manufacturers currently use for their product claims.

[5] ASTM E 241 – Guide for Limiting Water-Induced Damage to Buildings. This publication provides some general guidance of the building areas susceptible to water leakage.

[6] ASTM E 1105 - Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls and Doors by Uniform or Cyclic Static Air Pressure Difference. A calibrated, spray rack water test using zero or a predetermined negative pressure value can incorporate the window-wall interface. The designer/specifier needs to determine a test duration and test pressure appropriate to the wall assembly and window/doors used.

[7] ASTM E 1825 – Guide for Evaluation of Exterior Building Wall Materials, Products and Systems. This publication includes discussion of water testing for different wall cladding types.

[8] ASTM E 2112 -Standard Practice for Installation of Exterior Windows, Doors, and Skylights, ASTM International, West Conshohocken, PA, 2001. This document contains instructions and some illustrations for Method A and Method B. Self-adhering flashing use is described as a substitute for traditional flashing materials, but not specifically illustrated. This version of the document describes the use of 9-in. wide flashings for all types of flashing products and does not recognize potential for effective flashing with the use of narrower widths for self-adhering flashings. There is no flashing procedure included for recessed openings.

[9] Bateman, R., “A Detailing Method for Improving Leakage Prevention of Exterior Wall Weatherproofing,” *ASTM STP 1422*, ASTM International, West Conshohocken, PA, 2003. This paper promotes the use of 3-D and sequence (step-by-step) flashing details, as well as developing final flashing procedures at pre-construction mock-ups while consulting with the subcontractors.

[10] CAWM 400-95 – Standard Practice for Installation of Windows with Integral Mounting Flange in Wood Frame Construction. The first in the series of industry flashing references developed by the California Association of Window Manufacturers (defunct in 1997 and subsumed under the auspices of AAMA). This 4-page document succinctly presents flashing Method A and Method B for flush wall openings. SAF is not specifically mentioned. Section 5.5.5 notably describes sealing the edge of the weather barrier to the window frame. This effective technique for supplementing the perimeter flashing was omitted in the subsequent AAMA 2400 and ASTM E 2112 references.

[11] CAWM 410-97 – Standard Practice for Installation of Sliding Glass Doors with Integral Mounting Flange in Wood Frame Construction. It is the second in the series of industry flashing references developed by the California Association of Window Manufacturers (defunct in 1997 and subsumed under the auspices of AAMA). This 8-page document describes and illustrates flashing Method A & Method B for doors. It includes various sill and sill pan flashing examples. SAF is not specifically mentioned. Section 5.5.8 notably

describes sealing the edge of the weather barrier to the window frame. This effective technique for supplementing the perimeter flashing was omitted in the subsequent ASTM E 2112 reference.

[12] Holladay, M., "Choosing Flexible Flashings," *Journal of Light Construction*, Hanley Wood, Washington, DC, June 2001. This is a good introductory article for self-adhering flashings that also identifies and compares various flashing products.

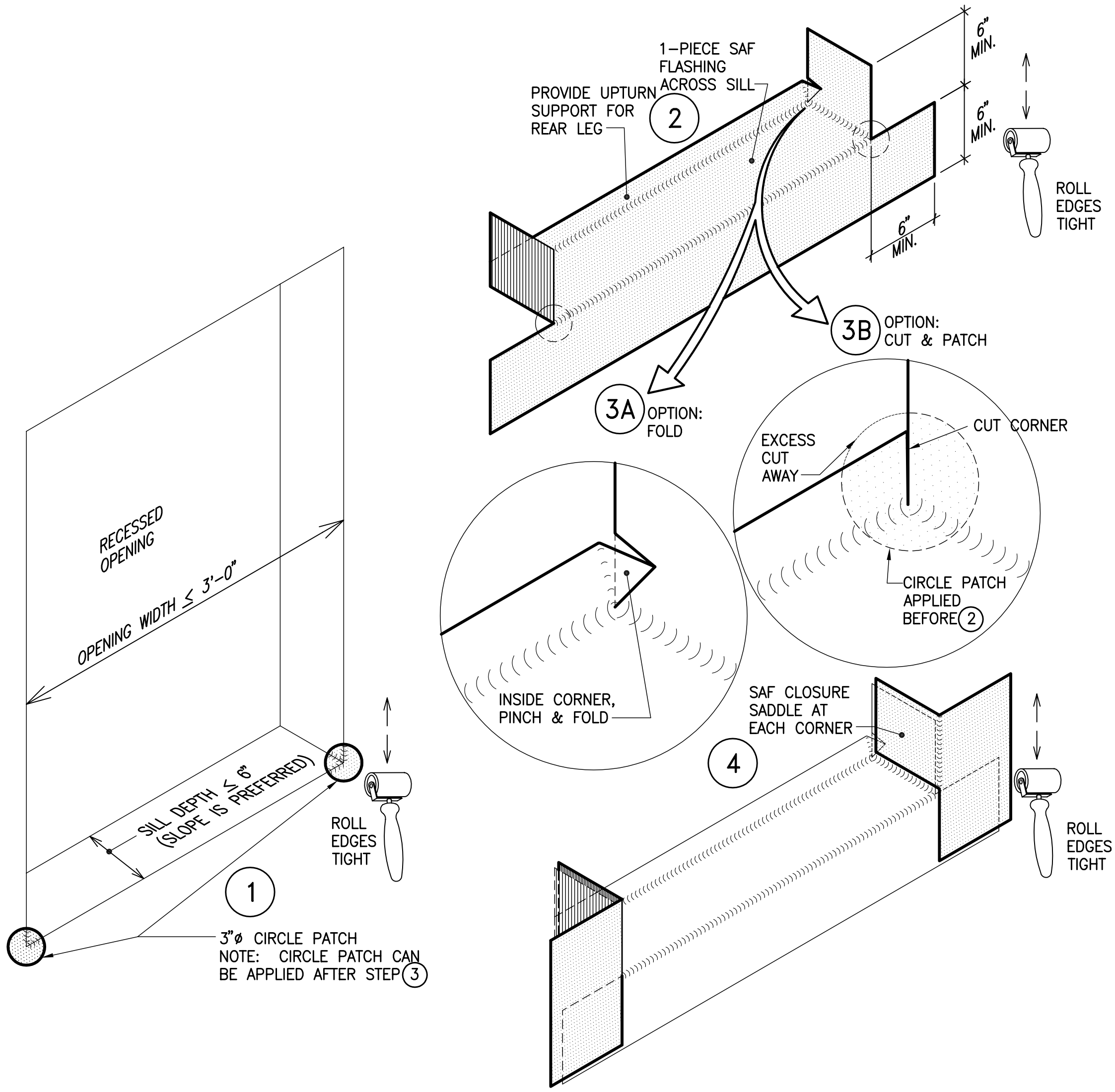
[13] Nail-On Windows: Installation & Flashing Procedures for Windows & Sliding Glass Doors, Robert Bateman, DTA, Inc., 1995, Mill Valley, CA. This reference contains details for various claddings using flashing Method A, Method B, details of a "sandwich" of flexible flashings for a fin window/door, as well as an early version of Method A1. It also includes the early CAWM 400-95 standard (Method A & B) that preceded the AAMA 2400 standard, which preceded ASTM E 2112.

[14] Polyken "Flashing Tapes" manual, Tyco Adhesives, Norwood, MA, 2001.This manual was produced by the author through SGH at the same time E 2112 was being developed. It includes flashing methods with SAF for the Methods A, A1, B, & B1 that are included in E 2112. It goes beyond E 2112 by introducing the flashing Method SAF, which is similar to Method C of this paper. Recessed opening flashing is not completely described or illustrated in the Polyken manual, but methods for creating inside and outside corner flashings with SAF are shown. The technique of using circle patches of SAF at corner junctures is introduced. A sample SAF specification is included.

[15] Fortifiber Buildng Systems Group, "Architectural Binder," Reno, NV, 2004. Refer to the guide sequence details for "Window Flashing Method 'A', Self Adhesive Flashing" with FortiFlash flashing and "Window Flashing Method 'B', Mechanically Attached." The combination of these two methods using self-adhering flashings is similar to Method C.

[16] Grace Construction Products, "Underlayments and Flexible Flashing" product binder, W.R. Grace & Co., Cambridge, MA, 2004. The flanged window flashing "Option 3 - Severe Exposure" (Grace detail VRCDET103, 06-24-03) with a 'sandwich" of Vycor Plus is similar to Method C of this paper.

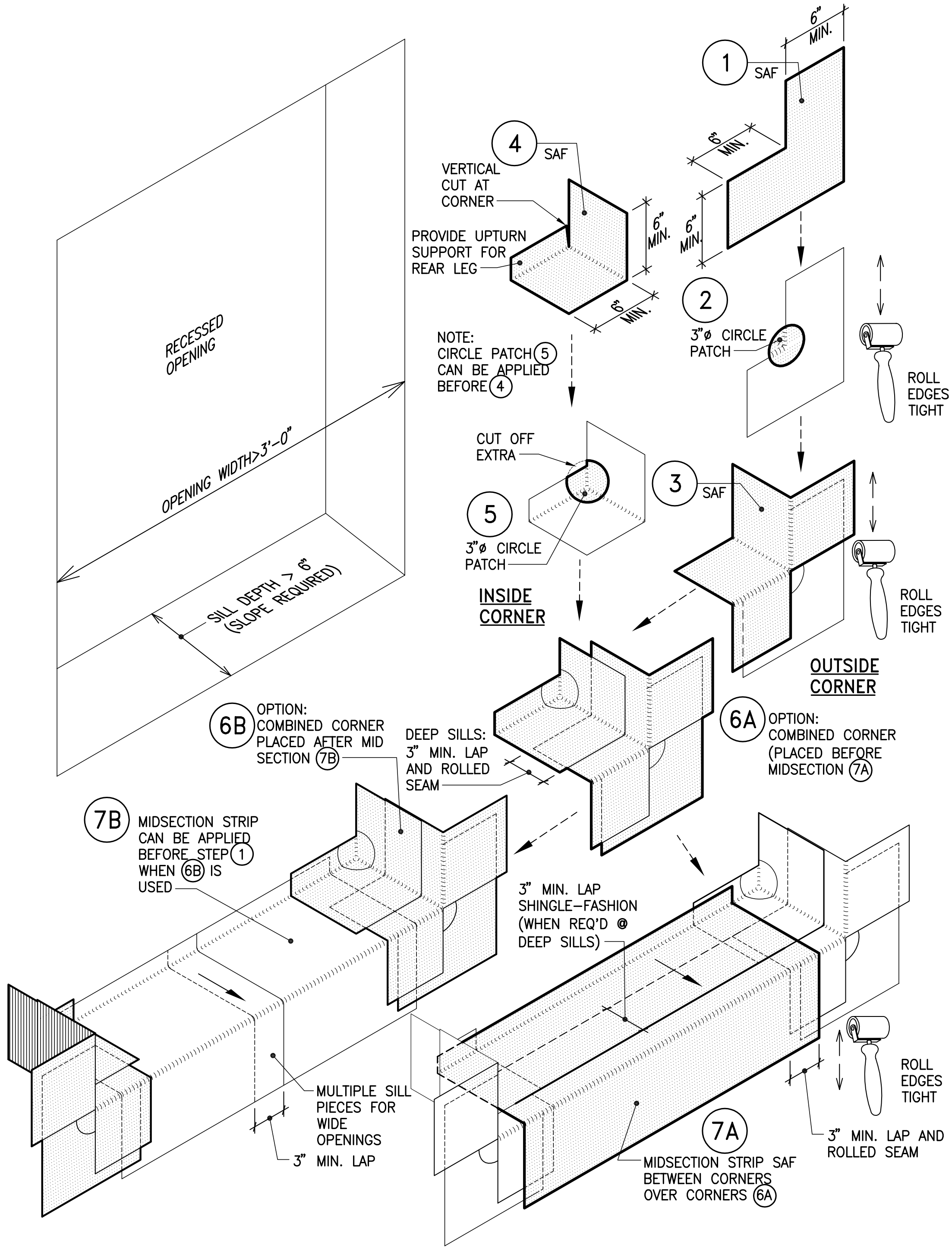
Appendix 1



Sill Pan Flashing – Continuous SAF

For sill widths 3 ft or less and sill depths of 6 in. or less (sloped sill preferred).

Designer's Note: Specific detail configurations, sequences and installation procedures must be independently developed by the design professional for each particular project.

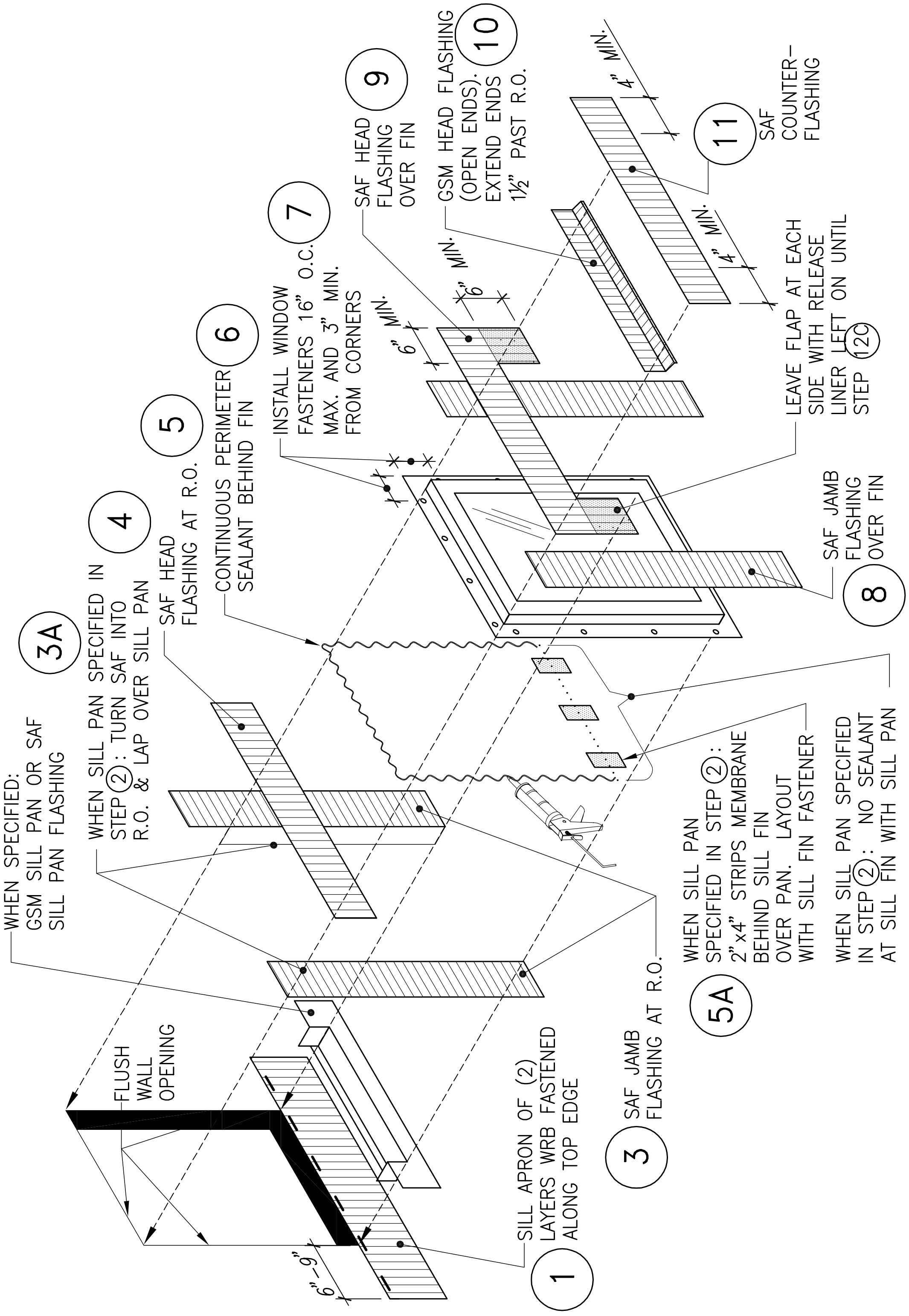


Sill pan flashing – multiple – piece SAF.

For sill widths >3 ft and/or sill depths >6 in. (Sloped sill required.)

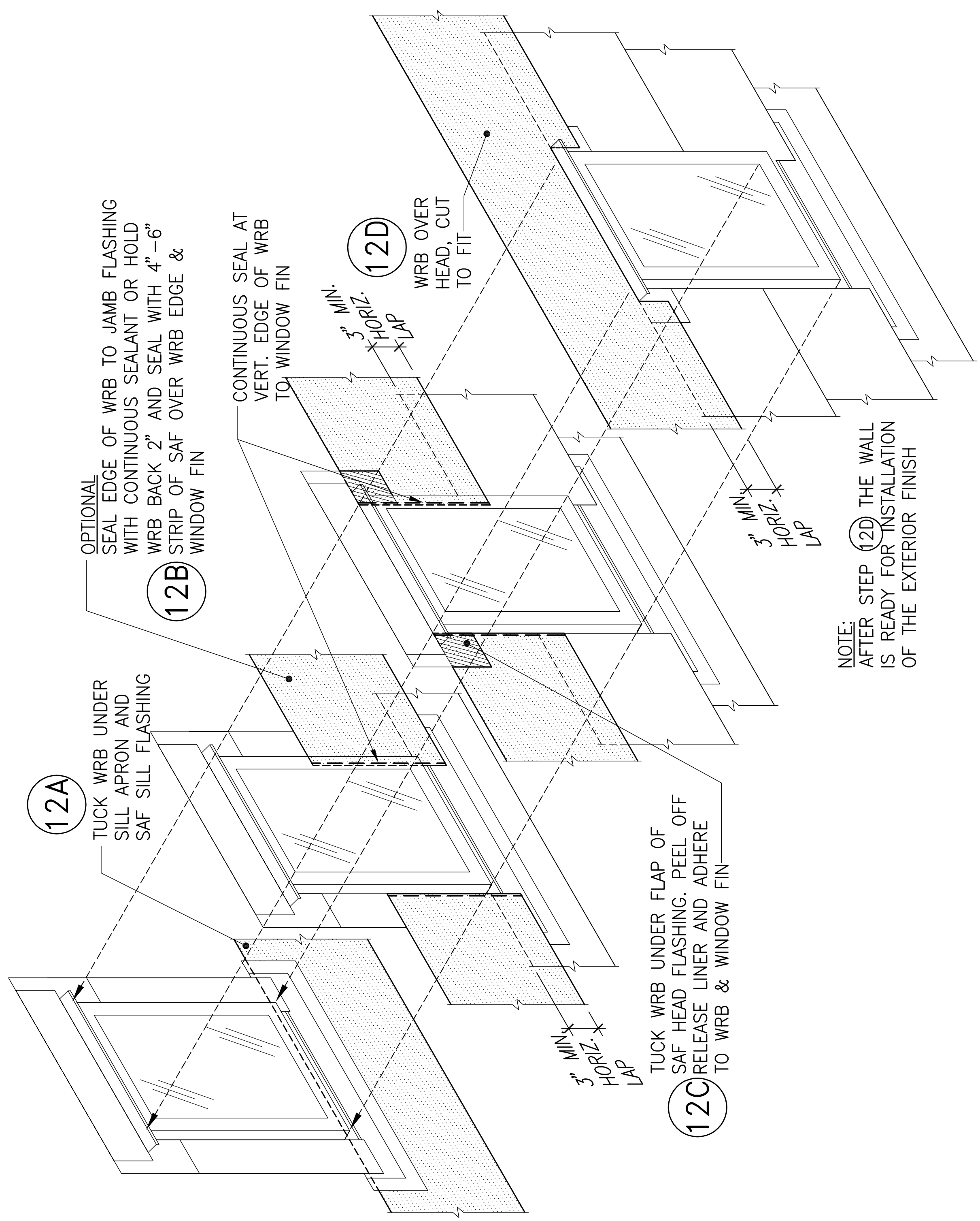
Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.

Appendix 2



SAF flush wall.

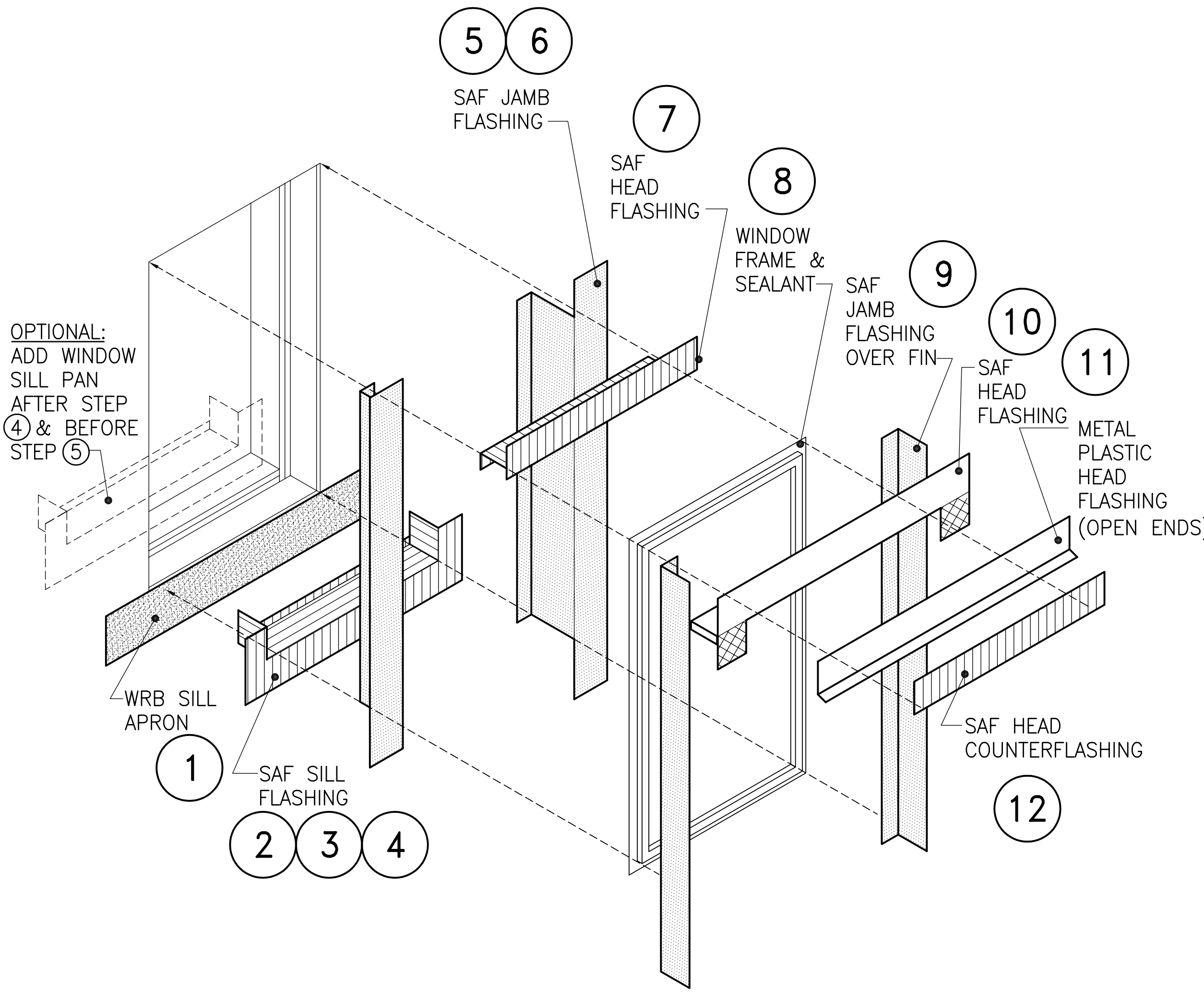
Designer's Note: Specific detail configurations, sequences and installation procedures must be independently developed by the design professional for each particular project.



SAF flush wall.

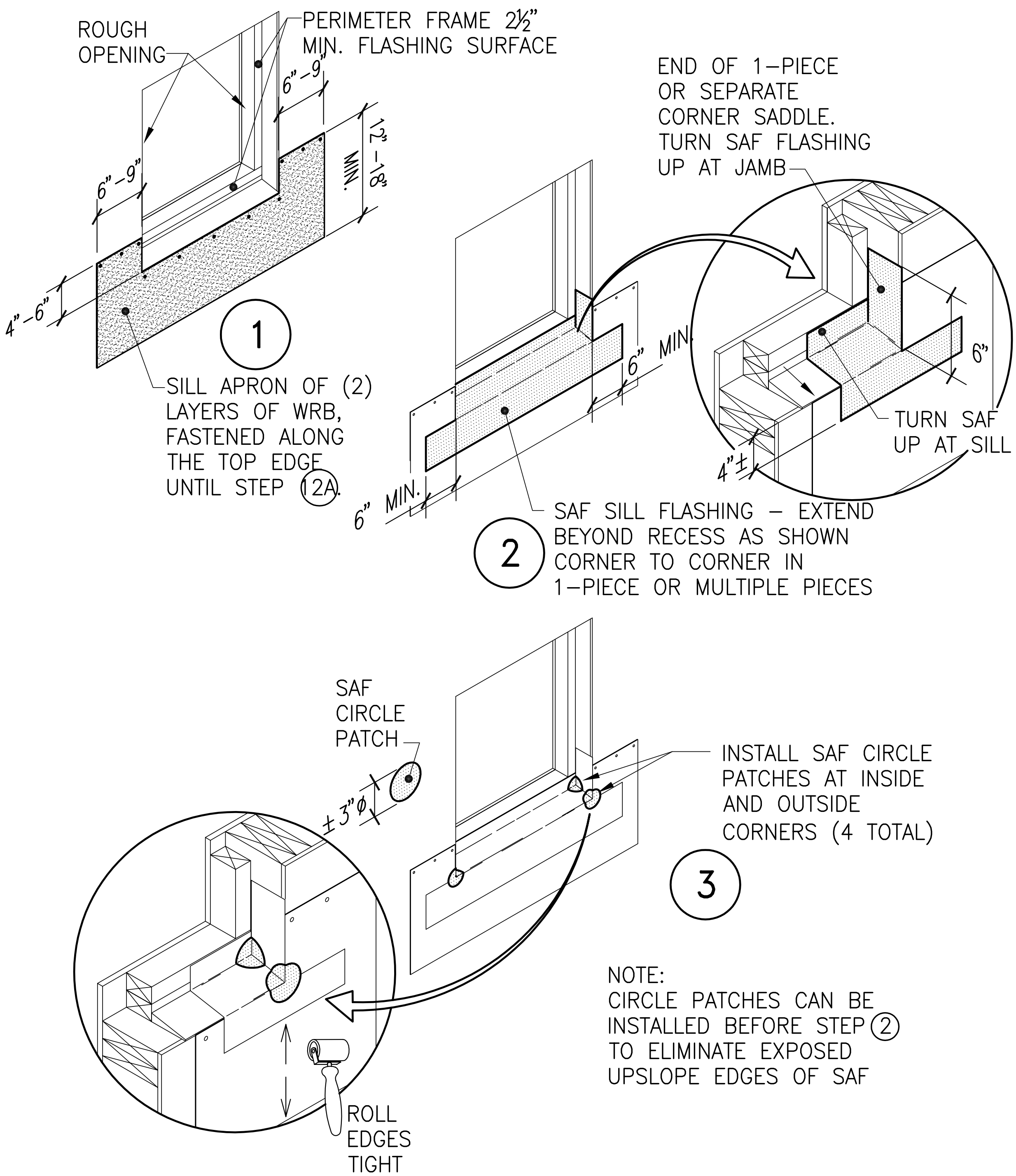
Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.

Appendix 3

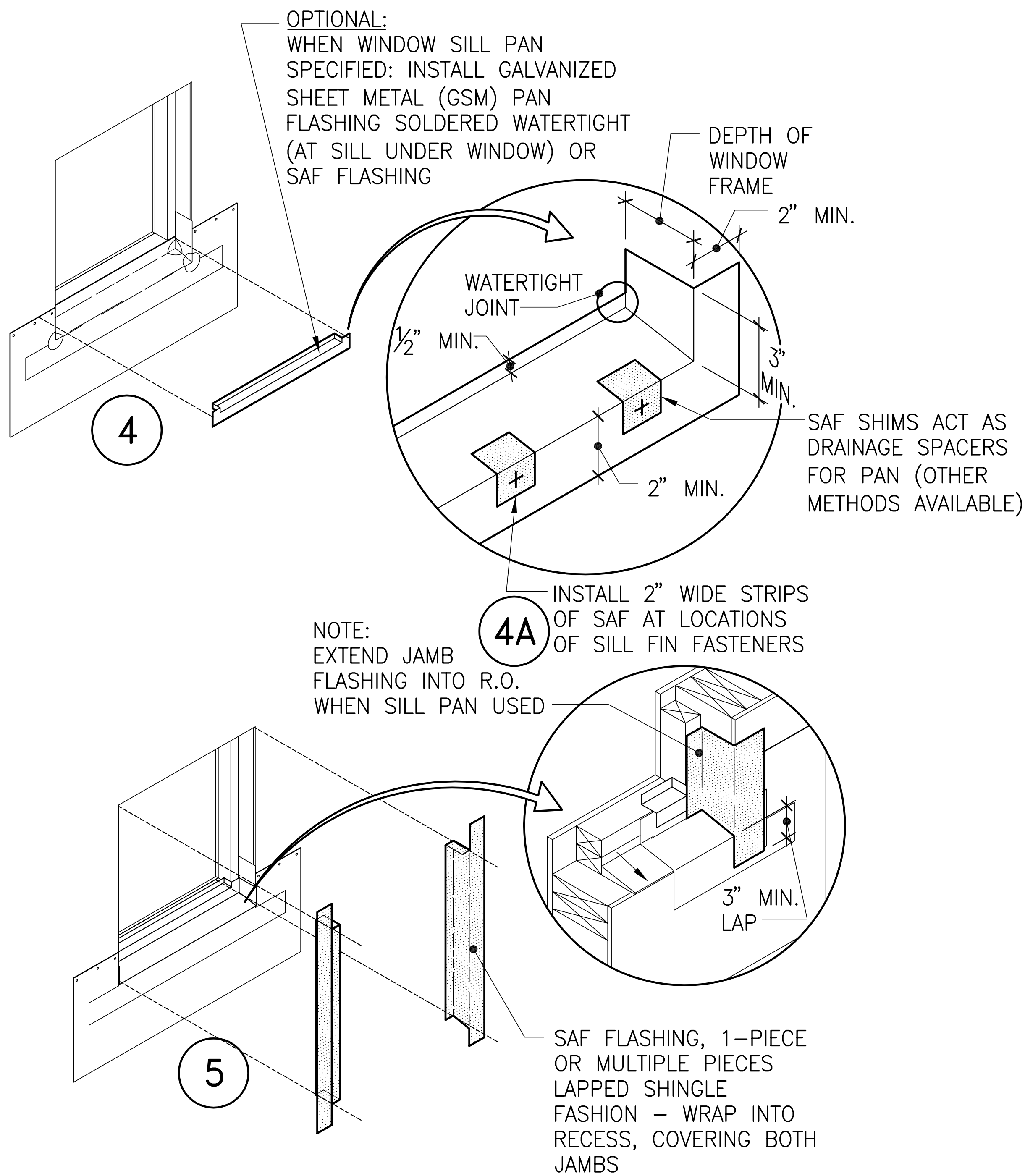


SAF recessed window opening flashing – Method C.

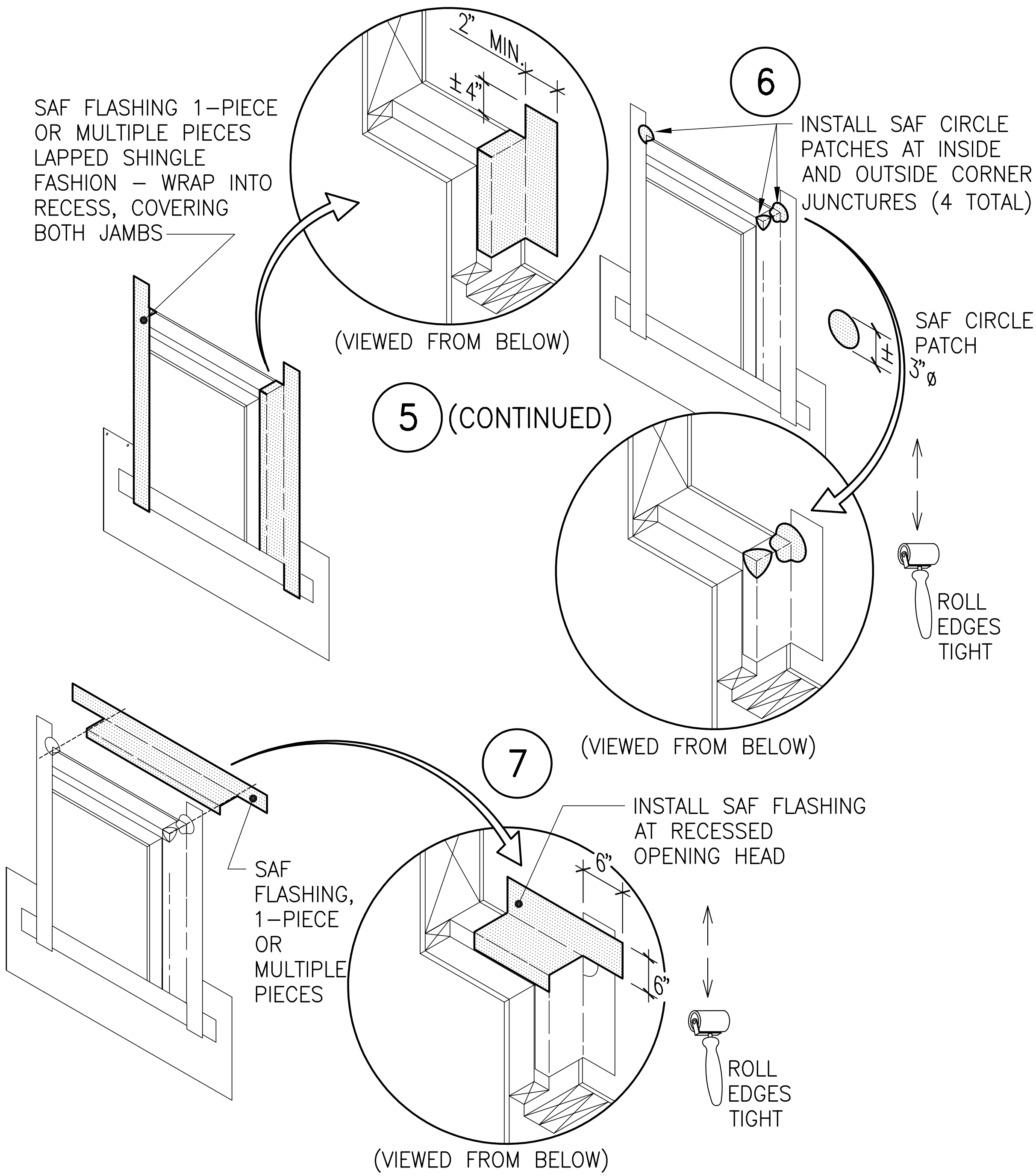
Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.



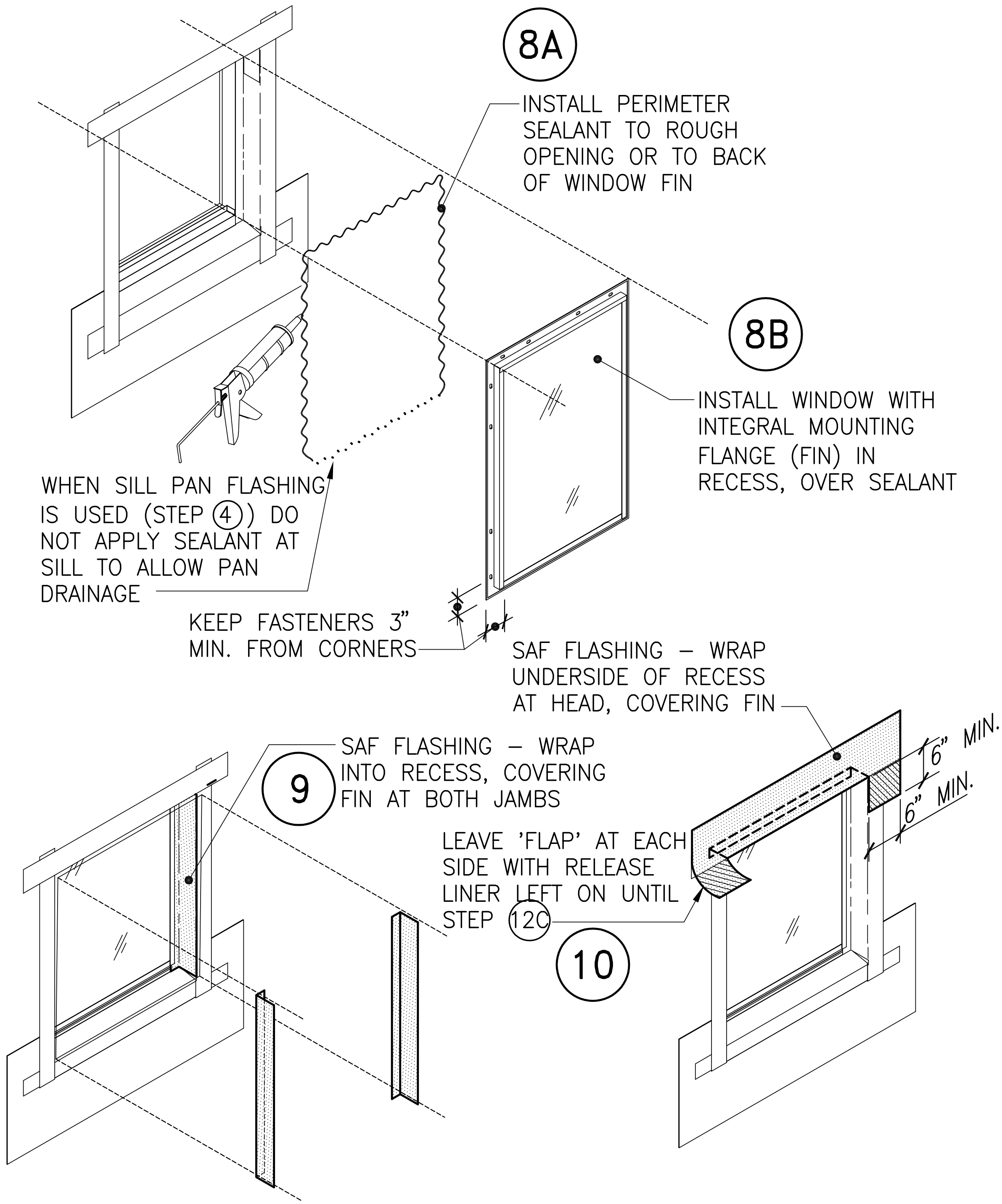
Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.



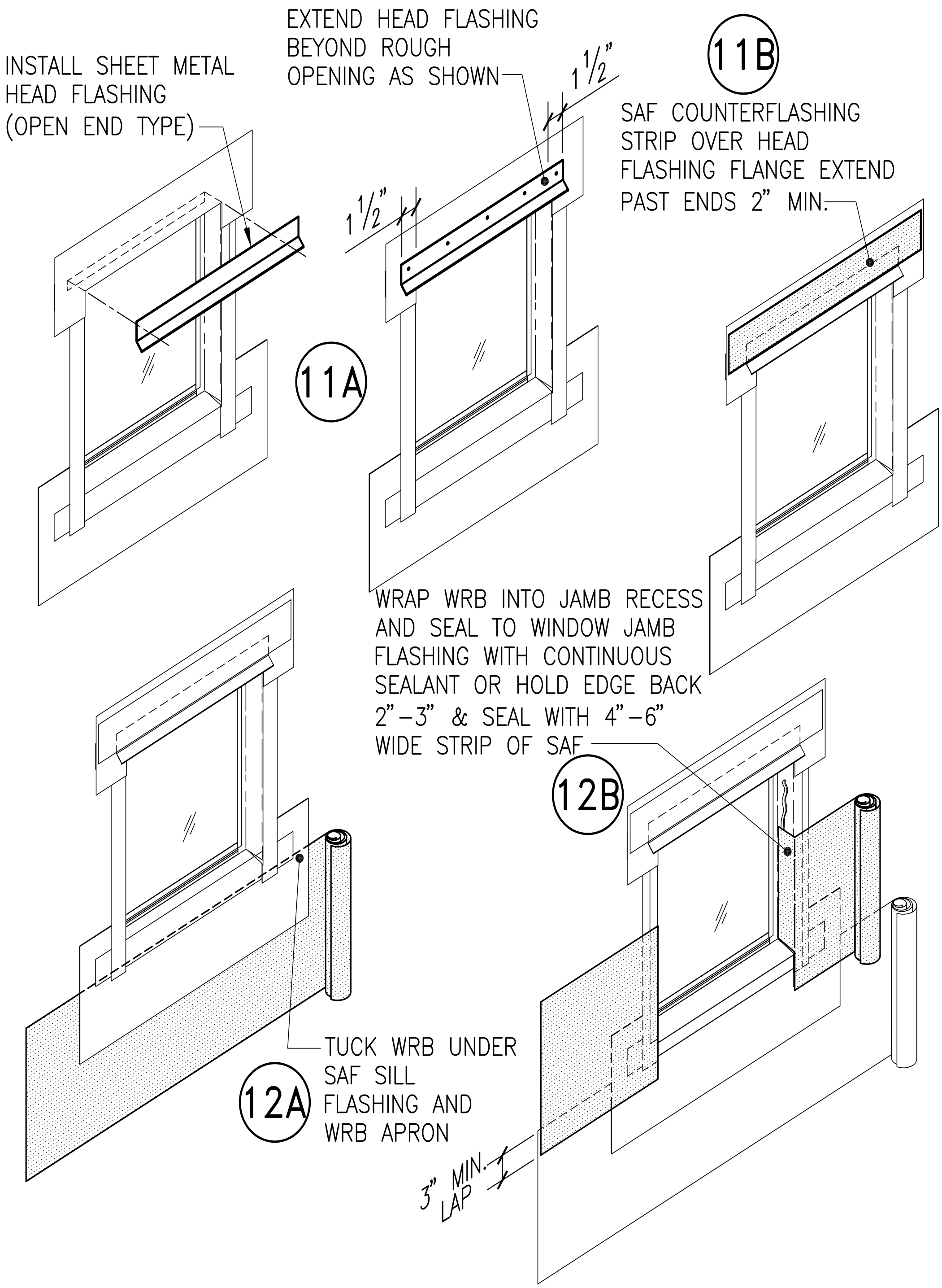
Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.



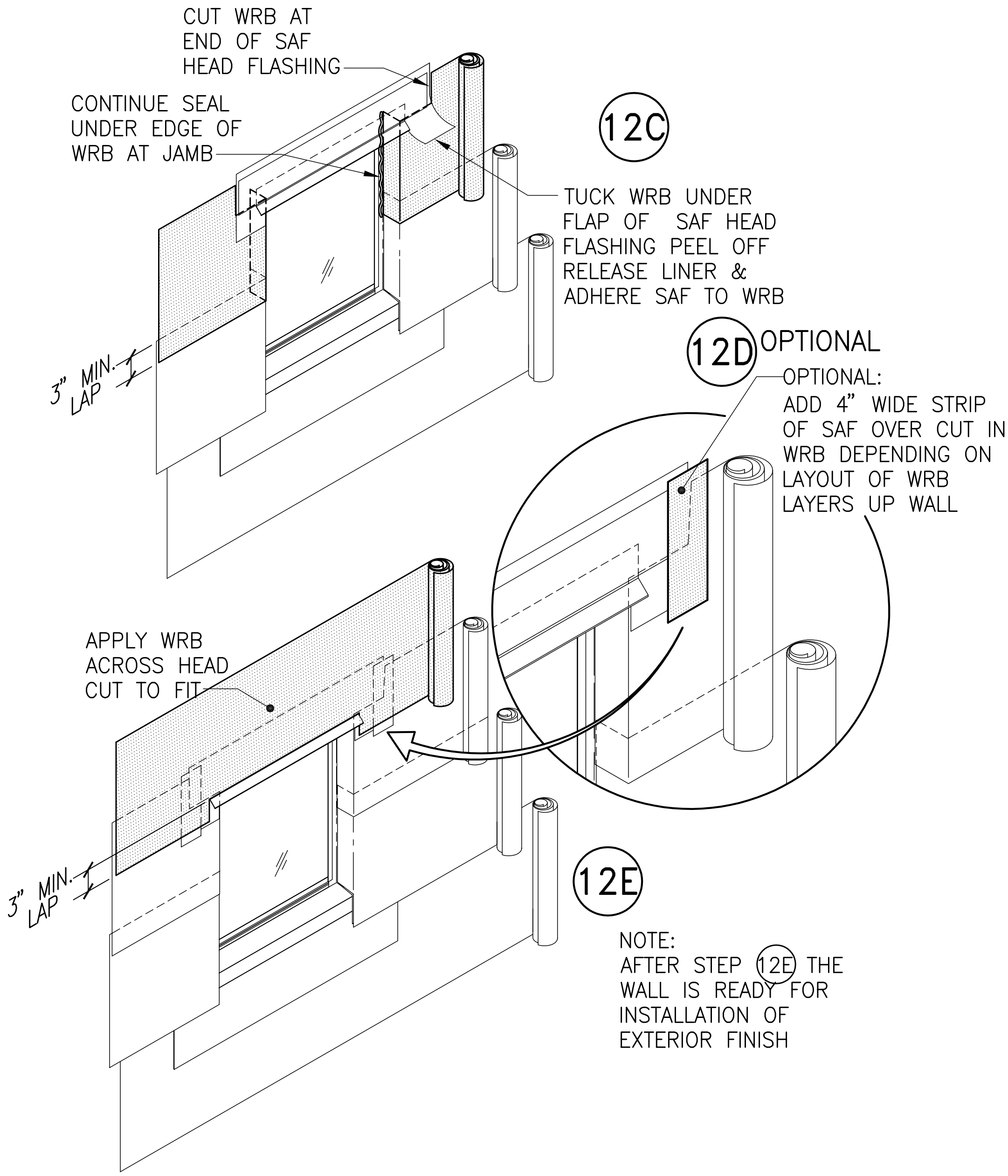
Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.



Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.



Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.



Designer's Note: Specific detail configurations, sequences, and installation procedures must be independently developed by the design professional for each particular project.

Appendix 4

SECTION 07660

SELF-ADHERING FLASHINGS

Specifier's Note: Edit specification content and format to suit particular project. This guide specification is not intended to be used word-for-word on any particular project. This specification presumes use with a wood-frame or steel-frame construction and an exterior wall sheathing and integral nail-fin windows, doors, and vents. It can be the basis of a specification for other systems with appropriate modifications.

PART 1 - GENERAL

1.01 SUMMARY

A. Section Includes: Installation of flexible, self-adhering membrane flashing consisting of, but not limited to, the sealing and flashing of windows, doors, wall penetrations, and above-grade building areas needing protection against water intrusion.

Specifier's Note: Edit related work sections as appropriate for the particular project.

B. Related Sections
1. Section 05410 — Load-Bearing Metal Studs Systems. [Bearing steel studs]
2. Section 06100 — Rough Carpentry. [Wood studs]
3. Section 06115 — Wood based Sheathing [plywood, Oriented Strand Board(OSB)].
4. Section 07260 — Vapor Retarders.
5. Section 07620 — Sheet Metal Flashing and Trim.
6. Section 07915 — Sealants, Caulking, and Seals.
7. Section 08100 — Metal Doors and Frames.
8. Section 08200 — Wood and Plastic Doors.
9. Section 08500 — Windows.
10. Section 08550 — Wood Windows.
11. Section 08560 — Plastic Windows.
12. Section 91000 — Metal Support Assemblies [non-bearing steel studs].
13. Section 09253 — Gypsum Sheathing (Gypsum Sheathing, Fiberglass-faced Sheathing).

1.02 REFERENCES

A. AAMA – American Architectural Manufacturers' Association
1. IM-TM – "Installation Masters" Training Manual, 2000.
2. 501.2 – Field Check of Metal Curtain Walls for Water Leakage.
3. 502 – Voluntary Specification for Field Testing of Windows and Sliding Glass Doors.

B. ASTM International
1. D 142 – Test Methods for Sampling and Testing Bitumen – Saturated Felts and Woven Fabrics for Roofing and Waterproofing.

2. D 412 – Test Methods for Rubber Properties in Tension.
3. D 903 – Test Methods for Peel or Stripping Strength of Adhesive Bonds.
4. D 1970 – Specification for Self-Adhering Polymer Modified Bituminous Sheet Materials Used as Steep Roofing Underlayment for Ice Dam Protection.
5. D 3767 – Practice for Rubber – Measurements of Dimensions.
6. E 96 – Test Methods for Water Vapor Transmission of Materials.
7. E 1005 – Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls and Doors by Uniform or Cyclic Static air Pressure Difference.
8. E 2112 – Practice for Installation of Exterior Windows, Doors and Skylights.

1.03 SUBMITTALS

A. Product Data
   1. Submit 2 copies of manufacturer's literature for all products furnished.
   2. Submit 2 copies of MSDS (Material Safety Data Sheets).

B. Sample(s). Submit 1 sample of various sizes and types of product used on project.

1.04 QUALITY ASSURANCE

Applicator: Installer shall be familiar with self-adhering flashing products and shall have experience in flashing installation. Flashing shall be installed by skilled workers trained for this type of work.

1.05 DELIVERY, STORAGE AND HANDLING

A. Deliver materials to job site in sealed, unopened cartons and construction.
B. Store products with protection from direct weather exposure.
C. Stack preformed material to prevent twisting, bending, or abrasion, and to provide ventilation.
D. Prevent contact with materials during storage which may cause discoloration, staining, or damage.
E. Read and follow instructions from MSDS for proper handling and disposal of materials.

PART 2 - PRODUCTS

2.01 MATERIALS

Specifier's Note: Select adhesive material type, usually rubberized asphalt based or butyl based, after determining desired performance and use of the flashings.

A. General: Self-adhering flashing consisting of a waterproof adhesive sheet membrane with an outer facing and release liner backing as manufactured by:
   1. ____
   2. ____
   3. Or approved equal.

B. Specific Products
   1. __ mil thick, ________for general flashing purposes.
   2. __ mil thick, ________for counterflashing purposes.

2.02 ACCESSORIES

A. Primer: Manufacturer's recommended primer for porous substrates, such as concrete, masonry, gypsum-based sheathing, and wood-based sheathing.

B. Sealant: As specified in Section 07900.

Specifier's Note: Sealant used in conjunction with the self-adhering flashing can be specified in this section. Regardless of where specified, the sealant needs to be chemically compatible with the flashing facings and/or adhesive. The sealant also needs to have good adhesion to the facing of the flashing material and adjoining materials. The specifier may need to check with both the sealant and flashing manufacturers for a specific sealant product selection.

PART 3 - EXECUTION

2.03 PREPARATION

A. Inspect and field measure site conditions and substrates prior to field fabricating work.

B. Substrates shall be clean, dry, uniform, and smooth prior to flashing application. Remove protrusions, and fill voids at substrates as necessary. Ensure fastener heads are set flush with substrate surfaces.

C. Allow wet substrates to dry thoroughly. Clean dust and debris from all substrates. Wipe metal surfaces with films or coatings interfering with adhesion clean.

D. Prime porous substrates according to manufacturer's recommendations.

E. Provide solid continuous backing or substrate filler to support all portions of self-adhering flashing.

2.04 INSTALLATION

A. General

1. Manufactured Products: Comply with manufacturer's written instructions.
2. Proceed with installation in conjunction with related waterproofing and flashing in each area.
3. Do not dilute primers, coatings, or sealants.
4. Keep containers closed except when removing materials from them.

B. Except as otherwise specifically shown on Project Drawings or approved shop drawings, conform to details included in manufacturer's recommendations.

C. Fit flashings tight in place. Make corners uniform, surfaces flat and straight in planes, and lines accurate to profiles.

D. Lap joints for continuous contact. Lap joints in direction of moisture drainage with laps oriented in shingle fashion, unless specifically designated otherwise.

E. Fabricate corners, transitions, and terminations with a minimum number of pieces. Provide a patch at pinhole conditions. A circle cut from the self-adhering membrane about 3 in. in diameter can be used to lap and cover pinhole conditions.

F. Do not apply self-adhering flashings to bridge or cover unsupported voids, gaps, or offset materials.

G. Roll all flashing seams and laps with a hand roller to flatten the flashing tight to substrates and itself for complete adhesion. Use a hand roller to remove air pockets near seams and laps. The hand roller should be solid with about 1–2 in. in width (rollers used for plastic laminate or wall paper installation are usually suitable). Do not roll a sharp edged roller too close to inside corners that could puncture the flashing.

2.05 POST-INSTALLATION PROTECTION

A. Protect exposed flashings after installation from mechanical damage, abrasion, and items, such as falling debris.

B. Do not exceed manufacturer's limits for direct weather exposure. Cover flashings, and provide protection from the direct sun exposure for prolonged construction periods.

C. Hand roll loose seams, laps, channels, fishmouths, and air bubbles prior to covering flashings.

D. Inspect for tears, rips, punctures, and other damage. Repair damage to flashings prior to covering flashings.

E. Apply final finish coverings over flashings in the proper construction sequence as soon as practical.

2.06 FIELD QUALITY CONTROL

A. Field Testing, Mock-Ups and Inspection shall be performed under provisions of Section 01400.

B. Water Testing. Coordinate flashing testing at wall opening perimeters with field testing provisions of the window and door sections of the Specification.

1. Extent of Testing: Test completed flashing installation for each type of opening condition. This testing can be accomplished with a mock-up program.

Specifier's Note: Determine the number of samples or test locations. For example, the 1990 AAMA 502 called for 3 locations. The 2002 AAMA 502 calls for 1 field test location with projects having less than 100 openings.

2. Test Methods: Test self-adhering flashing assemblies by methods described below:

a. Overall Opening Flashing - Use ASTM E 1105 or AAMA 502, Method B, spray rack test at zero pressure and up to a negative test pressure determined by the specifier.

Specifier's Note: Determine the test duration. ASTM E 1105 calls for a 15-min duration. This is based on window/door manufacturers' tests for the product in isolation. With a completed installation in a wall opening, a greater time duration may be appropriate for evaluating the flashings and completed components of the wall interface. The window/door unit can be isolated from the test if durations longer than 15 min are specified. Determine extent of perimeter wall assembly to include. The E 1105 and AAMA 502 spray rack tests do not indicate how much perimeter opening interface to include in the test area covered by the water spray. At least a 12-in. perimeter would address most wall cladding and flashing types. Adjust the dimension to suit the wall construction to account for other adjacent materials.

b. Sill Pan Flashing – Use AAMA 502, Method A, Optional Sill Dam Test at sill pan flashings under windows as part of the window sill track test.

Specifier's Note: Determine the test duration. For example, The 1990 AAMA 502 called for a 15-min duration at the sill track. The 2002 AAMA 502 does not indicate a sill test time period.

Determine height of water level. The 1990 AAMA 502 indicates to fill the sill track to the top of the rear leg. The 2002 AAMA 502 calls for filling the sill track (static water head height) to the height appropriate for its performance. If the unit manufacturer has not indicated this dimension, testing procedures and failure results could be subject to disagreement.

c. Opening Perimeter Flashing/Leak Diagnostic Survey – Use AAMA 501.2 spray nozzle test to supplement the spray rack tests. The AAMA nozzle can be used for determining specific leak locations or leak paths at perimeter flashings not passing the overall opening test.

Specifier's Note: Determine the test duration. AAMA 501.2 calls for a 5-min duration at the juncture of sash and frame or frame-to frame joints. If the AAMA nozzle is used to test the wall interface, a longer time period may be appropriate. Up to a 20-min period can be needed to diagnose delayed water leakage at concealed flashings and perimeter wall cladding materials.

2. Repair and Retest: Make repairs to failed flashing assemblies and retest until passing.

C. Inspection. Provide independent Structural Observation or Special Inspection service during construction to monitor the flashing installation. The Structural Observation or Special Inspection service shall comply with the applicable building code requirements. The observation/inspection can occur on a periodic basis.

END OF SECTION

Reference and Biography

Bateman, R., "Designing and Specifying Self-Adhering Flashings for the Window-Wall Interface," *Journal of ASTM International*, Vol. 2, No. 10, ASTM International, West Conshohocken, PA, November/December 2005.

Robert Bateman is a Senior Staff Architect with Simpson Gumpertz & Heger, Inc. (SGH) in San Francisco, California. He is a licensed architect in California and Washington, a licensed general contractor in California and an ICC certified Building Inspector and Plans Examiner. He is a member of the AIA, CSI, AAMA, and participates with ASTM E06 Committee task groups developing standards for weatherproofing buildings. He participated in the development of ASTM E 2112-01, CAWM 400-95, CAWM 410-97 and other window installation references and standards.

This paper was presented at the June 10–11, 2004 BETEC Spring Symposium, "Membranes in Enclosure Wall Systems," which was a follow-up to the April 18, 2004 ASTM E06 Symposium, "Performance and Durability of the Window-Wall Interface."

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Paper ID JAI12488
Available online at www.astm.org

Robert J. Kudder[1], *Ph.D., Sarah K. Babich,*[2] *and Dennis K. Johnson*[3]

Effect of Installation Details on the Condensation Performance of Window Frames

ABSTRACT: Industry standard tests and calculation methods under laboratory conditions are used to determine a Condensation Resistance Factor (CRF) for window frames. The CRF is one of several performance parameters used to select fenestration products for specific conditions of exposure and occupancy. Colder climates and higher interior humidity typically require fenestration products with higher CRFs. The CRF by itself is not necessarily a predictor of the ability of a window frame to resist interior surface condensation due to thermal bridges or breaches in thermal breaks created by installation details, rough opening materials, and surrounding wall details. This paper explores the affect of installation details on the interior surface temperature of metal window frames, and indirectly, the likelihood of surface condensation on the frame.

KEYWORDS: condensation, CRF, dew point, modeling, THERM program, window frames

Building construction, operation, and usage can promote conditions leading to condensation and frost formation on wall components in northern geographic locations during winter conditions. Even though cold climates typically result in reduced interior relative humidity (RH) values due to heated interior air, occupants can find these lower RH conditions objectionable from a comfort and health perspective or from concerns about maintaining appropriate environments for stored contents. To attain more desirable conditions, forced mechanical humidification becomes necessary. For example, hospitals maintain 40 % RH because these conditions have been found to comfort patients with respiratory problems, although it was originally intended to control static electricity and sparks near volatile materials like ether. Computer centers are humidified to minimize the likelihood of static electric discharges that could damage expensive equipment or contribute to the loss of vital, stored information. Libraries and museums humidify to increase and stabilize interior moisture levels to help preserve books and archival materials, while concert halls humidify to help stabilize musical instruments. In some instances, building usage by its very nature can generate high interior RH, such as pool enclosures, shower rooms, greenhouses, food, and industrial processing plants. However, with increased humidity levels come increased potentials for condensation.

Controlling Condensation of Windows

Condensation or frost formation within and on the interior surfaces of exterior walls is traditionally controlled by incorporating various forms of insulation in the wall system design and restricting vapor movement through the wall. Insulation serves to keep the surfaces above the dew point temperature (DPT). Similarly, vapor and air barriers contribute to condensation

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[2] Architect II, Raths, Raths, and Johnson, Inc., 835 Midway Drive, Willowbrook, IL 60527.
[3] Consulting Engineer, Raths, Raths and Johnson, Inc., 835 Midway Drive, Willowbrook, IL 60527.

control by limiting the mass of water vapor transported into the wall by diffusion or along air paths. However, both of these control strategies may be impractical or unfeasible at window locations, and therefore, different vapor control approaches specific to windows must be considered. Some of the design alternatives that have been developed for windows to improve condensation resistance are the following:

Insulating Glass Units (IGU)

The air or inert gas confined between two or more layers of glass or other isolating media comprising the insulating glass unit creates a temperature gradient across the plane of the IGU, which functions as insulation. However, the heat transfer across the typical edge spacers separating glass panes is greater than the heat flow through the gaseous layers, resulting in thermal bridges. To compensate for this design dichotomy between the center and edges of the glass, "warm edge" technology has evolved and improved the thermal characteristics of the edge spacers by using different materials or by increasing the heat flow resistance of traditional materials.

Multiple Sashes

In applications where a single layer of glass or a single IGU does not provide sufficient control of surface temperature, additional sashes or window assemblies are used in the window opening. Traditional storm windows and multi-sash windows used in hospitals are examples.

Framing Materials and Construction

The conductivity of the material selected for the window and sash frame construction influences the surface temperature of the frame, where lower conductivities can provide warmer interior surface temperatures. For example, wood has moderate conductivity and has historically provided success in resisting surface condensation. Modern composite materials and plastics also exhibit moderate conductivity, while metals, such as aluminum, brass, copper, and steel, have relatively high conductivity levels. Because window frames fabricated from aluminum can conduct heat very rapidly from the interior to the exterior and result in low interior surface temperatures, manufacturing techniques have been developed to counter the adverse effects of this material property. By incorporating a plastic band or other low conductivity strip into the aluminum frame cross-section, the continuous conductive heat transmission path is interrupted, and the heat transfer through the metal is reduced. The inserted thermal barrier material is often identified as a "thermal break" and results in a "thermally broken" or "thermally enhanced" frame.

Heat and Air

The heat and air circulation on the interior side of the window are also factors in controlling condensation on the window. Warm interior air provides heat to keep the surface temperature of the window above the Dew Point Temperature (DPT). Because interior air can stratify vertically and horizontally as it is cooled by the window, a method to renew and maintain the supply of heat to the interior window surfaces is needed. The traditional method is to wash the window with air, which also serves to dry condensation that may form and prevent or reduce its accumulation.

Operations

Although a constant level of interior RH is usually sought, it may not always be possible or desirable. Buildings operated in a manner that produce relatively high interior RH levels or those buildings constructed with materials that will release accumulated or construction moisture to the interior air during cold weather may create conditions that exceed the inherent condensation resistance of the window frame and glass components. Both conditions may create unacceptable frost and condensation on the windows.

Heat Transfer

Heat is transferred through window and wall systems by several mechanisms, defined as:

Conduction—Heat transfer through a solid, liquid, or gaseous material from a high temperature location to a low temperature location.
Convection—Heat transfer by air that moves under the influence of a density gradient. The moving air accumulates heat energy in a high temperature area and releases it to a low temperature area as it moves.
Radiation—Heat transfer by electromagnetic energy from an emitter at a high temperature to an absorber at a lower temperature. This mechanism can operate through a vacuum or through a gas.
Air Leakage—Heat transfer by air that moves under the influence of a differential pressure gradient.

As a consequence of this heat transfer or energy flow, temperature gradients develop between the inside and outside surfaces of the window. The enclosed spaces of the building can experience either heat gains or losses depending upon the interior and exterior environmental conditions. When the inside surface temperature of the window is lowered below the DPT during cold weather, unwanted condensation or frost formation can occur on the exposed interior surfaces. In addition, to maintain a relatively stable interior environment within normally accepted comfort zones, the building's mechanical system must use energy to add moisture to compensate for humidity removed from the interior air by condensation.

Rating Condensation Performance

To provide the building designer with product information regarding the thermal characteristics of window systems, various test procedures, and other analytical methods have been developed. Because the vulnerability of aluminum windows to condensation formation was a major concern, the American Architectural Manufacturers Association (AAMA) developed and published a standard for rating windows in terms of a condensation resistance factor (CRF) in 1972 in their standard AAMA 1502.3 [1]. This test method uses thermocouples to measure multiple interior surface temperatures of the frame and glass of standard-sized window specimens. The dimensionless CRF number is then computed based on the ratio of the numerical difference between the average measured inside surface temperature of either the frame or the glass and the cold side air temperature and the difference between the warm side air temperature and the cold side air temperature. Based on these tests, the CRF number is determined for both the glass and the frame. Since publication of the original standard, several changes have been made, and currently the test is conducted with a warm side air temperature of 70°F (21.1°C), a cold side air temperature of 0°F (-17.8°C), a 15 mph (25 km/h) perpendicular air flow on the cold side, a natural convection air flow on the interior, less than 15 % RH on the warm side. The test is performed without a differential air pressure across the window specimen, which in effect eliminates air infiltration and any influence it might have on the thermal and condensation performance of the window. AAMA has also extrapolated this CRF data to provide generic guidelines for assisting designers in selecting the appropriate CRF number at different cold weather design temperatures and different interior relative humidities.

To supplement this CRF information, AAMA published another test standard, AAMA 1503.1-80 in 1980 [2], which provided test procedures for measuring the thermal transmittance (U-factor) or air to air heat flow resistance capabilities of fenestration products. Steady state temperature differences and other criteria were established so that the heat flux could be measured and the U-factor determined [3,4]. ASTM International has also developed test methods and practices for determining the steady state thermal transmittance of fenestration systems including ASTM C 1199, ASTM C 1363, and ASTM E 1423 [5–7]. These ASTM test methods utilize similar warm side and cold side air temperatures of 70°F (21.1°C) and 0°F (–17.8°C), when testing fenestration systems. Interior air flow is also similar to AAMA, but the exterior air flow can be perpendicular or parallel to the plane of the glass. With the adoption of similar test parameters, the AAMA and ASTM test methods provide a basis for obtaining U-factor test results that can then be used with other analytical tools.

The National Fenestration Rating Council (NFRC) and its evaluation system for fenestration thermal performance next emerged as advancements in computer modeling programs were developing [8]. Computer modeling provided a new method of analysis that proved to be more economical and time-efficient than earlier chamber testing done in research and testing laboratories. Some of the first publicly distributed thermal performance simulation programs, such as WINDOW, FRAME, and KOBRU, were developed over two decades ago and calculated one-dimensional heat transfer [9]. Two-dimensional advancements were eventually released using the finite difference method (FDM), but these programs were still somewhat limiting. Ultimately, in 1995, a steady-state, two-dimensional heat transfer program using a refined finite element numerical method was released under the name of THERM [10,11]. THERM was developed by Lawrence Berkeley National Laboratory for NFRC rating purposes and incorporates the finite element method (FEM) to accommodate complex geometries and the effect of thermal bridges in walls and other interfacing components. THERM also incorporates element-to-element radiation heat transfer concepts for comprehensive design analysis.

Computer modeling provides consistency, accuracy, and reproducibility for rating systems for thermal performance. Previous studies over the past decade indicate that computer simulation models are reliable, producing results within 10 % of chamber testing results. Because acceptable correlation exists, many countries have adopted simulation modeling to assist in their fenestration rating program, and countries such as Canada have gone so far as to only require testing when computer simulation models are challenged. Simulation modeling has progressed beyond its initial use for window research and rating purposes.

All of the standards and their associated tests or analytical methods described above address the performance of a window as an isolated component, with no interactions or interfaces with other components of the wall. The installation conditions surrounding the window, including perimeter seals, air temperature and velocity, and the thermal properties of adjacent construction, are carefully prescribed in the standards. These prescribed conditions result in consistency and reproducibility in the CRF but do not necessarily represent service conditions. Fortunately, modern simulation modeling tools can be considered a viable option for thermal and condensation performance analysis of project-specific conditions including other wall components, in addition to the window itself.

Actual Condensation Performance

Both the CRF and U-Factor test methods, as well as simulation models, apply steady state measures at specific environmental conditions to obtain their results. However, many other variables can influence the results, including diurnal environmental changes; adjacent wall construction and building materials; interior finishes; building operating practices; location of heat sources relative to the windows; actual wind speeds; terrain and adjacent building locations; variations in building height and elevation; the size, shape, and finish of the fenestrations; and air leakage. Because the standardized CRF tests and models do not account for these dynamic environmental and building effects, the CRF values can be misleading and ineffective in predicting overall performance. Actual installation and wall construction can compromise the window design and jeopardize the system performance. Interpolating data beyond the test parameters may not accurately depict performance at those extended conditions.

Aluminum framing for windows and curtain walls is the dominant material choice for mid- and high-rise commercial buildings. Based on the writers' experience, significant differences between the condensation performance implied by the CRF and the actual condensation performance can be encountered. Resistance to the formation of surface condensation on a thermally broken window frame can be inferior to the performance implied by the CRF for several reasons. As indicated above, the CRF test itself may not be an applicable representation of service conditions. More importantly, the installation details of the window can differ significantly from the conditions of the CRF test, defeating the contribution of the thermal break. The conventional thermal break interrupts heat conduction from the interior to the exterior within the metal components of the window frame itself, in a direction perpendicular to the surface of the wall. If the installation details result in an alternative heat conduction path that bypasses the thermal break, or if the wall configuration exposes the frame to a temperature gradient with low temperatures on the interior side of the thermal break, then the thermal break is breached or bridged and cannot function properly. A variety of very common wall construction details can have unexpected adverse affects on the functionality of the thermal break and diminish the condensation performance of the window. Examples are discussed below.

Cold Cavity Air

The exterior brick wythe is a poor insulator, and the temperature of the air in the cavity closely approaches the exterior air temperature. If cavity air contacts the frame material on the interior side of the thermal break, the frame temperature can be reduced, approximating conditions as if there were no thermal break at all (Fig. 1). An effective way to prevent this problem is to detail an air barrier around the perimeter of the rough opening. This will prevent cavity air from reaching the frame on the interior side of the thermal break. A peel-and-stick membrane material is suitable for this purpose. Also, filling the space between the frame and the rough opening with insulation, such as spray polyurethane with controlled or limited expansion, further limits the contact between cold cavity air and the window frame.

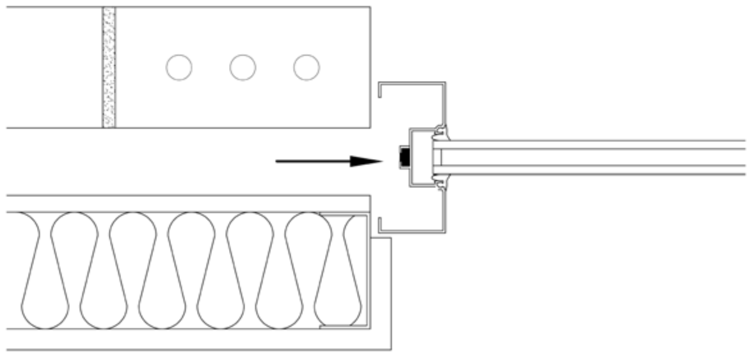

FIG. 1—*Cold cavity air.*

Break-Metal and Non-Thermally Broken Flashing Pans

Through-wall pan flashing is essential for controlling leaks at a window opening. Compatible thermally broken flashing and sill starter sections are available as accessories for many thermally broken window frames. However, the use of a break-metal flashing pan with a thermally broken window frame provides an additional conductive path (Fig. 2). Most of the flashing pan surfaces will have temperatures that approach the outside air temperature and will create a cold zone inboard of the thermal break. It is not uncommon to observe condensation and frost on the upturned interior leg of a flashing pan while the window frame itself exhibits neither. Using a metal drip edge and a peel-and-stick or adhered membrane to complete the flashing pan can assist in the prevention of this problem.

Insulated Precast or Tilt-Up Concrete Panels

Insulated precast (IPC) or tilt-up concrete wall panels can present a unique problem for condensation control at window penetrations. These panels are manufactured in two acceptable ways: metal ties are used to join the inside and outside skins that clad the insulation core, or ribs of concrete form the edges and join the faces encapsulating the insulation core. Both methods are effective in reducing overall building energy consumption, but the latter method creates a significant thermal bridge at window openings. Even though concrete is a relatively poor conductor, cold concrete surface temperatures can extend sufficiently into the interior to bypass the thermal break and reduce the temperature of both the panel and the window frame below the DPT. In addition, anchoring the window to the uninsulated rib can provide an additional path to conduct heat away from the window frame. If concrete ribs are used in IPC panels, the window frame should be thermally isolated from the concrete, and the space between the window frame and the concrete should be insulated (Fig. 3).

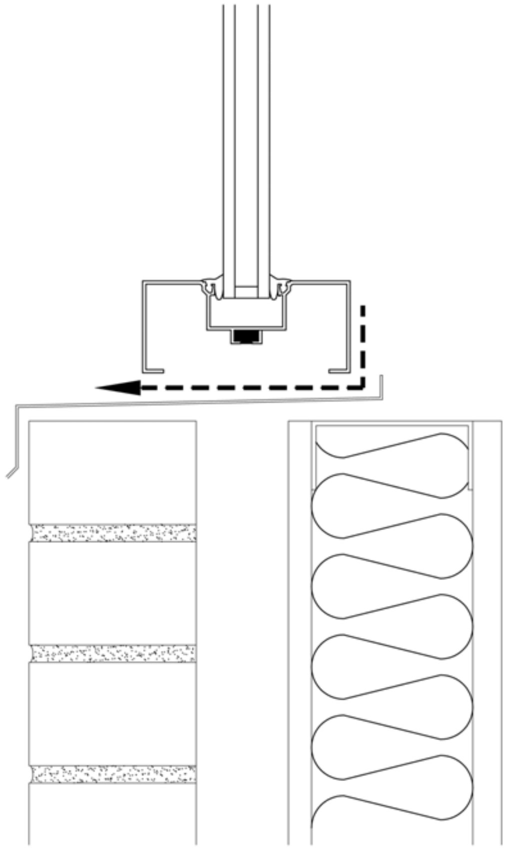

FIG. 2 – *Break-metal and non-thermally broken flashing pans.*

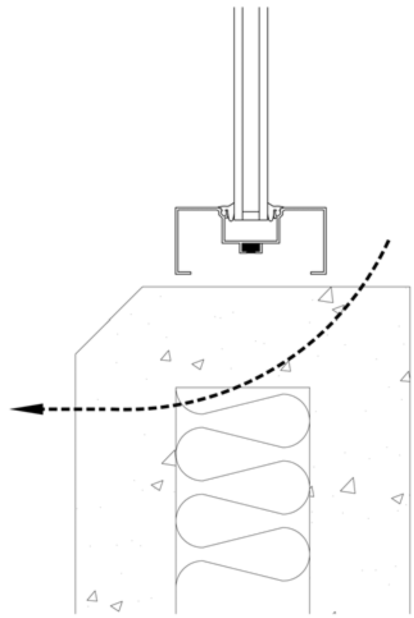

FIG. 3—*Insulated precast or tilt-up concrete panels*.

Misalignment and Imbalanced Areas

The thermal break essentially divides the window frame into a source heated by the interior air and a sink that loses heat to the exterior air. Similarly, the IGU is divided into a heat source and a sink or emitter because the confined air and edge spacers separate the glass panes and create a thermal gradient across its plane. If these window components, the thermal break, and edge spacers are not correctly aligned or if no definable plane divides the interior from the exterior, conductive, radiant, or convective heat loss paths could result that diminish the effectiveness of the thermal break. Ideal alignment in some window configurations, such as a double-hung unit, is not practical. Also, an advantage exists to locating both the glass and the thermal break closer to the exterior than the interior, thereby increasing the mass of the assembly heated by the interior air. The relative exposed area of the interior metal should also be at least as large as the exterior exposed metal so that the heat gained from the interior is more closely balanced with the heat lost at the exterior (Fig. 4).

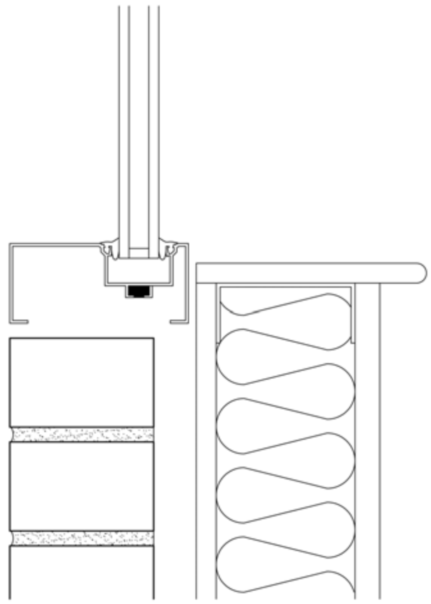

FIG. 4—*Imbalanced areas.*

Inadequate Interior Heat Supply and Air Flow

The thermal break reduces conductive heat movement through the window frame but still relies on a supply of heat at the interior surface to keep its temperature above the DPT. The building's HVAC system provides this heat. Warm air forced ventilation and baseboard heat are traditional methods for heating occupied spaces. The circulating forced air or air circulating by convection effectively wash the windows and provide heat as well as some drying to assist in removing condensation. Contemporary heating design is less reliant on forced air or baseboard heaters, and the trend is to use more radiant heat. In commercial and institutional spaces, the radiant heat is supplied by ceiling panels, whereas in residential spaces, the radiant heat is often supplied by underfloor systems. Radiant heat will raise the temperature of an exposed surface with a direct line-of-sight to the source, but it does not effectively heat the air. This trend toward radiant heat has improved occupant comfort in an economical manner, reduced drafts, and reduced the perception of low temperatures caused by convection near the windows. Unfortunately, this trend also creates new problems for condensation control at the windows. First, the wash of warming and drying air across the window is eliminated. Second, the surface of the window might not have direct line-of-sight exposure to the radiant source if the window is set outward from the interior surfaces or if the source is remote from the window (Fig. 5). Heat that might be available to the windows can also be blocked by window treatments such as curtains or blinds (Fig. 6). It is not uncommon to observe heavy condensation on windows where blinds are closed, while none is observed where the blinds are opened. It can be very dramatic to watch the condensation dry up after the blinds are opened. Conversely, interior conditions can exist where condensation may not form on the window frame until the blinds are opened and the frames are exposed to interior humidified air.

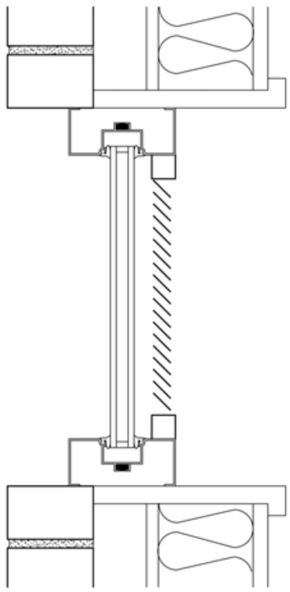

FIG. 5—*Inadequate interior heat supply.*

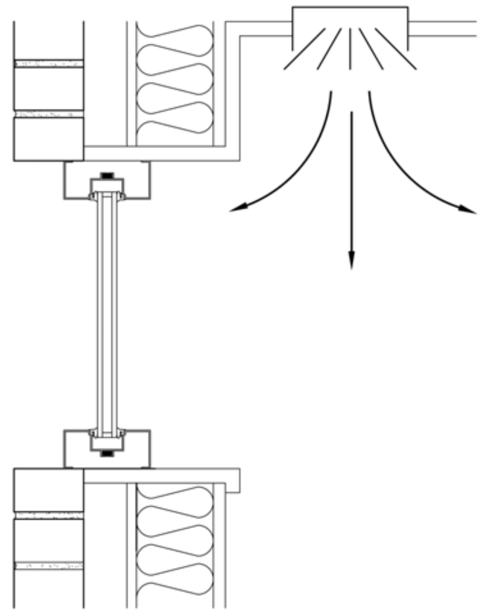

FIG. 6—*Inadequate air supply.*

Spandrel and Column Cover Conditions

Thermally broken and thermally enhanced window frames are intended to reduce heat loss along a conductive path perpendicular to the plane of the window when the window frame is exposed to a source of interior heat. This condition is approximated in the CRF test or simulation. However, in some horizontally ganged or vertically stacked window applications, window frames are glazed with spandrel glass and concealed behind an insulated section of the interior wall. As a result, the frames of these concealed windows are isolated from the interior. Condensation on the concealed window frames is typically controlled with vapor and air barrier details to prevent contact with the interior air. However, because the vision windows and the spandrel windows are connected through the framing members, a heat conduction path develops in the plane of the window in addition to the path perpendicular to the wall. As a result, a larger heat sink or emitter exists on the exterior and locally, the interior frame can become colder. This condition is seldom tested or simulated when determining the CRF. Heat will be conducted laterally from the vision to the spandrel windows unless a thermal break is installed between them (Fig. 7).

Several case studies involving window condensation performance problems that illustrate the concepts are presented below.

Case Study #1—Hospital

The aluminum, thermally broken window units installed in a health care facility in southern Minnesota were experiencing continual condensation. Based on product literature from the manufacturer and laboratory test results, the installed windows are rated with a CRF of 60. Therefore, it became necessary to consider not only the window units, but also the interfacing building components and the operation of the mechanical equipment. The “punched” window assembly, measuring approximately 8 ft wide by 5 ft high (2.4 m × 1.5 m), consists of three fixed lights and one operable vent. The frame extrusions are approximately 4-$^{1}/_{2}$ in. (1.7 cm) deep and are coated with an anodized finish. The sill pan flashing installed beneath the unit is thermally broken and supplied by the window manufacturer. The window is fastened with metal straps at the head and jambs and screws through the sill. The window sill pan has approximately $^1/_4$-in. (6.25 mm) of clearance above the sill plate.

The adjoining wall construction, from exterior to interior, consists of brick veneer, an air cavity, rigid insulation board, a building membrane, exterior gypsum sheathing, metal stud framing, and interior drywall. A sheet metal sill cover is installed extending under the sill pan over top of the brick (Fig. 8). To evaluate the conditions, a window was removed to permit examination and verified wood blocking and self-adhering membrane at the sill.

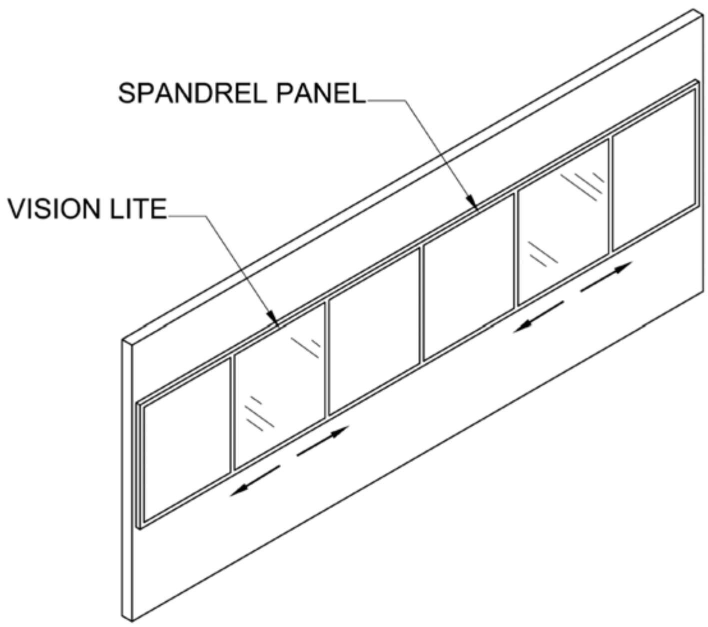

FIG. 7—*Spandrel and column cover conditions.*

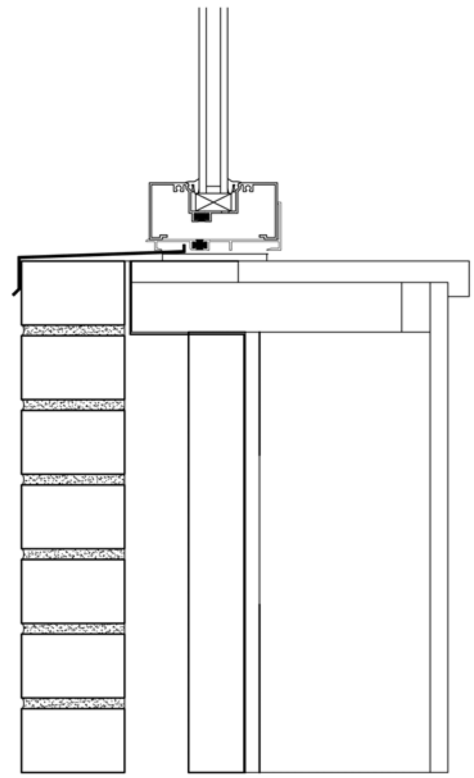

FIG. 8—*Wall construction.*

The design operating conditions are between 30 and 35 % for the interior relative humidity and an interior temperature of 70°F (21.1°C). The exterior design temperature for this location is -11°F (23.9°C) at 99.6 % confidence level. At 30 % RH, the dew point would be 37°F (2.8°C), and at 35 % RH, the dew point was calculated to be 41° F (5°C) [12].

An evaluation program using test results, computer simulation models, and trial implementation was undertaken to determine the cause(s) of condensation and to create repair schemes that would raise the frame temperatures above the determined dew point and alleviate the condensation.

Initially, chamber testing was performed on a window removed from the building at an AAMA approved facility to verify the published CRF rating of 60. Based on the laboratory tests conducted in accordance with AAMA 1503 [13,14], the window had a CRF of 59, indicating general conformance to submitted information and specified values. These test results correlated directly with results of the simulation models (Table 1). Additional environmental chamber tests were also conducted to determine the effect of the extended sill cover.

TABLE 1—*Results of tests.*

Condition	Computer Results, °F (°C)	Chamber Results, °F (°C)
Fixed, without sill cover	35.6 (2.2)	34.1 (1.2)
Vent, without sill cover	33.2 (0.7)	31.6 (-0.2)
Fixed, with sill cover	29.7 (-1.2)	31.4 (-0.3)
Vent, with sill cover	27.9 (-2.2)	26.1 (-3.2)

Using 0°F and 70°F as boundary conditions.

Installed conditions were also modeled in THERM using as-built construction information, architectural drawings, and window shop drawings as reference material. To maintain a consistent set of environmental conditions, AAMA 1503 testing parameters were used in all of the simulation models and during the testing. A reference point was established at the top of the sill, on the interior side, so that models of varying construction could be compared (Fig. 9).

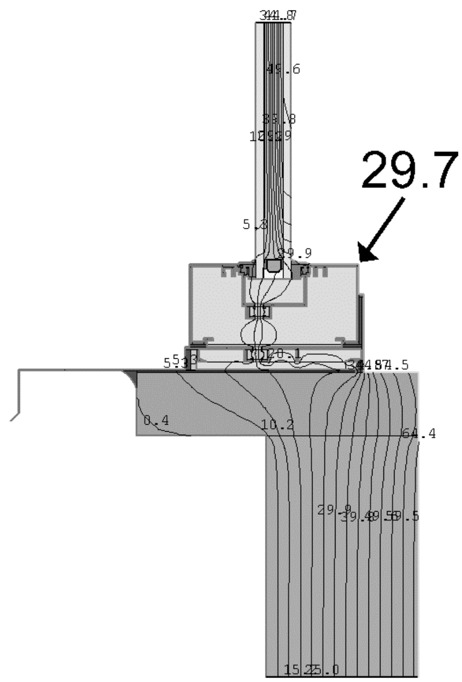

FIG. 9—*Results of computer simulation for fixed lite, with drip edge under test chamber conditions.*

Many variations were modeled utilizing expansive foam in attempts to insulate and isolate the frame from the wall cavity. However, even injecting expansive foam into the entire sill section and shim space did not raise the temperature of the frame to an acceptable range. Other logical changes that were expected to have a significant effect only yielded small changes. It was realized that the application of insulation alone would not be sufficient if the blocking under the stool continued to obstruct any warmed interior air from reaching the frame or sill pan. Once interior air was introduced by replacing the blocking with intermittent shims, the inside frame surface temperatures surpassed the minimum dew point temperature at the fixed lite framing and at the vent framing. The models helped to illustrate the counterintuitive nature of heat transfer and to understand the heat paths at this location. Based on the results of various models, the solution illustrated in Fig. 10, consisting of a new rectangular cover filled with batt insulation and applied over the existing sill cover, proved to be the least intrusive to the interior and raised the temperature of the frame to an acceptable range.

Several trial repairs involving both changes to the window unit and installation, as well as modifications to the interior environment, were implemented and monitored throughout the winter months. At one location, the original window was replaced with a unit that had the same profile and glass, however the flashing was cut to prevent a breech of the thermal barrier. At a second location, no changes were made to the existing construction, but a linear diffuser was applied to wash the window.

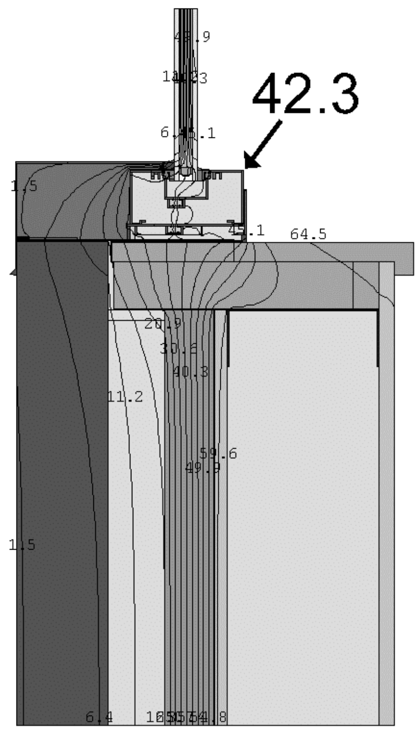

FIG. 10—*Results for computer simulation for analysis 10.*

At a third location, an exterior flashing was installed without changes to the existing construction. Results were monitored throughout the winter months but unfortunately did not eliminate the formation of condensation with closed window treatments. To address this, a perimeter fin tube radiator was installed above the floor, approximately 6 in. (2.4 cm). A slot was cut in the stool with a perforated metal diffuser to allow the heat source to reach the window with the blinds opened or closed. The laboratory testing verified the manufacturer's claims, and the computer models proved to be a useful tool in narrowing the scope of repairs and predicting the feasibility of some of the repairs before selections for mockups were made. The field mockups provided additional information that assisted in making final refinements to the repairs.

Case Study #2—Energy Efficient Residence with Clad Wood Windows

The Owner of two residential buildings in a mountainous region of the Northwest United States complained of various window problems, and the presence of condensation formation on the metal clad wood windows proved to be most distressing. The custom wood windows were integrated into a highly energy efficient building enclosure constructed with insulated concrete and wood framing clad with stucco and plaster. The overall wall system was designed as an R12 wall with minimal air infiltration. The heating system for this "green" house was a centrally located wood-burning stove supplemented with base mounted electrical convection strip heaters.

During the first two years after the house was constructed, the Owner complained of condensation formation and commenced replacing the existing clad wood windows with new clad wood windows. Upon completion of the window replacement, the Owner was satisfied that the condensation problems had ceased. The replacement windows were very similar to the original windows, making it questionable whether replacing the windows solved the problem or whether the problem was actually the result of some other cause, such as excessive humidity within the residences due to moisture release from the cementitious building materials and the lifestyle created with a "tight" building envelope.

To compare the two windows (original and replacement), an evaluation program was undertaken to test the windows for thermal characteristics and to run THERM models on the two windows. An independent test laboratory was used to perform the laboratory tests including CRF, U-factor determinations, and condensation formation tests. Both the tests and the models revealed similar thermal and condensation resistance performance, indicating that the problems were most likely associated with interior environmental conditions. The problem would have disappeared as the original construction moisture dried out, and the windows did not need to be replaced.

FIG. 11—*Pooling of water at the stool.*

Case Study #3—Computer Center

The interior room conditions of this building are humidified at 45 % RH with a positive interior pressure. The aluminum strip windows consisting of a single row of IGUs and a large extruded aluminum stool integrated into a brick masonry wall exhibited severe condensation problems, including pooling of water on the stool and water runoff onto the drywall below the windows (Fig. 11). This strip window system performed adequately elsewhere in the building. However, at the building locations where the RH was increased to 45 %, the window's design parameters for condensation resistance were exceeded. A supplementary interior sash with insulating glass was investigated as a way to improve the condensation performance of the window without the need to remove and completely replace them. The large aluminum stool posed an additional problem that had to be addressed independently from the glazing system. A window section was removed from the building, the supplementary sash was added, and the assembly was tested in an environmental chamber with controlled interior and exterior temperature and humidity. The supplementary sash was positioned on the extruded stool to provide sufficient clearance to clean between IGUs. The tests showed that the supplementary sash successfully eliminated condensation on the windows and frames, but the extruded stool still exhibited condensation problems. If the extruded stool was located entirely on the interior side of the supplementary sash, this would probably not have been a problem. A way to increase the surface temperature of the stool by reducing the conductance of heat past the supplementary sash was needed.

In the environmental chamber, an experiment was performed by cutting slots in the extruded sill under the supplementary sash and filling the slot with sealant (Fig. 12). The slot increased the length of the conductive heat path through the stool and effectively increased its surface temperature. This test result, and subsequent observations of the building after the repair was implemented, demonstrated the success of this repair approach.

FIG. 12—*Slots under supplementary sash filled with sealant.*

Case Study #4—Insulated Precast Concrete Panels

The walls of this office/warehouse consist of insulated precast concrete panels. The panels were fabricated with concrete ribs around the edges and openings rather than with metal ties, and as a consequence the rough window openings in the panels were uninsulated solid concrete. The interior was not mechanically humidified but had an RH higher than a typical office occupancy due to storage of cardboard and paper products, wood pallets, and the use of natural gas forklift trucks. The windows exhibited condensation problems, including the accumulation of water on the sills and runoff onto the drywall below the windows. An analysis of the wall construction revealed that the problem was caused by the solid uninsulated concrete around the rough opening that provided a conductive heat loss path that bridged the thermal break in the window frame members.

The clearance between the window frame and the rough concrete opening was approximately $^{3}/_{16}$-in. Previous repair attempts included injecting expansive foam insulation between the frame and the concrete, but it was ineffective because the clearance was so small. Simply replacing the window would not have addressed the underlying cause of the problem. As an alternative, a repair was developed to add an Exterior Insulation and Finish System (EIFS) and insulated frame covers on the exterior concrete surfaces and insulated metal covers of selected window frame members (Fig. 13). The insulation provided by these two measures reduced the heat loss through the concrete and increased the surface temperatures of the window frame, eliminating the condensation problem.

FIG. 13—*Repair with exterior insulation and finish system and insulated frame covers.*

Case Study #5—Hospital with Double Windows

A hospital in the upper Midwest has a wall system constructed with brick-veneer metal stud walls and a dual window system. The outer window was a horizontal slider glazed with an IGU, and the inner window was a horizontal slider glazed with a single pane of glass. The frames for the outer and inner windows were independent. Typically, these windows are expected to perform well in the humidified hospital environment, but condensation and ice frequently formed between the two windows, and the perimeter of the interior window often exhibited frost and condensation.

A review of the window shop drawings and the architectural drawings revealed that the inner window bridged the masonry cavity and was therefore exposed to cavity air at a temperature close to the exterior air temperature. The inner window frame was not protected by the outer window. To isolate the inner window from the cavity air, the window was removed, and the cavity was sealed with insulation and a peel-and-stick membrane. After the repair, condensation and frost no longer formed between the windows or on the inner window frame.

Conclusions

The CRF is a reliable indicator of the condensation performance of a window as an isolated product under exposure conditions and installation details similar to those assumed in standard tests and analytical simulations. However, project-specific installation details can introduce heat loss paths that are not anticipated or simulated in the standard determination of CRF and can produce in-service condensation performance that is inferior to performance anticipated by the CRF. In some situations, the condensation performance is so adversely affected that modifications and repairs are necessary. Various analytical tools, including laboratory testing and simulation modeling, are available to assist the designer in evaluating wall components and systems for condensation resistance. However, both methods require a working knowledge or understanding of the value and limitations of the information and results that are generated from these processes. Standard laboratory tests and simulation models do not routinely include project-specific boundary conditions or adjoining construction and are conducted at standard conditions that may not apply. However, both techniques can be modified or adjusted to include non-standard conditions. The expanded usage of these tools is especially useful in assessing and repairing wall systems with known thermal problems. By modeling various proposed wall system repairs or modifications, the simulation can assist in identifying effective approaches. Both field and laboratory test mockups can be constructed for further evaluation of the remedial concepts before full-scale mobilization.

Understanding how installation details affect the thermal and condensation performance of a window and reviewing the details to identify unintended heat loss paths which breach or bridge the intended thermal breaks in the window system are necessary to avoid window condensation performance problems.

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Review of Specific Local Fenestration Units, Building Envelope Interface Practices, and Materials Compared to ASTM E 2112, Current Acceptance Criteria, and Evaluation Practices.

ABSTRACT:

1. Variations in physical installation environments
   a. Weather variations in Washington
   b. Types of construction and materials used
   c. Weather impact on interface materials and exposure periods
   d. Installation practices during varying conditions
2. Installation of windows and flashing in single and multifamily projects in the Northwest
   a. Divergence of methods between locations and type of construction
   b. Agency requirements and inspections
   c. Architect construction plan specifications
   d. Practice compared to window manufacturers and E2112 specifications
   e. Common Installation Problems Caused By Window Installers
   f. Practical considerations, standards vs. the real world
   f. Window manufacturer's instruction, guidance and training
   h. Flashing observations encountered in the development of a new product
3. Consideration of current Acceptance Criteria and Evaluation Reports

KEYWORDS: window flashing, ASTM E2112, flexible flashings, flashing, AC 148

Introduction

Installation of windows in the Seattle market has changed significantly over the past several years. This change has been driven primarily by litigation of condominium home owner associations against developers. The Seattle market, like Vancouver BC, which had a similar experience, has become very divergent in window installation practices. Condominiums and many commercial buildings overseen by building envelope consultants generally follow or exceed the requirements of ASTM E 2112, Standard Practice for Installation of Exterior Windows, Doors and Skylights, while single-family construction is significantly less detailed.

Variations in Physical Installation Environments

Weather Variations between Locations

Some flashing manufacturers' instructions indicate that products should not be installed in the rain or are not suitable for use in the southwest. There is a tendency to assume that significant weather variations only

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Seattle - 2001	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Number of Days With Precipitation													
Rain	22	12	23	18	11	14	6	9	8	20	19	22	184
Snow	0	3	0	0	0	0	0	0	0	0	0	0	3
2001 Seattle Precipitation Summary - In millimeters													
Actual	69	53	69	80	35	77	26	59	21	79	235	150	953
Maximum 24 Hour Precipitation Totals - In millimeters													
Amt	19	11	15	20	14	29	17	36	9	11	66	41	
2001 Seattle Temperature Summary - In Celsius Degrees													
Average Daily High	9	9	11	13	18	19	22	23	20	14	11	8	
Average Daily Low	2	1	4	5	8	10	12	13	11	7	5	2	
Maximum High	14	13	19	22	29	26	28	31	25	22	17	12	
Minimum Low	(3)	(3)	(1)	1	4	7	9	11	7	-	1	(1)	
2001 Seattle Wind Speed Summary - In km/h													
Daily Average	11	11	12	12	10	10	9	9	7	12	11	14	11
Maximum Peak Gust	61	47	60	64	53	48	45	35	42	69	64	72	
Gust Direction	SW	SW	SW	SW	SW	W	SW	SE	S	SW	S	SW	

FIG. 1—*Monthly summary of weather conditions for Seattle for 2001.*

FIG. 2—*Plywood sheathing showing an unadjusted reading from a moisture meter of 26.1 %.*

take place within major regions of the United States and that regional variations are insignificant. In the Northwest there are major variations in weather patterns within 30 miles (42 km), let alone 300 miles (420 km).

Figure 1 shows the monthly summary of weather conditions for Seattle for 2001. Fully half the days of the year there was rain and during six of the twelve months there were over 18 or more days with rain. In that year the high rainfall for one day was 2.6 in. (66 mm) while November accumulated 9.3 in. (235 mm) and December was 5.9 in. (150 mm). Three months had temperatures ranging from 83 to 89°F (20 to 23°C) while two months had lows of 26°F (−3°C). Finally, wind speed averages around 7 mph (11 km/h) year round with the monthly average low being 5.5 mph (7 km/h) and the high monthly average being 9 mph (14 km/h). Maximum wind speed was 45 mph (72 km/h) in 2001 with the maximum exceeding 40 mph (64 km/h) in four different months.

One hundred miles (161 km) west from Seattle in Ellensburg the average wind speed is 16 mph (25 km/h), or 10 mph (16 km/h) greater than Seattle. In 2003 the annual rainfall for Seattle was 40 in. (101.6 cm), high daily rainfall of 4.9 in. (124.5 mm), high temperature of 88°F (31°C) and a low of 25°F (−3°C). 140 miles (225 km) from Seattle in Yakima the annual rainfall was 8 in. (203 mm) with a daily high of 0.7 in. (18 mm), high temperature of 100°F (37.8°C) with a low of 0°F (−17.8°C).

These variations are significant because construction rarely stops anywhere in the region due to weather. Exterior work will stop due to high winds or snow, but day in and day out, construction continues. Over several years homes are also exposed to significant variations in wind, rain and temperature. Regional methods of installation are unrealistic while higher standards are needed for mid- and high-rise

FIG. 3—*Photo of exterior gypsum.*

construction compared to low rise and residential construction. Does caulk cure properly if set on a wet surface? Will window installation stop in northern locations where cold temperatures are more prevalent? Do adhesive tapes stick later if they do not adhere in the cold but are stapled in place? Installers think so.

Types of Construction and Materials Used

Sheathing used in construction includes plywood, OSB, gypsum, and synthetic scrim covered gypsum. Framing material is typically dimensional lumber with metal being used in buildings exceeding four stories. As is the case every where, one of the interface challenges with these materials includes round or arched windows and windows that are inset.

Figure 2 is plywood sheathing showing an unadjusted reading from a moisture meter of 26.1%. Figure 3 is a photo of exterior gypsum. The self adhering adhesive was adhered directly to the gypsum at the time of installation but a few weeks later has lost its hold due to a damp substrate.

Figure 4 is OSB with an unadjusted moisture meter reading of 19.7%. Figure 5 is a product that has a fiberglass scrim bonded over gypsum. The product is often used in condos and other large structures but often is very challenging for adhesion.

Weather Impact on Interface Materials and Exposure Periods

Logic would suggest that the surface of any substrate will have a high moisture content while it is raining and immediately after. Several substrates were tested with a moisture meter almost a full week after a period of heavy rain. As is shown in Fig. 2, plywood still had a reading of over 26% with other materials having slightly lower readings. The readings were not adjusted based on the types of wood fiber or

FIG. 4—*OSB with an unadjusted moisture meter reading of 19.7 %.*

FIG. 5—*A product with a fiberglass scrim bonded over gypsum.*

material so are not accurate in an absolute sense but are indicative of very high moisture levels. As can be seen in Fig. 3, regular gypsum suffers significant degradation when exposed to rain and it is not unusual to treat this material for obvious mold growth prior to cover.

It is very rare for installers to provide screening from weather conditions during installation. Only high rise buildings would normally have scaffolding and tenting during construction. In very cold and wet weather skilled installers will use a primer before applying self adhesive membranes. Results are still mixed due to insufficient tack time being allowed and rain.

Installation of Windows and Flashing in Single and Multifamily Projects in the Northwest

Divergence of Methods between Locations and Type of Construction

Most condominiums constructed in Washington State now have some level of voluntary oversight by building envelope consultants and generally exceed requirements of ASTM E 2112. It would be rare for installation not to include a flashing base wrapped into the rough opening, in some cases sill pans, windows set in caulk, and self-adhesive tape over the flange. Vancouver requires envelope consultant oversight along with construction inspections and long-term insurance coverage of the completed structure. However, Vancouver Canada utilizes a system that is commonly referred to as a "Rain Screen" that differs in several aspects from ASTM E 2112.

Installation techniques of single-family construction in Washington and Vancouver Canada would be considered deficient when compared to ASTM E 2112. Many builders of single-family homes believe that their homes do not have the same issues of water penetration that occur in larger structures. These builders often cite the lack of warranty claims by their buyers as support for their position. Many builders offer warranties of short duration (as short as one year) while the State does not require a longer warranty.

FIG. 6—*Polyethelyne Terephthalate fleece material.*

Typically some flashing steps are employed but the sealing goals of ASTM E 2112 are generally not met. This divergence in method is true even for builders who build both building types.

Factors Influencing Installation Methods

Washington State has an implied warranty of quality (RCW 64.34.445), that provides that "a unit…will be…(b) Constructed in accordance with sound engineering and construction standards, and in a workmanlike manner in compliance with all laws then applicable to such improvements." Due to numerous construction defects, caused significantly by improper window installation and other building envelope failures, multimillion dollar settlements have become common. Because of Washington's warranty provision destructive testing is routinely performed by litigation consultants on condos within four years of construction. This expected future has caused builders of condos to take much greater care with window installation.

Washington condominium builders have seen construction insurance cost increase dramatically, with the general contractor and developer paying in excess of $10,000 per unit while many subcontractors have exclusions related to condos. Many policies now wrap coverage for the developer, general and subcontractors in one policy. Washington does not have a buyer warranty insurance policy, as is required in Vancouver BC.

Specific building envelope inspection or plan submittal requirements by any oversight agency in Washington State for single-family or multifamily construction have not been identified. As indicated previously, Vancouver BC has a requirement for plans to include flashing and envelope detailed specifications defined by a certified building envelope consultant for condos. Some consultants have discretion in the specifications they define but must follow the Rain Screen principles, including venting at the plate line for each floor. Single-family construction has no similar requirement.

Architect Construction Plan Specifications

The detail defined by architects often follows the same pattern; more detail with condos while less detail in single-family plans is defined, if any. Many architects are now including boiler plate drawings similar to those depicted in ASTM E 2112. Among some building envelope consultants the unique definition of installation detail has almost become part of the firm identity.

The material of Fig. 6 is a fairly thick Polyethelyne Terephthalate (PET) fleece material bonded with PET that has a relatively low perm rate. As shown, the manufacture makes corner boots of the same material. The material of Fig. 7 was designed as a roofing underlayment but is used here as a flashing. This material has a very high perm rating, in excess of 200. The flashing is overlaid with a self-adhesive tape that is 6 in. (152 mm) wide that may mitigate the perm rate issue at the head and jamb. A growing number of consultants in Seattle and Vancouver Canada prefer to avoid self adhering flashing placed directly on sheathing.

One area of significant debate among these consultants is the perm value that flashings should have. ASTM E 2112 defines a 24 hour minimum result for flashings following ASTM D779, Standard Test

FIG. 7—*Material designed as a roofing underlayment but used as flashing.*

FIG. 8—*Sill pan visible.*

Method for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry Indicator Method. This generally will correspond to a very low perm rating, yet some consultants are specifying flashings made from materials with very high perm values that likely would return an ASTM D 779 test value of only a few minutes. Some consultants in Vancouver Canada are specifying two layers of 30 minute building paper as flashing. The 30 minute designation comes from the test result under ASTM D779. Many believe those current tests are not indicative of essential product performance.

Practice Compared to Window Manufacture's and E 2112 Specifications

Vancouver Canada detail often follows one of two variations that adapt to the rain screen siding suspension system. Omitting sealing the window at the flange with caulk, use of sill pans with flanged windows and lack of 24 hour minimum rated flashings are some of the significant deviations from ASTM E 2112. One example of this system specifies:

- The sill is flashed with two layers of 30 minute building paper,
- a sill pan is then installed,
- the jambs and head are then flashed with two layers of 30 minute paper folded into the rough opening and shingled over the sill pan,
- the window is set without caulk, in one instance on treated plywood lath, 1/2 in. (12.7 mm) to

FIG. 9—*A demonstration of installation of interior caulk.*

3/4 in. (19 mm) thickness and in the alternative on the building sheathing. In the latter instance, the window is inset from the plane of the siding.

- the window flange at jambs and head are then sealed with a self adhering flashing tape,
- head flashing extends across the full width of the window trim.

In Fig. 8, the sill pan is visible below the sill flange. A lath is used to support the window across the sill since the window has been set proud of the sill on a 1/2 in. (12.7 mm) lath. Distortion of the window frame will occur otherwise. Figure 9 demonstrates that much greater care is taken in the installation of interior caulk with this system since it is the water barrier.

Figure 10 is an example of a prefabricated pan that has an outward sloping surface with periodic inset supports that are level for the window to rest on. Generally, sill pans are built up from adhesive tapes or are made from galvanized or stainless steel sheet metal. Often the caulk detail at the back of the pan to window interface is skipped or done poorly.

Figure 11 is another sill pan system that uses prefabricated corner blocks, and builds a rear dam and sloped surface utilizing adhesive tapes.

In Seattle condo window installation generally follows a system of a nonadhesive flashing folded into the rough opening. Consultants are specifying flashings as wide as 26 in. (660 mm) to facilitate interweav-

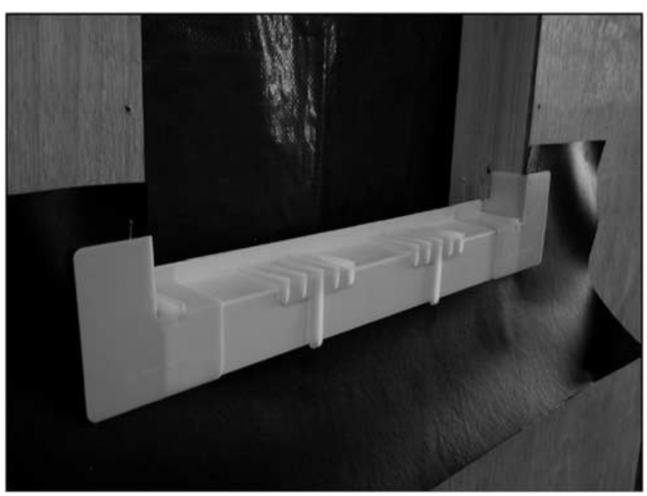

FIG. 10—*An example of a prefabricated pan.*

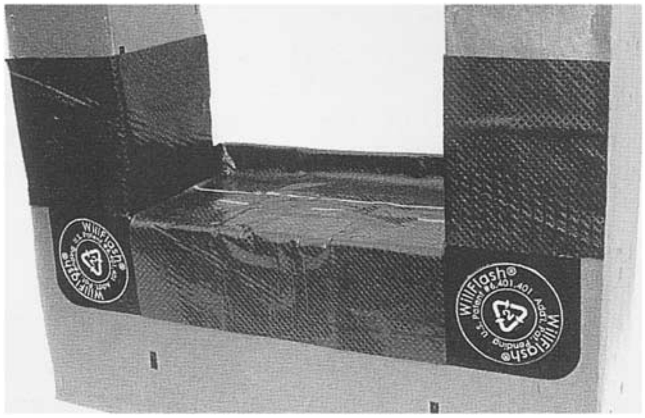

FIG. 11—*Sill pan system using prefabricated corner blocks.*

ing two layers of building paper and provide for the entire inside of the rough opening to be covered. In some instances sill pans are utilized. The window is set with caulk at the perimeter with adhesive flashing tapes overlaying the window flange at the jamb and head.

Figure 12 shows a condo installation that goes beyond the requirements of ASTM E 2112. A second layer of building paper is yet to be installed.

Figure 13 demonstrates a metal sill pan with a rear leg that is 1/2 in. (12.7 mm) in height.

Single-family construction installation generally is less detailed or sophisticated when compared to condos. It is rare to find installation that fully follows the detail steps recommended by ASTM E 2112. There are installers who either do not care about this issue or do not understand the effects of gravity and wind pressure.

Figure 14 is a condo project where the adhesive tape has been installed directly to sheathing that was damp enough to cause the tapes adhesion to fail. This detail is discouraged by several consultants in the Seattle and Vancouver area due to later moisture substrate damage, particularly wood, under the tape.

Figure 15 shows an installer securing the flange with galvanized lath screws after having set the window in a bed of ample caulk. The flashing was folded into the rough opening around the full perimeter.

Imagine a leaky windshield in your car; the carpet is soggy, water dripping on your feet. That is an experience that no one would tolerate for a minute. The difference in homes is that windows often leak and no one knows about it for years. Over time significant structure damage occurs.

FIG. 12—*A condo installation beyond ASTM requirements.*

FIG. 13—*Demonstration of metal sill pan.*

FIG. 14—*Adhesive tape failure due to moisture.*

FIG. 15—*An installer securing window with lathe screws.*

FIG. 16—*Poor use of a lot of caulk in single family construction.*

Common Installation Problems Caused by Window Installers

The following examples demonstrate very typical installation issues that are installer related.

Figure 16 demonstrates caulk installation that is unusual, not because of the poor quality of work but because in single family construction it is rarely done at all. If caulk is used the bead size is closer to 1/8 in. (3.2 mm) rather than the 3/8 in. (9.5 mm) recommended by ASTM E 2112.

Figure 17 shows windows set without caulk on plywood and then building paper placed over the flange at the sill. Water runs directly behind the exposed edge of the building paper onto the sheathing. This particular detail is responsible for many millions of dollars in damage to condos in the Northwest and is still occasionally seen on new construction.

Figure 18 is a photo of a window that is set with very little caulk and secured with staples through the nailing flange.

The installation shown in Fig. 19 demonstrates a lack of basic flashing understanding. Unfortunately, it is not uncommon for installers to have little idea how to deal with curved surfaces.

Figure 20 demonstrates a new product that replaces caulk with a compressible seal. The seal is positioned under the flange around the entire perimeter of the window. Recently, in North Dakota, with temperatures well below freezing window, installation continued because of the Sure Flash rubber seal while siding installation stopped with materials too frozen to cut.

FIG. 17—*Reverse lapped installation with no caulk.*

FIG. 18—*Improper use of staples as fasteners with little caulk.*

FIG. 19—*A lack of basic flashing understanding.*

Figure 21 is an installation where an estimated 1/4 in. (6.4 mm) of caulk was used but the window was not secured well at the head. The caulk and adhesive tape could not make up for this error.

Figure 22 shows almost every error that an installer could make in setting a window. While it is unusual to find this many problems in one window, it is very common to find some of these issues in the majority of windows that are observed. Little or no caulk, improper fastener selection, too few fasteners, placement of fasteners through the flange rather than the nail slot and fasteners too close to the corner are almost universal errors.

Figure 23 is representative of many installations with no caulk, flashing reasonably well laid out but with few nails holding the window in position.

Figure 24 is a masonry clip that a window installation company uses on the interior window frame instead of fasteners through the nailing flange on the exterior of the window. This allows the installer to set the window entirely from inside the building. In single-family construction, the removable vents are taken

FIG. 20—*A new product that does not use caulk.*

FIG. 21—*Too few fasteners at head with little caulk.*

FIG. 22—*Errors installers can make.*

FIG. 23—*Representative of many installations with no caulk.*

out, the window is rough nailed in, the vent reinstalled to check operation, and then the vent is removed again so that the remaining fasteners can be placed in the nailing flange. This is particularly true for windows on upper floors.

Figure 25 is an installation of a new product. It is unique in that the flashing extends into the rough opening 3.5 in. (89 mm), an EPDM rubber seal is adhered to the flashing such that it is positioned under and compressed by the flange around the perimeter of the window, with a second layer of flashing that

FIG. 24—*Masonry clip.*

FIG. 25—*Installation of a new gasket seal product.*

folds back on top of the flange after the window has been properly set. The second flashing layer has a synthetic rubber adhesive tape that is exposed by pulling a release liner. The end result is two shingled layers of flashing and a seal at the flange that does not rely on caulk.

Practical Considerations, Standards vs. the Real World

What must be understood is that few installers bother to read the instructions on the back of windows. Based on working in the Seattle market on this issue for almost a year, it is found that most management staff has now heard of ASTM E 2112 but few have read it. Builders will not spend money on issues where they do not have a clear financial risk and where the buyer can not see the improvement. Influence from insurance companies, code authorities or legislative change will be required to improve flashing quality.

Windows are typically installed by framers or in some instances by siding contractors. Windows for condominiums are often installed by companies that specialize in window installation. AAMA certified installers are still a real rarity in the area. Some window manufacturers have begun selling windows installed due to insurance constraints on other subcontractors but these programs have yet to demonstrate a significant change in installation technique.

Some have suggested that inclusion of ASTM E 2112 type standards in the building code will help. Unfortunately, experience shows that building inspectors pay specific attention to issues of structural, fire, safety, insulation, and electrical with only passing review of other issues. Inspections vary across the country and based on an informal survey conducted at a recent trade show range from the level previously described to "the only time I see a building inspector is at the coffee shop when I picked up my permit."

The guidance offered by manufacturers varies significantly. Some may provide excellent field support and engineering at the time windows are ordered. A review of process with the goal of improving quality control related to window selection, delivery and installation is essential.

Our observations suggest that regularly:

- Windows are mishandled, flanges and seals broken before they are installed.
- Detailed review of support and alignment is not undertaken at the time of installation. Installers only check to determine if a window is reasonably level and will operate. Typically windows are set directly on the sill leaving a 1/2 in. (12.7 mm) gap at the head rather than the 1/4 in. (6.4 mm) specified by most manufacturers in the area.
- Weather issues are ignored; installers do not tent work areas or carry absorbent towels to dry surfaces before installing adhesives.
- Windows are consistently not properly secured. The concepts of sealing defined in ASTM E 2112 are not followed in single-family and some condo construction.

Window Manufacturers Instruction and Guidance

Critical element instruction should be part of purchasing and delivery process by the manufacture. Large bold labeling by the manufacturers for critical instructions should be placed on the window. The small print labels, some with booklets attached, are completely ignored by most installers.

FIG. 26—*Damage to window flanges.*

FIG. 27—*Bolts neither tightened nor caulked adequately.*

If an installer or contractor were required to complete and submit an affirmative installation compliance check list for the manufacture's warranty to be effective the quality of installations would likely improve.

Figure 26 shows damage to window flanges that has occurred during handling. As many as a dozen windows are often stacked against each other. Sometimes there is protective blocking to support the flange. Delivered 8 ft. (243.8 cm) long windows have been observed with only blocking at the end of the window. Prior to installation many window seals were broken and frames distorted.

Flashing Observations in The Development of a New Product

Over the past four years we have worked on the development of a new flashing system. Some observations from this effort are as follows.

Some window design issues contribute to leaks. There are designs that allow bolts to penetrate through the window frame to secure mullions or joined mullions that have an exposed joint.

Figure 27 shows bolts that were neither adequately tightened nor caulked. This point of water entry is not uncommon. Figure 28 shows a composite window joined at a mullion. The manufacture in this instance applied a tape over the exposed joint but by the time the window was installed the tape had already delaminated and been damaged.

FIG. 28—*Manufacture sealing tape failure.*

FIG. 29—*Flashing that failed due to water and wind exposure.*

Flashing is often installed in single family home construction prior to walls being stood up. This means that the flashing material has a longer exposure to moisture and wind. It also means that all the staple penetrations are stressed by wind with resulting elongation of holes. In some cases flashing materials were observed that failed. Flashing standards for materials need to be consider wet and dry condition.

Figure 29 shows a flashing that failed due to water and wind exposure prior to being covered by a weather resistive barrier.

Staples that are typically used to hold flashing in place are easily pulled out of gypsum sheathing and with wood substrates the flashing is torn away by stronger winds. In other instances the flashing is not stapled to the wall and is left to flap in the breeze like a flag. Study needs to be done to define the minimum flashing staple tear strength for flashing materials. 40 mph (64 km/h) winds are not uncommon, even in Seattle.

Nail and staple penetrations can be a significant source of moisture. Testing seems to indicate a significant variance in the volume of water that comes around a fastener that penetrates through a membrane. Not only are there differences between types of nails but staples tend to leak significantly more than nails. We also have observed that different types of staples have a different effect. A square faced staple penetrates flashing differently than a staple that has an angled face. In some tests, it was found that five

FIG. 30—*Typical caulk failure at wood trim.*

staples would not leak at a certain pressure, but the sixth would leak a lot (Construct a cup by folding edges up on fabric, stapling corners to hold in place. Place the cup on a layer of packing foam and puncture fasteners through fabric. Fill the cup with water at varying depths and observe water leakage). When you consider how many staples and nails are around a window holding flashing, WRB, window trim, and finally siding, this is a significant issue.

Figure 30 shows caulk failure at both sides of window trim after less than two years. Significant moisture will enter at both sides of the 6 in. trim suggesting that 9 in. (228.6 mm) flashing is a minimal width regardless of type. Some Seattle consultants are now extending flashing as much as 16 in. (406 mm) around the opening.

When the adhesion of a variety of caulks to numerous flashing materials was evaluated variances were found between brands of caulk to the same flashing. Some caulks adhere to flashing better than others. What was a surprise was that some flashings adhere well on one side and not as well on the other even though the flashing material appears to be the same on both sides. Caulk also often does not adhere well to ink used for graphics. In other cases the flashing materials characteristics are changed significantly as the caulk cures.

Figure 31 shows a window prepared for stucco installation. It would be easy to estimate as many as 200 penetrations around some windows.

Consideration of Current Acceptance Criteria and Evaluation Reports

Few flashing materials have been certified or have Evaluation Reports issued. In large part it may be assumed this is due to recent changes in the certification process. More importantly it is likely due to a lack of criteria that cover the diverse products in the market today. Review of the Interim Acceptance Criteria for Flashing Materials—AC148 and ICBO Legacy Evaluation Reports that have been issued is still instructive in understanding what changes should be considered.

It should be obvious that few end users of flashing materials will study the details of a specific report or the specific test that were run. The manufacturer refers to a test report in their published information. The test report is available on request or on the internet. The user must then obtain details of the test method, normally an ASTM standard and interpret the test and its relevance to their current application. Not only does this process take time but cost money to obtain the standards referenced. The user instead normally assumes that since the material is certified that it will perform in the variety of conditions typically met in its use. Standards therefore must attempt to meet this expectation.

In the past, for example, it seems that manufacturers have been able to pick a subset of substrate materials that are evaluated in certification testing for adhesion. Clearly the test defined by criteria like AC148 have borrowed their testing protocol from other disciplines and these do not cover the full scope of issues related to flashing materials as installed in the field. The problem is that the objectives for flashing have not been adequately defined.

We were recently advised by research staff of a major window manufacturer that they have developed a long cycle test for window flashing. It is understood that the test runs over a period of some 30 days. The window and wall assembly are cycled back and forth between high temperature and freezing temperature numerous times with pressure and moisture loads applied. At least one result discussed from the test was that vinyl window flanges develop unexpected puckers away from the sheathing between fasteners of as much as 1/8 in. (3.2 mm). Caulk failures were apparently noted at these locations. It was only through this cycle test that this issue became apparent. This may suggest that a longer duration test is required for flashings.

Moisture readings in sheathing show elevated moisture almost one week after a major rain. There are many photo examples of self-adhering flashings that appeared to have adhesion at the time of application but later failed. The substrate may have been damp at the time of application or the substrate may have absorbed moisture from adjacent surfaces that became saturated after subsequent rain storms. It should be obvious that all tests, including tensile strength, should be performed in a wet substrate condition.

Some window manufacturers specifically define particular types of caulk and as specifically exclude others. We know that construction rarely stops just because the temperature is below 40°F (4.4°C). Certain butyl and bitumen adhesives are reported to be incompatible with the vinyl of some window flanges[3]. Testing with various caulks and primers needs to be included in hot, cold, and aged conditions.

A significant number of issues would be addressed if self-adhering flashings were not placed directly to substrates but rather only interfaced with subflashing materials that do not absorb moisture. Experience in Vancouver Canada and Seattle seems to support this direction.

FIG. 31—*A window prepared for stucco installation.*

[3]Colin Murphy Exterior Research & Design, Seattle WA, 98119. Speaker, Western Regional AAMA Conference April 2003.

Fasteners tear and stretch flashing at penetrations in windy conditions. There are no standards that consider this common condition.

Nail on flashing system are acceptable that have no standard for leakage at fastener penetration while a high standard is being contemplated as a requirement for adhesive flashing used in the same manner.

Finally, the perm requirement needs to be clarified as to where and what needs to have a low perm rating in flashing assemblies.

Testing and certification of products must become comprehensive. These standards must consider the skill of the installation labor force, the physical conditions of installation, and interface materials encountered in the field. Hopefully, manufacturers can then embrace the certification process giving builders confidence in their decisions related to flashing systems and windows without having to consult an engineer or chemist.[2]

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Leonard Dorin[1]

The Importance of Integrating Flashing and the Water Resistive Barrier in the Exterior Wall Systems of Residential Buildings

ABSTRACT: Building science studies have recognized the importance of the proper installation of flashing and its integration with the water resistive barriers as very important to the success of a wall assembly. The roll of flashing is to direct water away from the opening to the water resistive barrier, which in turn directs the water to the exit point in the wall. The integration of these two elements and the quality of their installation is ultimately important to the success of the wall system. It is equally important to select products, which perform as intended after installation. Extensive testing has been conducted on local and

methods completely fail to perform the required function of preventing water leakage. Conclusions are that it is important to follow E 2112 in installing flashing and integrating it with the water resistive barrier (WRB). It is equally important that a WRB is used. Each element of the installation is important. If the flashing is perfect, but the WRB lets water through, then there are potential problems.

KEYWORDS: flashing, WRB (water resistive barrier), wall assembly, window installation

Introduction

The importance of a well-integrated flashing/water resistive barrier (WRB) system cannot be underestimated. The Oak Ridge National Laboratory Study done in conjunction with the City of Seattle [1] states as one of their general observations:

"Building envelopes should be designed to manage the flow of incidental moisture. It is especially important to reduce the amount of water entering the wall where adjoining building envelope components meet and where there are envelope penetrations such as windows, vents, doors, and decks.

Proper installation of weather resistive barriers and integration with flashing is one of the most important factors in the successful performance of exterior walls. Two layers of WRB (one installed behind the other) was shown to provide better drainage control than one layer."

The role of flashing is to redirect water away from the window/door opening to the outside of the wall. There are a number of different types of flexible flashings which can accomplish this. Mechanically attached flashings have been successfully used in the western United States for over 50 years. Self-adhering flashings, made with a variety of adhesive types and configurations, are a more recent addition. Self-adhering flashings offer an additional level of sealing to the window, but they are technically very demanding and need to be installed correctly.

The role of the WRB is to protect the sheathing and prevent water intrusion into the building. Water directed from the flashing to the WRB must be allowed to drain quickly out of the wall. This interface between the flashing and the WRB is critical to managing moisture in the wall. This is why flashing installation standards, such as E 2112 [2], detail not only the installation method of the flashing, but its integration with the WRB.

The AAMA Task Group on Installation Issues developed a new Standard, AAMA 504-05 [9] detailing how to test installations that deviate from ASTM E 2112. The purpose of this standard, which details a comprehensive test method, is to allow for installation variations particularly for new products and new methods.

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The AAMA Flashing Task Group has developed a performance standard (AAMA 711-05) [10] for self-adhering flashings. Part II of this standard, currently being developed, will be the installation issues surrounding self-adhering flashings. Part III will deal with the issues of mechanically attached flashings.

As the standard develops, the performance categories will become more specific and more reflective of how the products function.

WRBs were also described by a general material description, but there is now a movement starting to look at water resistive barriers by classifications based on the material structure of the product, rather than just perms and strength. This system better distinguishes the various products on the market and should provide greater ability to understand the characteristics of each product. See Table 1.

TABLE 1—*Classification of WRB by structure.*

•Type C	Asphalt impregnated cellulose fiber
•Type P	Polymeric fibrous
•Type PP	Perforated polymeric film
•Type L	Liquid applied (trowel, roll, spray)
•Type M	Microporous film

We relate laboratory testing to field experience. Problem installations are more often the result of poor workmanship than product problems. We are often asked to approve various regional installation methods. Testing these methods highlights what works and what does not.

Our testing has helped us define installation criteria and advise customers on their installation methods. The integration of flashing into the WRB creates a water management system that time and again proves to be the most successful method of managing water intrusion.

The tests below are only a representative sample of the testing we have completed, but they highlight the points above and illustrate how the information can be used:

1. To confirm installation methods.
2. To test real life field applications, particularly common current regional field practices.
3. To obtain objective results to understand the needs of future products and testing.

Tools Used in Evaluation

We used our own laboratory, third party laboratories and we participate in a number of important building science projects.

While we use standard test methods, our field experience requires that we modify and adjust tests to answer field questions and learn how our products perform under varying conditions. In all cases we are trying to duplicate the real world we see regularly. For example:

1. Hydrostatic head test: In addition to the standard test procedures, we introduce various elements to determine how various products perform under real field conditions when in contact with various substances, such as surfactants, sealants, paint and preservatives.
2. Cold box test: We had field reports from Texas that one type of butyl, flashing, installed on a cold morning ($<40°F$) would fall off as the day warmed. After duplicating this condition in our cold box multiple times, we now know that these types of adhesives are more subject to this phenomena than other adhesive types. This test criteria gives us a good performance method for evaluating new adhesive developments.
3. Compatibility testing. Materials need to be compatible and as there are no industry standards on compatibility. As a result we test our own systems and define which materials are compatible with our products. We have looked at the following and can make firm recommendations on use with our products:
   - Sealants and caulks
   - Plasticized PVC (polyvinylchloride)
   - Foams
   - EPDM (Ethylene propylene diene monomer)
   - Surfactants and wood extracts
   - Water sealants and coatings

Using third party laboratories, we test to recognized ASTM standards, such as E 1677 [3], E 283 [4], E 330 [5], E 331 [6], E 547 [7], E 96 [8], etc. We subject our products to more severe conditions than called for in the test. For example, in order to test to failure, we generally will run the test buck with only the water resistive barrier, flashing, and window. We may also test to failure in order to better understand the product and installation implications. In many cases a complete wall system (with a facing material) is difficult to analyze. Our goal is to determine if there is any product or installation defects as soon as possible.

Test Results

The following tests are representative and illustrate some of the issues discussed above. The tests highlight some installation issues and the importance of integrating flashing into the WRB system. In the course of conducting these tests, we have also learned that water/moisture intrusion is not just a flashing, integration or installation issue, but that the WRB can play a significant part in the success of a wall assembly.

In the early development phase of our first self-adhering flashing, we did a number of ASTM E 331 tests. Installations were tested under pressure at one hour and up to eight hours, far in excess of the test requirement. We learned that self-adhering flashing should not be put over the bottom flange of the window. When water gets through the facing material, the jamb flashing directs the water down, as it should. However, covering the bottom flange created a dam effect and the water came up and over the flashing, clearly blocking the water from exiting. Simply taking a razor and cutting the corners of the flashing over the bottom flange immediately stopped the leak. Bolstered by subsequent testing of this concept, our installation instructions tell customers not to use a self-adhering flashing over the bottom flange of the window.

We conducted a battery of tests on four different flashing types, using Methods A, B, A1, and B1 using the installation standard developed by CAWM (California Association of Window Manufacturers). The CAWM Association was absorbed by AAMA. The test wall was covered with 60 min paper and a plastic house wrap. We tested these integrated systems according to ASTM E331 at 2.86 psf (33 mph) and 6.24 psf (50 mph). It became clear that all elements of the installation have to work, or the installation fails. See Table 2.

A wood window with a brick mold was tested in an installation using Method B1 with a 60 min asphalt saturated WRB and 9 in. Self-adhering flashing. Using the ASTM E331-96 test, there was no water

TABLE 2—*ASTM E331 moisture test of an installation.*

Product	Test pressure Psf	Results
60 minute paper	2.86	No leakage
Method A	6.24	No leakage
60 minute paper	2.86	No leakage
Method B	6.24	No leakage
Self-adhering Fl.-60 minute paper	2.86	No leakage
Method A	6.24	No leakage
Self-adhering Fl-60 minute paper	2.86	No leakage
Method B	6.24	No leakage
Bitumen Fl-plastic house wrap	2.86	No leakage
Modified method A1	6.24	Leakage at top diagonal WRB cut due to sealing tape pulling away at corner.
Bitumen Fl-plastic house wrap	2.86	No leakage
Modified method B1	6.24	Leakage at top diagonal WRB cut due to sealing tape pulling away at corner.
Self-adhering Fl-plastic house wrap	2.86	No leakage
Modified method A 1	6.24	Leakage at top diagonal WRB cut due to sealing tape pulling away at corner
Self-adhering Fl-plastic house wrap Modified Method B1	2.86 6.24	Leakage at top diagonal WRB cut due to sealing tape pulling away on both levels of pressure.

NOTE: Two types of flashing were tested and defined as self-adhering flashing=nonbitumen adhesive; bitumen adhesive=bitumen based adhesive system.

entry at 2.86 psf or 6.24 psf. We test various window types in order to be certain that our methods are appropriate to all parts of the country.

We had requests from builders in various parts of the country to test common installations in their area. We tested various flashing products and sizes, such as 4 in., 6 in. and 9 in.. To summarize the major results:

1. Regardless of the flashing size, products installed directly on OSB (oriented strand board) without a WRB failed at 2.86 psf. There was substantial water on the OSB, which in turn deteriorated. While most of the self-adhering flashings remained adhered and pulled fiber from the OSB after the test, the structure of the OSB deteriorated to the point where water came in behind the flashing affecting the ability of the flashing to perform its function. In the southeast, many builders consider OSB a weather barrier and do not see the need to cover it with a WRB.
2. A structural polycoated fiberboard was installed as per the instructions printed on the product. The expansion gap between sheets proved to be a channel for water. These installations failed consistently at 2.86 psf. The only way to eliminate water coming in behind the well-adhered flashing and into the window opening was to seal the gap with tape.
3. Using the above installations (OSB and polycoated fiberboard) with the addition of 2 ply 60 min WRB, the installation passed at up to 12 psf (68.5 mph), the limit of the testing equipment.
4. A competitive 4 in. bitumen flashing, using the manufacturer's instructions of no sealant, no WRB, was tested on OSB, and it failed at 2.86 psf.

In developing our new mechanically attached flashing, the next generation of mechanically attached flashing, we conducted the ASTM E331 test with 2 ply 60 min Asphaltic paper as the WRB. The Method B installation passed with wind speeds up to 25.6 psf (100 mph). Mechanically attached flashings, installed correctly, are effective at high wind speeds.

Testing in-house and with outside laboratories, it became clear that there were certain non-flashing issues that lead to moisture/water during the test. See Table 3 for what was discovered in a first test.

TABLE 3—*Water penetration test—ASTM C547-93.*

Material	Test pressure range PSF (mph)	Water permeability gallons/day/ft2
60 minute paper #1	36.3–34.7 (119–116)	0.023
60 minute paper #2	36.5–35.4 (119–118)	0.028
Plastic house wrap	36.5–32.5 (119–113)	0.096

Additional field and laboratory observations, led us to another step in the testing. There were reports in certain geographic regions where stucco contractors were using detergent as a slip agent to apply the stucco. They reported problems with water in the wall assembly. Previous tests showed that water was getting into the wall even though there were no visible leaks in the flashing. It was clear that issues such as taped seams, the tape itself could affect tests results. We decided to modify the test so that only product performance would be tested, not only installation differences between products. The test wall assembly was modified to 4 ft × 4 ft in order to fit the size of all the products tested without seams. A trough was built into the bottom of the test wall and the water captured was weighed. We tested a number of products under these conditions, using ASTM E283 Air Infiltration and ASTM E331 water resistance tests. We tested an extra wide version of 60 min paper. The products were sprayed with a diluted detergent/water spray, allowed to rest and then retested. The tests show that paper performs better under moisture/surfactant conditions than plastics and virtually the same on air penetration. The results are summarized in Table 4.

The ASTM E1677-95 test was conducted on various product configurations. ASTM E1677 is a combination of ASTM E331, E547, and E330. In this test, our concept of using the very severe conditions of no facer and no sheathing, made it difficult to get a good detailed reading of the products. However, we learned a number of things: perforated wraps leak very quickly under pressure; with taped seams, 60 min paper passes the air tests equal to the plastic house wraps. Observing the tests we saw that every element used in the installation is important to its success. For example, sealants were often used badly, seam tapes need to stand up to moisture/water, and under these very severe conditions workmanship was key. See Table 5.

TABLE 4—*Competitive product test before/after surfactant ASTM E283/E331.*

Test	Plastic #1	Plastic #2	Plastic #3	60 min paper	60 min paper 2 ply
Air infiltration per E283					
1.56 PSF/25 mph	0.0 cfm	0.0 cfm	0.0 cfm	0.2 cfm	0.0 cfm
6.24 PSF/50 mph	0.1 cfm	0.4 cfm	0.8 cfm	0.7 cfm	0.3 cfm
Water resistance per E331					
2.86 PSF/33 mph	No leakage	No leakage	No leakage	No leakage	No leakage
6.24 PSF/50 mph	No leakage	No leakage	No leakage	No leakage	No leakage
Spray samples with 10% concentration of detergent/rest 15 min					
Water resistance per E331, weight of water in the trough					
2.86 PSF/33 mph	0.585 lbs	0.4765 lbs	0.433 lbs	0.167 lbs	No leakage
Air infiltration per 283					
1.56 PSF/25 mph	0.0 cfm	0.0 cfm	0.0 cfm	0.2 cfm	0.0 cfm
6.24 PSF/50 mph	0.1 cfm	0.1 cfm	0.2 cfm	1.6 cfm	1.2 cfm

TABLE 5—*ASTM E1677 test of seven products.*

Product tested	E331	E547	E330+	E330−	E283
Plastic WRB, taped seam	pass	pass	pass	tape[a]	pass
Plastic II WRB, no seam	pass	pass	pass	pass	pass
Plastic III, taped seam	pass	pass	pass	pass	pass
Plastic perforated, no seam	pass	water	pass	pass	pass
Extra wide 60 min	pass	pass	pass	pass	pass

[a]Tape kept coming off after repeated exposure to water.

Summary

It is clear from this testing that certain things are very important:

1. Quality installation is of basic importance in determining how a wall assembly will perform. Field short cuts and poor supervision often are the source of problems. Flashing is not the first line of defense, but only one part of the defense system to manage water.
2. Proper integration of the flashing with the WRB is extremely important. Time and again tests show that flashing without a WRB or where not well integrated will limit and direct the water, but often will not offer full protection.
3. Using approved installation methods, such as E2112, where the flashing is integrated into the WRB works. Eliminating the WRB is a source of future problems.
4. A WRB is very important element in the performance of the wall assembly. It becomes the key element in carrying diverted water down to the exit point in the wall.
5. The installation methods as well as each part of the installation: the flashing, the WRB, any tape used, the sealant, and fasteners, all contribute to the success or failure of the wall assembly. We know that many products work when tested, but observation show that their integration is very important.
6. Not all WRB products are equal and they do not perform equally under all conditions, so WRB selection is as important as the flashing in predicting the long term success of a wall assembly.

A great deal of research has been done with results that help us improve, not only our products, but give the industry information which will help minimize future problems. Good installation practices are everyone's concern.

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EVALUATION AND TESTING

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Durability Testing of Polyurethane Foam Sealant in the Window-Wall Interface

ABSTRACT: In late 1990, the National Research Council of Canada (NRC-CNRC) and the Canadian Construction Materials Centre of Canada (CCMC) set about developing a durability protocol for aerosol foam sealants. Major input for this effort was supplied by Dr. Mark Bomberg then on the NRC-CNRC staff. At that time a major manufacturer of aerosol foam sealant wished to address some developing concerns whether foam sealant used around the perimeter of windows and doors during their installation was really durable. The manufacturer completed the durability testing according to the established NRC protocol. Now the protocol is also part of a new Standard CAN/ULC-S710.1 and CAN/ULC-S711.1. This paper will describe that testing as it was completed at the third party laboratory, Air-Ins Inc., of Montreal, Canada using criteria from the 1995 National Building Code of Canada [1]. The data obtained also formed the basis for CCMC Evaluation report 13074-R [2].

KEYWORDS: foam sealant, polyurethane foam sealant, aerosol foam sealant, expandable polyurethane sealant, air barrier foam sealant, window and door foam sealant, low pressure-build foam sealant, air leakage

Introduction

Although aerosol foam sealants have been used in window installation for many years and are represented in Annex A of the ASTM E 2112 Standard Practice for the Installation of Windows, Doors, and Skylights. Concern about their high pressure expansion properties during cure has limited their use [3]. There has been particular attention and focus of late on developing standards for foam sealants that generate less pressure in the cavity during cure. These products are entering the market as "window/door foam sealants" rather than the "minimally expanding foam sealants" or the "high expansion foam sealants." These are now also called "low pressure-build foam sealants" and an American Architectural Manufacturers Association (AAMA) task group has developed a standard for these low pressure generating foams. This standard is titled AAMA 812. The major application for these products is the perimeter rough opening air seal around window and doors. In this particular application, there are a number of potential problems, which must be dealt with. First of all, there is in an increasing variety of window and door materials. Also, the rough opening itself can be extremely varied. For example, this opening is generally in a dimensional lumber rough opening frame but it can also be in concrete block or poured concrete. The window units themselves can be manufactured from wood, vinyl, aluminum, or steel. There are various building wrap, panning, and flashing materials that often layer into the rough opening gap. There are also new composite window materials entering the market. The modern aerosol window foaming sealant must perform each of five critical characteristics adequately in order for the overall air barrier system to be successful.

—Low expansion pressure to eliminate deformation of sensitive window frames.
—Air tightness to provide energy efficiency and assist in preventing water ingress.
—Continuity between the window frame and the rough opening lining.
—Structural integrity which improves the window's design pressure.
—Durability to maintain this performance during building movement.

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FIG. 1—*Test wall under construction.*

Testing Program

The testing program described here was conducted as part of the referenced Canadian CAN/ULC protocol Masterformat number 07272.1. This protocol is designed to evaluate air-barrier foam sealants for durability in sealing performance. Data from this evaluation technique are presented here for the tested products. A full-sized wall assembly (see Figs. 1–5) is made and several window openings are evaluated to determine if the foam sealant will maintain an air tight seal both before and after pressure cycle testing of the wall assembly. The foam sealant joints must conform to the allowed air leakage requirements established by the CCMC before and after cycling. The test is specific to the substrates involved and is intended to document the material's ability to maintain an "adequate" long-term seal with the chosen substrate materials. These data can then be used to obtain a full CCMC wall designed system approval if desired and provide data needed for one of the major test requirements in the new CAN/ULC-S710.1 and CAN/ULC-S711.1 Standards.

FIG. 2—*A test wall containing five vinyl test window frames with the window blanked out using sealed plywood. Here the spun-bonded polyolefin house wrap is in position around window opening with foam products installed.*

FIG. 3—*A second wall unit setup with black building paper; plywood is installed in place of glazing.*

FIG. 4—*Wall system being lifted into place on the conditioning chamber. The chamber can test air leakage, apply water spray, and temperature cycling.*

Tested Products

Five commercial products manufactured by the same company were tested according to the referenced protocol. The ASTM C 1536-02 volumetric yield for tested products ranged from 2 cm of bead per gram to over 4 cm of bead per gram of product. The five foam sealants were packaged in several sized containers with three different type dispensers [4]. They represented a normal product offering range from the manufacturer.

Wall Construction

A wall is first constructed from standard framing materials and sheeting. Five openings are framed out to receive the vinyl window units.

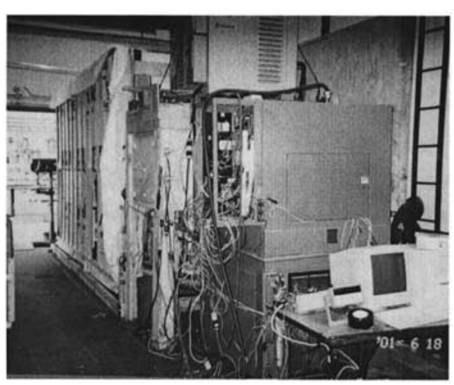

FIG. 5—*Instrumentation units for the evaluations.*

TABLE 1—*Summary of environmental conditioning cycles applied to test panel.*

Interior Side	Exterior Side	
	Apply 60 – 6 hour cycles	
	Environmental Conditioning	Duration
Maintain Room Side @ 24 ± 2°C, 50% ± 10°C R.H.	Room @ 66 ± 3°C	
	Apply water spray 14 l/min w/water Temp. 15 ± 10°C	
	Positive pressure of 1000 Pa	60± 2 min
	Room @ 66 ± 3°C ending in cooling Transition	
	Negative pressure of 1000 Pa	60± 2 min
	Room cooled to –20 ± 2°C over 90 min.	
	Negative pressure of 1000 Pa	90± 2 min
	Room @ -20 ± 2°C	
	Positive pressure of 1000 Pa	60± 2 min
	Room @ -20 ± 2°C	
	Negative pressure of 1000 Pa	60± 2 min
	Rapid heating transition to 66 ± 3°C	30± 2 min
	TOTAL (6 hours)	360 min

Initial Air Leakage Measurement and Calibration

Air leakage testing is performed as specified by ASTM E 283 using five measuring points and pressure difference from 50 to 250 Pa. The room is maintained @24±2°C and 50±10 % RH.

Test Protocol

The wall units with the windows installed are subjected to the following test cycling during 12-week testing (also see Table 1):

Environmental Conditioning

—Heat to 66°C plateau
—Apply positive pressure @1000 Pa
—Water spray @2.3 L/min/m^2
—Maintain temperature @66°C for 1 h but change to negative 1000 Pa
—End heat at 1 h and allow cooling
—Force cool to −20°C over 1.5 h
—At −20°C plateau apply +1000 Pa for 1 h
—Apply −1000 Pa still at −20°C
—Hold for 2 h @−20°C and then rapidly heat to 66°C in 30 min or less
—Total cycle time… 6 h
—These are the basic cycles described above:

a. Dry heat at 66°C with positive 1000 Pa pressure
b. Wet heat at 66°C with change to negative 1000 Pa pressure
c. Force cool to −20°C with 1000 Pa positive pressure
d. Then switch to negative 1000 Pa pressure still at −20°C

—Environmental cycling is applied on weekdays and a 66°C dry temperature is maintained on weekends.

TABLE 2—*Initial air leakage data.*

DIFF. PRESSURE	AIR LEAKAGE
+ Pa	$m^3/h\text{-}m$
50	0.05
75	0.07
100	0.09
150	0.12
250	0.17

—A total of 60 environmental cycles were applied

Final Leakage Measurement and Assessment

—Visual inspection was made each seven days

—Upon the final test cycle, an air-leakage test per ASTM E 283 is performed and the overall leakage must not exceed the CSA Standard A440-98/CCMC Air Barrier Guide values.

—In this test the max allowed air leakage was 0.25 L/s for the 3.65 m foam sealant joint.

—After each 7-day period, the visual examination revealed no sign of deterioration on the interior side for each window and very little sign of adhesion loss between the different bead sealants and exterior materials. No adhesion loss was noticed between the sealant and the PVC window.

TABLE 3—*Final air leakage data.*

DIFF. PRESSURE	AIR LEAKAGE
+ Pa	$m^3/h\text{-}m$
50	0.06
75	0.08
100	0.09
150	0.13
250	0.18

Test Conclusions

Several products, including the low pressure-build specialized semi-flexible Window & Door foam product, met the performance requirement of the CCMC Technical Guide MS 07272.1 for Durability Assessment of Bead-Applied Urethane-Based Sealant Foam for Air-Barriers. The initial air leakage data for the low pressure-build Window & Door foam sealant are shown in Table 2 below for the spun-bonded building wrap window combination test. Table 3 shows very comparable data after the 60 cycle durability evaluation. All foams performed well before and after for air leakage testing but the more flexible one-component foams all met the stringent test requirements.

Based on the above findings, the manufacturer has plans to submit at least two of the tested foam sealants for third party conformance testing to CAN/ULC-S710.1 and CAN/ULC-S711.1.

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[4] ASTM C 1536 (Standard Test Method for Measuring the Yield for Aerosol Foam Sealants) is under the jurisdiction of Subcommittee C24.61 which currently has five additional standards under development for foam sealants.

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Performance Testing of Flashing Installation Methods for Brick Mold and Nonflanged Windows

ABSTRACT: One of the major sources of water intrusion in buildings is through openings in walls caused by windows and other fenestrations, in particular the interface between the window and wall. Numerous flashing products, including self-adhered products, have recently been developed to protect this window-wall interface from moisture intrusion. However, the proper installation of these flashing products is not well understood and installation methods are often misused. Various installation methods have been developed and tested to evaluate performance and ease of installation. While most of the flashing installation development has been focused on residential flanged-style windows, effective installation methods for wood framed "brick mold" windows as well as other "nonflanged" windows have not previously been developed and tested. A series of laboratory wall tests were used to compare the air leakage resistance (ASTM E 283), water leakage resistance (ASTM E 331), and durability (ASTM E 330) of various flashing materials and installation methods. The performance and durability of flashing as installed with round top windows, brick mold windows, and nonflanged windows were tested and evaluated.

KEYWORDS: Flashing performance, moisture intrusion, window installation, weather resistive barrier (WRB), housewrap, flanged window, nonflanged window, brick mold window

Introduction

One of the major sources of water intrusion in buildings is through openings in walls, in particular the interface between the window and the rough opening. One of the top ten callbacks on newly constructed buildings is for water penetrating the wall cavity or interior spaces around windows due to "omitted or improper flashing details" [3]. Water is often found "to enter the wall assemblies at interface details; primarily at windows, at the perimeter of decks, balconies and walkways, and at saddle locations. The problems with these details were found to be related to aspects of the design and construction rather than operations or maintenance, or the materials themselves" [5]. A study conducted in Canada revealed that "35 % to 48 % of newly installed windows were found to leak through the window unit itself, through joints between the window and the rough opening, or both" and that "100 % of installed residential windows examined after years in service were found to leak either through the window unit itself or at points of attachment to the building" [2]. The conscientious builder can help prevent moisture intrusion around windows and other fenestrations by appropriately flashing to mitigate costly callbacks due to water leakage.

Flashing is necessary to integrate wall components to manage water drainage and intrusion. Caulking the interface between windows and walls and any cracks or joints will serve to manage moisture temporarily. Joints or "cracks re-open quickly as siding and trims dry out and with the expansion and contraction of heating and cooling. Thus, well installed flashings at openings

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during construction is required to protect the structure from water damage" [6]. However, flashing installation methods are often poorly understood by the groups involved in the construction process including builders, inspectors, contractors, specification writers, and owners. Flashings should be integrated "(installed shingle style) with a drainage plane (installed shingle style) so that any water penetrating the window won't wet the wall" [1]. Sound research and effective communication are desperately needed to educate the building community on best practices to prevent moisture intrusion into buildings.

Some preliminary research and testing have been conducted to evaluate the performance of various flashing materials. While there is a large difference between flashing products in terms of performance and ease of installation, one principle holds true for them all. Materials should always be installed to promote water drainage. If water is trapped in a building system, problems are eminent.

Detailed flashing installation methods have been developed for windows with integral flanges in typical frame construction walls and are detailed in ASTM E 2112, Standard Practice for the Installation of Windows, Doors and Skylights. This standard's methods focus on installations using mechanically attached flashing. Installation methods utilizing self-adhered flashing, one of the largest growing segments of the flashing market, are not adequately addressed in this standard. Guidelines for flanged window/frame wall installations using self-adhered flashing have been published [4] [7] [8]. However, the installation methods for integral flanged windows do not apply to other window styles, such as brick mold windows and non-flanged windows, or to other wall systems such as concrete masonry unit (CMU) wall construction. Therefore, testing has been conducted to evaluate various installation methods using self-adhered flashing for performance and water management.

The objective of this research is to compare the water resistance, air leakage resistance, and durability of various flashing installation methods on brick mold windows, nonflanged windows, and flanged windows. Flashing will also be evaluated for performance on concrete masonry unit (CMU) walls.

Development of Improved Installation Methods and Performance Testing

Current test methods and standards describe methodology for evaluating individual wall components or for evaluating windows as a component. There are no standards that address how to test and evaluate the performance of a wall system with a window installed. Weston et al. developed a test protocol for evaluating the installed window/wall system [7]. This testing protocol was utilized to evaluate the performance of novel flashing materials and installation techniques and is briefly described below.

Experimental Method

Flashing and Window Installation Details

The proposed installation methods were tested for performance, ease of installation, and durability using the protocol outlined in Fig. 1.

Windows were installed in 60 × 90 in. walls with oriented strand board (OSB) sheathing and wood studs 16 in. on-center. Window units were factory constructed wood framed brick mold windows, factory constructed nonflanged windows without wood framing, and windows with integral flanges. A description of the walls tested, including comparison and variant walls are shown in Tables 1 and 2.

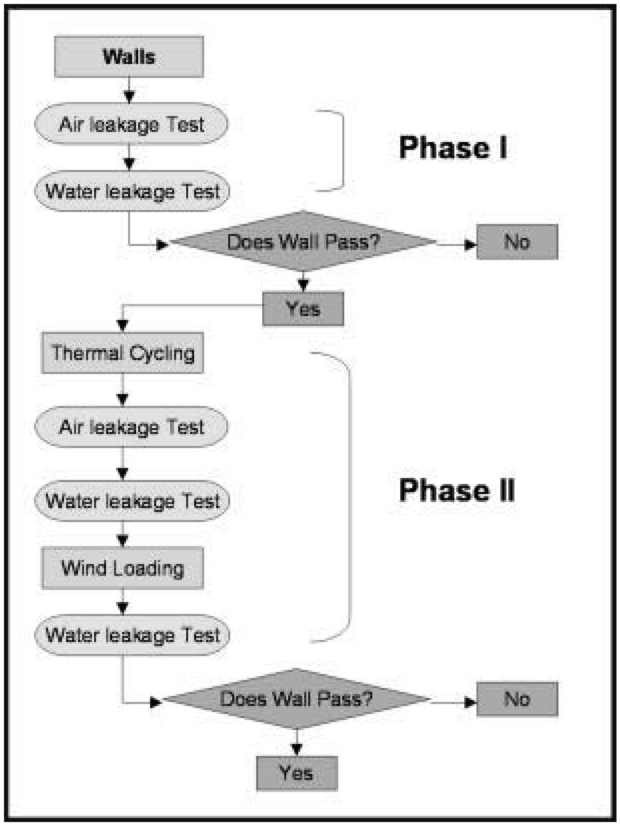

FIG. 1—*Outline of test protocol used to evaluate flashing installation performance and durability.*

TABLE 1—*Window flashing installation details per wall for brick mold, nonflanged, and flanged windows. Flanged windows listed below were installed into CMU walls.*

Wall #	Window Type – Description and Size	Installation Order – WRB before or after window	Sill Flashing / Detail	Jamb Flashing / Detail	Head Flashing / Detail
1A/2A	Wood frame brick mold 37 3/8 × 48 ½ in.	1A Before window / 2A After window	Elastomeric nonwoven composite flashing	6-in. nonwoven composite flashing installed with 90° turn onto jamb of brick mold wood frame	Aluminum drip cap lapped by 4-in. nonwoven composite flashing lapped by WRB and taped
3A/4A	Wood frame brick mold 37 3/8 × 48 ½ in.	3A Before window / 4A After window	Elastomeric nonwoven composite flashing	6-in. nonwoven composite flashing installed with 90° turn onto jamb of brick	Aluminum drip cap lapped by 4-in. nonwoven composite flashing with chevrons at each corner then lapped by WRB and

				mold wood frame	taped
5A/6A	Wood frame brick mold 37 3/8 × 48 ½ in.	5A Before window / 6A After window	Elastomeric nonwoven composite flashing	Caulk	Caulk and aluminum drip cap with WRB lapped over the drip cap and taped
9A/10A	Wood frame brick mold 37 3/8 × 48 ½ in.	9A Before window / 10A After window	Elastomeric nonwoven composite flashing installed over aluminum pan back dam	Caulk	Aluminum drip cap lapped by 4 in. nonwoven composite flashing lapped by WRB and taped
11A/12A	Wood frame nonflanged 37 3/8 × 48 ½ in. installed 1 ¼ in. protruding	11A Before window / 12A After window	Elastomeric nonwoven composite flashing	6-in. nonwoven composite flashing installed with 90° turn onto jamb	4-in. nonwoven composite flashing installed with 90° turn onto head and aluminum drip cap lapped by 4-in. nonwoven composite flashing lapped by WRB and taped
13A/14A	Wood frame nonflanged 37 3/8 × 48 ½ in. installed 1 ¼ in. protruding	13A Before window / 14A After window	Elastomeric nonwoven composite flashing	6-in. nonwoven composite flashing wrapped into the jamb to form a boot	Aluminum drip cap lapped by 4-in. nonwoven composite flashing lapped by WRB and taped
15A/16A	Wood frame nonflanged 37 3/8 × 48 ½-in. installed 1 in. recessed	15A Before window / 16A After window	Elastomeric nonwoven composite flashing	6-in. nonwoven composite flashing wrapped into the ja mb to form a boot	Aluminum drip cap lapped by 4-in. nonwoven composite flashing lapped by WRB and taped
17A	Integral flanged 24 ½ × 24 ½-in. installed 2 in. recessed	None	9 in. elastomeric nonwoven composite flashing	6-in. nonwoven composite flashing	4-in. nonwoven composite flashing
18A	Integral flanged 24 ½ × 24 ½ in. installed 2 in. recessed	None	Two pieces of overlapping 7-in. elastomeric nonwoven composite flashing	6-in. nonwoven composite flashing	4-in. nonwoven composite flashing
19A	Integral flanged 24 ½ × 24 ½ in. installed 2-in. recessed	None	7-in. elastomeric nonwoven composite flashing over 1 × 2 in. furring strip (back dam)	4-in. nonwoven composite flashing	4-in. nonwoven composite flashing

20A	Integral flanged 24 ½ × 24 ½ in. installed 2-in. recessed	None	9-in. elastomeric nonwoven composite flashing over 1 × 2 in. furring strip (back dam)	4-in. nonwoven composite flashing	4-in. nonwoven composite flashing

An elastomeric latex sealant was used to seal various joints depending on the flashing details. The weather resistive barrier (WRB) and the window were installed according to the manufacturers installation guidelines. For walls 1A–4A, 11A and 12A, 6-in. nonwoven composite flashing was installed along the jambs such that ½" of flashing was adhered to the edge of the brick mold or nonflanged window and turned 90° to cover the joint between the brick mold or nonflanged window and the face of the wall. Drip caps were installed such that ¼" kicked out over the edges of the windows at the head to help shed water away from the head of the window.

The chevrons (Fig. 2) used in Walls 3A and 4A were made of nonwoven composite flashing that was cut to the appropriate size and shape. Chevrons were used to evaluate what impact, if any, they would have on protecting the interface between the wall and the window at the head from moisture intrusion.

FIG. 2—*Chevron made of nonwoven composite flashing installed at the corner of the head of a wood framed brick mold window.*

Walls 17A–20A were concrete masonry unit walls with a 2 × 4 in. wood buck installed in the center of the rough opening. The wood buck was caulked at the buck/block joint and spray adhesive was applied to the block where flashing would be installed. Masonry screws with 1.5-in. washers were used to fasten mechanically the elastomeric nonwoven composite flashing to the face of the wall.

The opposite side of the CMU walls for 17A and 18A were reused for Walls 19A and 20A. The 2 × 4 in. sill plate was removed and replaced with a 1 × 4 in. sill plate with a 1 × 2 in. furring strip installed flush with the interior edge of the sill plate to serve as a back dam.

Round top windows mulled to fixed picture frame windows with integral flanges were installed in wood framed walls and tested to confirm earlier results obtained by Weston et al.

2002. A description of the walls tested is shown in Table 2. Flashing was installed in accordance with the recommendations of Weston et al. 2002 [7].

TABLE 2—*Window flashing installation details per wall for round top windows mulled to fixed picture frame windows with integral flanges*.

Wall #	Window Type – Description and Size	Installation Order – WRB before or after window	Sill Flashing / Detail	Jamb Flashing / Detail	Head Flashing / Detail
1B	Round top 36 × 18 in. mulled to fixed pane picture window with integral flange 36 × 36 in.	Before window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	Elastomeric nonwoven composite flashing
2B	Round top 36 × 18 in. mulled to fixed pane picture window with integral flange 36 × 36 in.	Before window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	Elastomeric nonwoven composite flashing
3B	Round top 36 × 18 in. mulled to fixed pane picture window with integral flange 36 × 36 in.	Before window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	Elastomeric nonwoven composite flashing
4B	Round top 36 × 18 in. mulled to fixed pane picture window with integral flange 36 × 36 in.	Before window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	Elastomeric nonwoven composite flashing
5B	Round top 36 × 18 in. mulled to fixed pane picture window with integral flange 36 × 36 in.	Before window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	Elastomeric nonwoven composite flashing
6B	Round top 36 × 18 in. mulled to fixed pane picture window with integral flange 36 × 36 in.	Before window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	Elastomeric nonwoven composite flashing
7B	Fixed pane picture window with integral flange 36 × 36 in.	After window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	4-in. nonwoven composite flashing
8B	Fixed pane picture window with integral flange 36 × 36 in.	After window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	4-in. nonwoven composite flashing
9B	Fixed pane picture window with integral flange 36 × 36 in.	After window	Elastomeric nonwoven composite flashing	4-in. nonwoven composite flashing	4-in. nonwoven composite flashing

Testing Protocol

Air infiltration and exfiltration were tested using the standard ASTM E 283, Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen, with pressure differences of 25, 75, and 300 Pa. Air leakage measurements are not applicable for comparing installations, as leakage through windows was not isolated from the wall. In addition, some installations had back dams incorporated into the sill design, which greatly influenced air leakage. It was found during air leakage testing that the windows with back dams installed were too leaky to allow the testing equipment to stabilize in order to determine an air leakage rate. Therefore, an air seal had to be added to the back dam to allow for air leakage measurements. Air leakage measurements were primarily used to monitor sealant durability through thermal cycling.

After testing the walls for air leakage, the standard ASTM E 331, Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference, was used to test for water infiltration. Water infiltration pressures were set at 25 and 75 Pa for 15-min periods each and visual inspections were conducted during the test. Once the walls were tested for air leakage and water leakage as installed, the walls were thermal cycled to help understand the long-term performance of the walls. Walls were subjected to four 6-h cycles of thermal cycling (– 17.8°C to 71.1°C) per day for seven days. The AAMA default recommendation from the Test Method for Thermal Cycling of Exterior Walls is to cycle ranging from –17.8°C to 82.2°C. However, in previous tests, vinyl windows were tested according to the AAMA recommendation and were severely damaged due to the higher temperature. It is common that a wall will experience temperatures as high as 71.1°C when exposed to sunlight during the summer months [7].

After the walls were thermal cycled, they were retested for air leakage and water leakage. Then the walls were subjected to wind loading at 500 Pa according to the standard ASTM E 330, Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference, and retested for water leakage.

Experimental Results

General Observations

Brick Mold Windows (Walls 1A to 10A)

The brick mold windows were not painted or caulked along miter joints or at joints in the framing. This provided for the worst-case scenario under which to evaluate flashing performance. The brick mold windows used in this study had factory installed frames. Gaps were often observed at joints between the framing members of the window. These gaps are potential entry points for water in addition to air leakage (Fig. 3).

FIG. 3—*Smoke flowing into a gap at the interface between the exterior sill and jamb brick molding illustrates air and water infiltration.*

After thermal cycling, the miter joints on several windows opened up, which could allow substantial amounts of water to pass to the interior (Figs. 4 and 5). However, the backer rod and caulk on the interior directed water down the jambs toward the sill where it could escape to the exterior. The control walls were caulked on all four sides of the window on the exterior. The windows leaked and the water could not escape because of the caulk on the exterior side of the sill. Because of the sill design of the windows, caulking the interior sill is not a sufficient back dam for these designs. However, the design of the back dam needs to be carefully considered because of air infiltration.

FIG. 4—*Brick mold window miter joint before thermal cycling.*

FIG. 5—*Brick mold window miter joint after thermal cycling.*

A drip cap was installed at the head of all the brick mold windows. The drip cap served two basic functions. First, the drip cap shed water from the top of the frame of the brick mold window. Second, the drip cap provided a shingle for the head flashing to be attached. The WRB was shingled over the head flashing and, as a system, provided effective drainage of water over the head of the window.

The 90° turn method is described in Walls 1A through 4A for brick mold windows and walls 11A and 12A for nonflanged windows. The 90° turn had to be installed so that the flashing would not detract from the aesthetics of the window and would be covered by the wall cladding (Fig. 6). In general, it was difficult to get a reliable, watertight seal into the joint between the window and the exterior sheathing because only a ¼ to ½-in.-wide region of adhesion was achieved (Fig. 7). The material was difficult to press tightly into the corner, resulting in a narrow region of adhesion to the jamb of the brick mold. After thermal cycling, puckering was observed in the flashing along the window jambs (Fig. 8). The formation of these puckers demonstrates that there is an insufficient amount of surface area to adhere to the frame of the brick mold to ensure a tight water seal. Rather, water could potentially be channeled into the rough opening through these puckers, leaving the interior caulk joint as a last line of defense against water intrusion. In addition, typically only ¼ in. or less adhesive was adhered to the side of the brick mold window frame. This is an unacceptable amount of adhesion to rely on for long-term durability, especially considering that the wood frame of brick mold windows may rot over time and that there is joint movement between the window and the wall. Also, irregularities in the wood frame can cause reduced adhesion over such a small surface area. Therefore, it is not prudent to rely on a narrow seal to the wood framing of the brick mold window or the nonflanged window.

FIG. 6—*Vinyl cladding details must conceal flashing details along the jambs of the brick mold window for the 90° turn method.*

FIG. 7—*Investigation shows approximately ¼ in. of adhesion of the flashing to the jamb of the brick mold window frame.*

FIG. 8—*Channel formation along jamb flashing after thermal cycling.*

Walls 5A and 6A were control walls where caulk was used to seal the joints around the jambs and the head. Walls 9A and 10A were installed similar to Walls 5A and 6A, except that a back dam was incorporated under the sill flashing in such a way to create a pan. This pan effectively controlled water from entering into the interior side of the wall and helped divert the water to the exterior. However, achieving a good air seal between the back dam and the window is still a challenge. During the test, a piece of self-adhered jamb flashing was installed to create an airtight seal between the top of the back dam and the interior sill of the window (Figs. 9 and 10). The surface was clean and dry during the installation. The self-adhered flashing adhered very well to the window sill, the back dam, and the wood framing.

FIG. 9—*Self-adhered flashing being applied to create an airtight seal between the top of the back dam and the interior sill of the brick mold window.*

FIG. 10—*Self-adhered flashing used to create an airtight seal between the top of the back dam and the interior sill of the window.*

The types of leaks observed with wood framed brick mold windows (Tables 3 and 4) were very different from the types of leaks observed with vinyl round top windows mulled to fixed pane picture windows with integral flanges. Leaks were observed at the glazing, jamb legs, sill legs, and along sill extensions. Some of these leaks resulted in water penetrating to the interior of the wall system. The majority of these leaks could be managed with a properly designed and installed back dam in conjunction with a good flashing installation method.

TABLE 3—*Water leakage test results (ASTM E 331) at 25 Pa for brick mold windows before and after durability testing.*

Wall #	Before Thermal Cycling	After Thermal Cycling	After Wind Loading
1A	No leak	No leak	No leak
2A	No leak	No leak	No leak
3A	No leak	No leak	No leak
4A	Jamb leg	No leak	No leak
5A	Jamb leg/sill plate	Jamb leg/sill plate	Jamb leg/sill plate
6A	Jamb/sill connection	Jamb leg/sill plate	Jamb leg/sill plate
9A	No leak	No leak	No leak
10A	No leak	No leak	No leak

TABLE 4—*Water leakage test results (ASTM E 331) at 75 Pa for brick mold windows before and after durability testing.*

Wall #	Before Thermal Cycling	After Thermal Cycling	After Wind Loading
1A	Jamb leg	No leak	No leak
2A	No leak	Jamb leg	No leak
3A	No leak	No leak	No leak
4A	Jamb leg	No leak	No leak
5A	Jamb leg/sill plate	Jamb leg/sill plate	Jamb leg/sill plate
6A	Jamb/sill connection	Jamb leg/sill plate	Jamb leg/sill plate
9A	No leak	No leak	No leak
10A	Glazing leak	Gap in framing leak/contained by back dam	Gap in framing leak/contained by back dam

Air infiltration and exfiltration results at 75 Pa are shown in Figs. 11 and 12. All walls tested experienced higher air leakage after thermal cycling as compared to before thermal cycling. Thermal cycling could have reduced the effectiveness of the caulk air seal or changed the physical properties of the window, allowing more air to penetrate through any openings in the window. The increase was most likely due to a reduction in caulk effectiveness.

Nonflanged Windows (Walls 11A to 16A)

The nonflanged windows were installed in one of two ways, protruding from the wall face 1 ¼ in. or recessed into the rough opening 1 in. In the case of the protruding windows, the 90° jamb flashing installation was tested and a method for protecting the cavity of the rough opening was tested. The recessed window was tested with the flashing protecting the cavity of the rough opening.

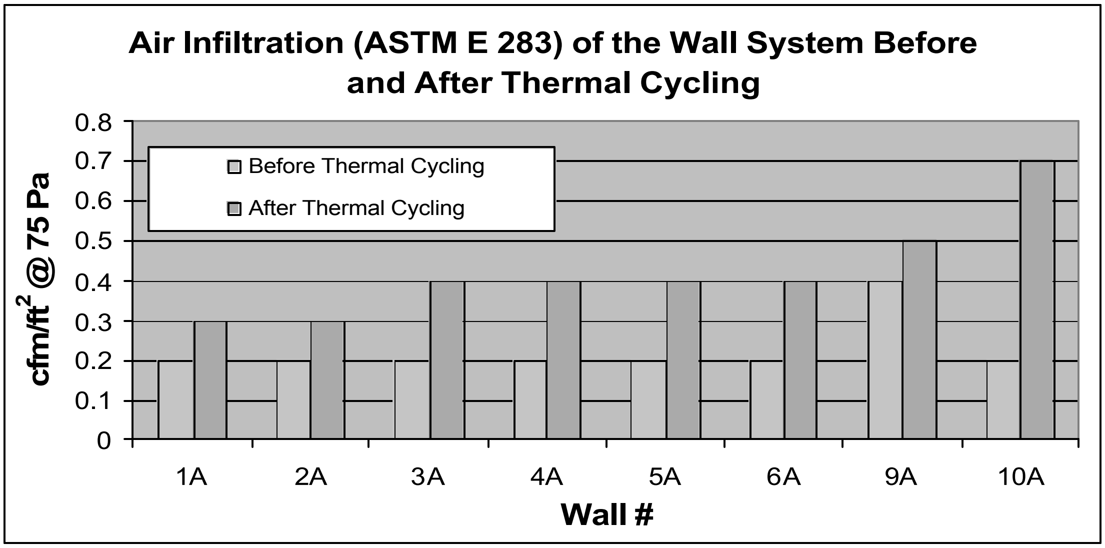

FIG. 11—*Air infiltration (E 283) at 75 Pa for brick mold windows before and after thermal cycling.*

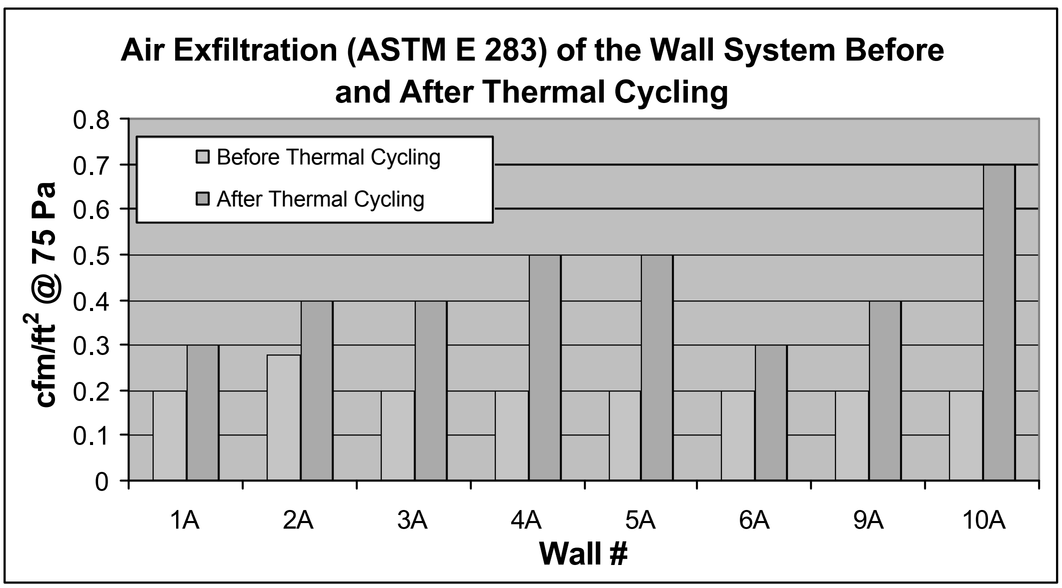

FIG. 12—*Air exfiltration (E 283) at 75 Pa for brick mold windows before and after thermal cycling.*

The amount of adhesion to the surface of the nonflanged window for the 90° turn method was somewhat greater than the amount of adhesion to the surface of the brick mold windows. However, it was still an inadequate amount of adhesion to maintain a tight water seal. The 90° installation of the jamb flashing would be an acceptable redundant method provided that the rough opening was protected by a water resistant WRB in the jambs, nonwoven composite flashing, or both. The 90° method has further problems if the substrate for adhesion has imperfections in the surface, such as rough wood.

The nonflanged windows were installed by fastening through the jambs into the rough opening. No moisture was observed around fastener penetrations in the jambs of the rough opening. In the cases where the WRB was installed after the window, the jamb flashing provided protection to the rough opening. In the cases where the WRB was wrapped into the jambs before the nonwoven composite flashing was installed, the WRB provided redundant protection of the rough opening. Similar leaks to those observed with the brick mold windows were observed in addition to caulk failures for the nonflanged windows (Tables 5 and 6). The caulk failures were observed between the sill flashing and the caulk bead on the interior side of the sill. This observation reinforces the need for a good back dam to manage moisture intrusion.

TABLE 5—*Water leakage test results (ASTM E 331) at 25 Pa for nonflanged windows before and after durability testing.*

Wall #	Before Thermal Cycling	After Thermal Cycling	After Wind Loading
11A	No leak	No leak	No leak
12A	No leak	No leak	No leak
13A	Sill leg and extension	Crack in sill	Crack in sill
14A	No leak	No leak	No leak
15A	No leak	No leak	Sill caulk failure
16A	No leak	No leak	No leak

TABLE 6—*Water leakage test results (ASTM E 331) at 75 Pa for nonflanged windows before and after durability testing.*

Wall #	Before Thermal Cycling	After Thermal Cycling	After Wind Loading
11A	No leak	No leak	No leak
12A	No leak	Jamb leg	No leak
13A	Sill leg and extension	Crack in sill	Crack in sill/sill leg
14A	No leak	Sill caulk failure	Sill caulk failure
15A	No leak	Sill caulk failure/sill leg	Sill caulk failure/sill leg
16A	No leak	Glazing leak	Sill caulk failure

Integrating a nonflanged window with the wall is particularly challenging and leaves the caulk seal as a temporary line of defense against moisture intrusion. Air leakage data show that leakage increases after thermal cycling (Figs. 13 and 14). One reason for increased air leakage is due to reduced effectiveness of the caulk.

Flanged Windows in Mass (CMU) Walls (Walls 17A to 20A)

Preliminary tests were conducted to investigate the potential problems with installing self-adhered flashing to concrete masonry unit (CMU) walls. Concrete block is very porous and must be sealed from water. Wood bucks are commonly used in the rough opening either to adjust the size of the opening for a window or to provide a surface to fasten the window. Any water leaking through or around a window will contact the wood buck. Therefore, flashing has two roles. One role is to divert or manage water away from the building interior. The other role is to help protect the wood buck from degradation.

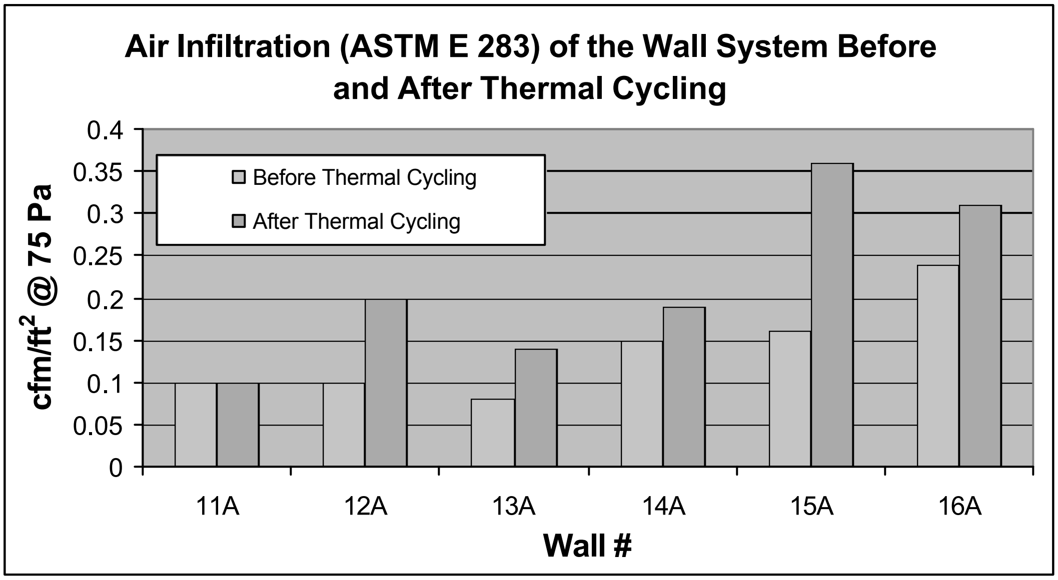

FIG. 13—*Air infiltration (E 283) at 75 Pa for walls with nonflanged windows before and after thermal cycling.*

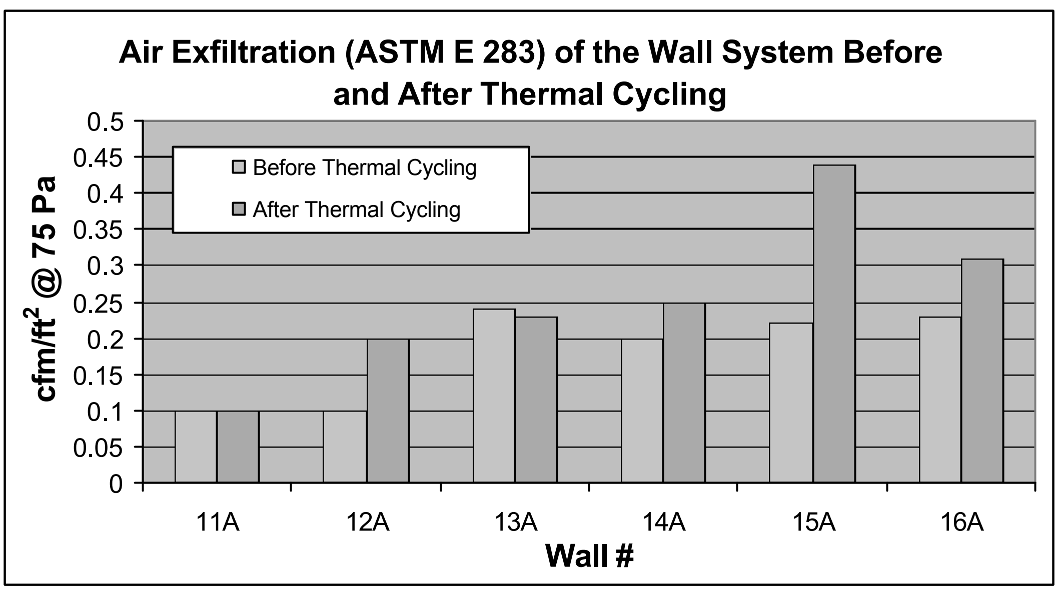

FIG. 14—*Air exfiltration (E 283) at 75 Pa for walls with nonflanged windows before and after thermal cycling.*

The block walls in this test were not sealed. A spray adhesive was used to prime the block for the self-adhered flashing. Masonry screws with 1.5-in. washers were used to fasten the corners of the flexible sill pan flashing to the face of the block. Flanged windows were installed into the CMU walls and tested for air and water resistance per the above protocol. The flashing seemed to adhere adequately when the spray adhesive was used. However, if the block is not sealed, flashing does little to protect the wood buck from the moisture absorbed by the block. The seal to mortar joints are also problematic in that water could travel along these joints behind flashing. More work is needed to develop a robust installation for self-adhered flashing to CMU block. It is also important to consider the exterior finish of the wall to ensure that the flashing details do not interfere with the finish.

Flanged Windows in Wood Framed Walls (Walls 1B–9B)

The types of leaks observed with round top windows mulled to fixed pane picture windows with integral flanges were consistent with the types of leaks observed in previous studies by Weston et al. At 25 Pa, one window leaked at the mull joint before thermal cycling. After thermal cycling, half of the windows leaked at the mull joint (Fig. 15) and after wind loading, all of the windows leaked either through a mull joint or through the glazing (Fig. 16). Window leaks were more frequent and more severe when tested at 75 Pa pressure. However, fixed pane vinyl windows with integral flanges did not leak before or after thermal cycling or after window loading.

The primary water entry point was the horizontal window mullion. The windows used in this study were similar in size and style to windows used in previous tests. However, these windows were from a different manufacturer than the windows used in the Weston et al. 2002 study. At 75 Pa, one window leaked at the horizontal mullion and one window leaked at the horizontal glazing bead. However, thermal cycling exacerbated this water entry. Five out of the six windows leaked at the horizontal mullion, the glazing, or a combination of the two. Interestingly, the window with the glazing leak during Phase I did not leak after thermal cycling. Water resistance was evaluated again following 1-h each of positive and negative wind loading at 500 Pa (65 mph wind). Five out of six windows had both mullion leaks and glazing leaks, one window had only a glazing leak (Tables 7 and 8).

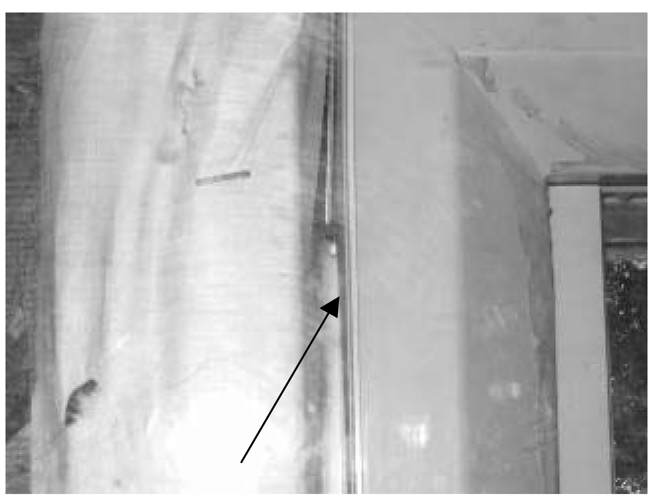

FIG. 15—*Water leak at the mullion between the vinyl clad round top window and the vinyl clad square picture window.*

FIG. 16—*Glazing leak in the vinyl clad round top window above the mullion to the vinyl clad square picture window.*

TABLE 7—*Water leakage test results (ASTM E 331) at 25 Pa for round top and fixed pane windows with integral flanges before and after durability testing.*

Wall #	Before Thermal Cycling	After Thermal Cycling	After Wind Loading
1B[a]	No leak	Mull leak	Mull/ Glazing leak
2B	No leak	No leak	Mull/Glazing leak
3B	No leak	No leak	Mull/Glazing leak
4B	Mull leak	Mull leak	Mull/Glazing leak
5B	No leak	No leak	Glazing leak
6B	No leak	Mull leak	Glazing leak
7B[b]	No leak	No leak	No leak
8B	No leak	No leak	No leak
9B	No leak	No leak	No leak

[a]Walls 1B through 6B contained round top windows mulled to fixed pane windows.
[b]Walls 7B through 9B were fixed pane windows.

TABLE 8—*Water leakage test results (ASTM E 331) at 75 Pa for round top and fixed pane windows with integral flanges before and after durability testing.*

Wall #	Before Thermal Cycling	After Thermal Cycling	After Wind Loading
1B[a]	No leak	Mull/Glazing leak	Mull/Glazing leak
2B	No leak	Mull/Glazing leak	Mull/Glazing leak
3B	No leak	Mull/Glazing leak	Mull/Glazing leak
4B	Mull leak	Mull leak	Mull/Glazing leak
5B	Glazing leak	No leak	Glazing leak
6B	No leak	Mull leak	Mull/Glazing leak
7B[b]	No leak	No leak	No leak
8B	No leak	No leak	No leak
9B	No leak	No leak	No leak

[a]Walls 1B through 6B contained roun d top windows mulled to fixed pane windows.
[b]Walls 7B through 9B were fixed pane windows.

None of the fixed pane windows wrapped with WRB after window installation leaked during any of the water resistance tests. However, water was able to enter between the WRB and the flashing after wind loading, due to tape failure, and drained down the sheathing. Water did not enter under the flashing.

Air infiltration and exfiltration results at 75 Pa are shown in Figs. 17 and 18. Air leakage increased after thermal cycling for all walls tested, which is consistent with findings for other window types.

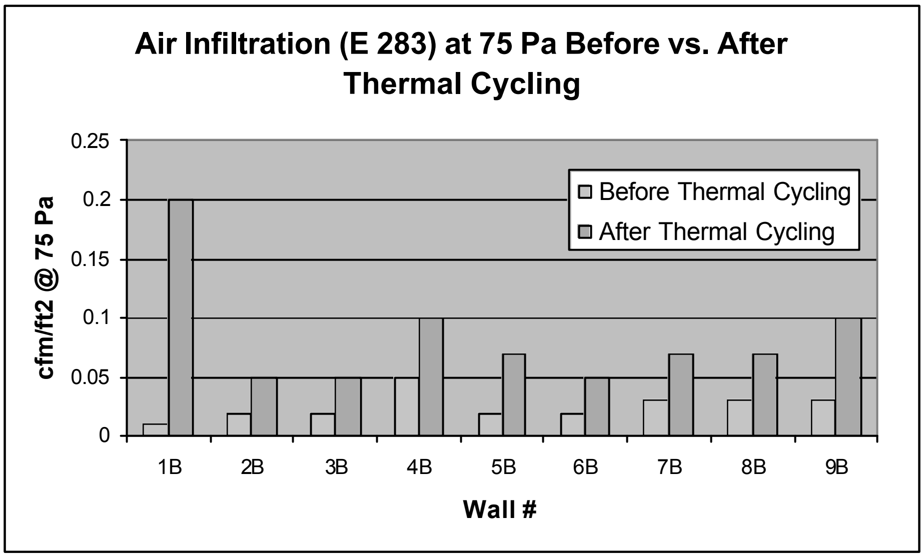

FIG. 17—*Air infiltration (E 283) at 75 Pa for walls with round top windows mulled to fixed pane picture windows before and after thermal cycling.*

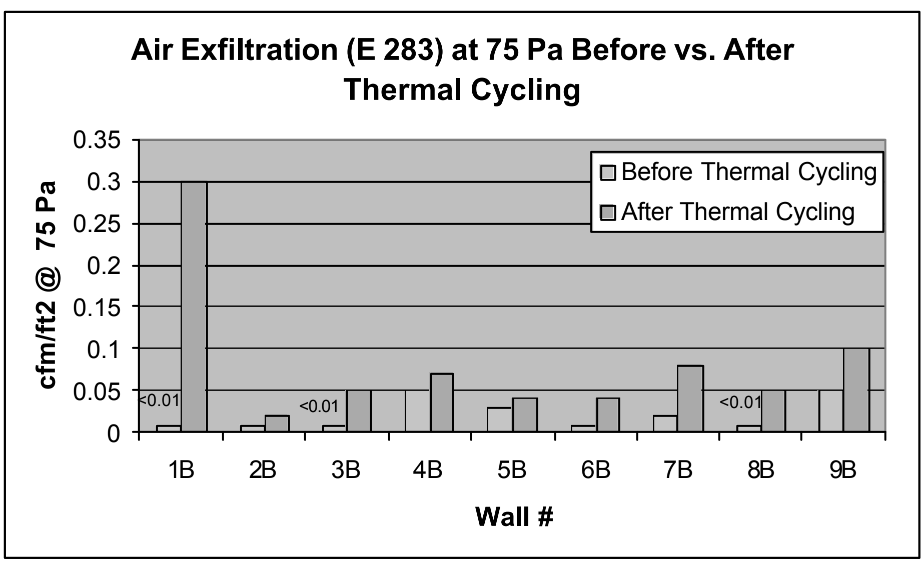

FIG. 18—*Air exfiltration (E 283) at 75 Pa for walls with round top windows mulled to fixed pane picture windows before and after thermal cycling.*

Conclusions and Recommendations

The Effects of Thermal Cycling on Air Leakage and Water Leakage

Thermal cycling has a great impact on air and water leakage in wall systems as illustrated in the air leakage and water leakage data. The results show that thermal cycling increased the air leakage measured for the wall assemblies. Thermal cycling could have reduced the effectiveness of the caulk air seal or changed the physical properties of the window, allowing more air to penetrate through any openings in the window (i.e., mull joints, weep holes, glazing bead cracks, miter joints, etc.). Water resistance testing results support the findings from the air leakage test.

System Water Management Performance

All variations of the flexible sill flashing performed well. Not applying caulk to the bottom exterior flange or brick mold of windows allows for any water entry to drain to the exterior. Caulking the interior sill of flanged windows provides a dam to help divert water to the exterior of the wall. However, other window designs require a carefully designed back dam to manage any water intrusion to the interior of the wall effectively. A back dam consisting of backer rod and caulk was an effective air seal, whereas the rigid back dam system was difficult to air seal. Many of the brick mold windows leaked through joints in the window frame after thermal cycling or wind loading. These leaks occurred in locations on the window where flashings on the face are ineffective. Several of the windows in this study experienced physical changes as a result of thermal cycling that increased the vulnerability to water intrusion. Miter joints opened up, in some cases leaving ¼-in. gaps in the window frame for water to infiltrate. In other cases, the frame was poorly constructed, with gaps between framing members that would allow significant water to penetrate into the rough opening. Given these observations, it is important to ensure that the rough opening is protected from moisture intrusion.

Due to the design of brick mold and nonflanged windows, it is important to protect the wall cavity or rough opening. Therefore, it is recommended that the rough opening be well protected assuming that the window will leak and that water will enter. The sill should be flashed with elastomeric nonwoven composite flashing in accordance with the recommendations by Weston et al. Six inch nonwoven composite flashing should be used to protect the jambs by wrapping into the jamb to form a boot with the elastomeric nonwoven composite flashing in the sill. The head detail will depend on the window type and how it is set into the rough opening. For brick mold windows, a drip cap should be installed and then nonwoven composite flashing should be shingled over the drip cap for proper drainage. The WRB should be shingled over the head flashing. This recommendation applies to brick mold windows and nonflanged windows that are installed protruding from the face of the wall. The flashing installation would be similar for nonflanged windows that are recessed, except that a modified drip cap should be used to help shed water.

It is less costly to replace windows periodically than to replace deteriorated walls. It remains a challenge to integrate fully these styles of windows with the wall and not detract from the aesthetics of the building as a whole. However, more testing is needed to explore methods and flashing materials that are designed to better integrate the window with the wall and that are robust and relatively easy to install.

Testing walls, windows, and accessories (flashing, weather resistive barrier, etc.) as an integrated system is critical to understanding the performance of the system. These systems not only need to be tested as installed, but also tested for durability to provide a greater understanding of how the system will perform in the field over time. Where flashing is concerned, the devil is in the details. It is important to understand flashing details for various types of windows and to do things that make sense for managing water and increasing the longevity and functionality of the wall system.

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A Review of Climate Loads Relevant to Assessing the Watertightness Performance of Walls, Windows, and Wall-Window Interfaces

ABSTRACT: When assessing a wall assembly's ability to manage rainwater and control rain penetration, the two key climatic elements to consider are wind speed and rainfall intensity. However, of significance to rain penetration is the effect of wind-driven rain on the building cladding – that is wind coincident with rainfall. When water is present at openings in the cladding, water is driven into the layers of the assembly by the action of wind. Paths providing a direct line from openings in the cladding to inside the assembly offer particularly vulnerable points for water entry. Performance testing helps determine the location of vulnerable locations in a wall assembly and the test loads at which penetration occurs, and it possibly relates the amount of entry to specific details and simulated climate effects. Undertaking watertightness performance tests requires knowledge of extremes in wind-driven rain or specifically the occurrence and level of extreme rainfall events for locations of interest. A review of climate information on wind-driven rain is provided, and its relevance to assessing the watertightness performance of walls, windows, and wall-window interfaces is discussed. Values of rainfall intensity, duration, and frequency or occurrence are given, emphasizing the level of significance of these variables to different North American climates.

KEYWORDS: climate loads, performance testing, rain, walls, wind, wind-driven rain, watertightness, windows, wall-window interface

Introduction

One the most important factors affecting the durability of exterior walls is the ability of the wall to manage moisture. The most significant source of exterior moisture is rain, a basic climate element. In and of itself rain should not pose a significant problem to a well-designed and well-built wall. The interaction of rain and wind, another basic climate element, can lead, however, to the deposition of liquid water on vertical walls in the form of wind-driven rain. Water deposition on exterior walls can lead to films of water forming on the surface. Pressure differences, created by wind, across the wall section of the wall can drive water through openings in the wall. Openings, defects, or deficiencies in the cladding offer particularly vulnerable points for water entry.

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Durability and Watertightness Performance

Rainwater intrusion has always been a threat to the durability and serviceability of light-frame buildings [1]. In regard to low-rise buildings the standard *Guide for Limiting Water-Induced Damage to Buildings* (ASTM E 241-00) indicates that among the many examples of the degradation of building components due to the presence of moisture, the most significant in regard to low-rise buildings are the decay of wood-based materials that can lead to creep deformation and reduction in strength or stiffness and the corrosion of metals. It also notes that precipitation has the potential for delivering exceptionally large moisture loads to buildings and is usually the largest potential moisture source.

Of importance regarding the topic of durability is the following: how much water entry is acceptable? Carll states [1] that there are no standard methodologies in North America for characterizing rain exposure of a given low-rise building wall for design purposes. Hence, obtaining an answer to the question of how much depends on being able to determine the amount that is first deposited on the wall. As well, how much water enters depends on the specifics of the exterior wall, such as the materials and construction, the climate, the interior conditions, and the type of deterioration under consideration.

Consider two types of events to which a wall might be exposed, an extreme event such as a 1 in 10-year rainstorm and a typical event that might represent normal in-service conditions. A wall that has acceptable performance under extreme conditions should perform adequately under in-service conditions. A criticism of setting testing thresholds at or near extreme levels is that when a test protocol covers a large geographic area, the thresholds might be too severe for certain areas and lead to over designed walls in those regions. The challenge therefore is to develop protocols that can capture both extreme and in-service conditions related to the likelihood of climatic events. Undertaking watertightness performance tests requires knowledge of extremes in wind-driven rain or specifically the occurrence and level of extreme rainfall events for locations of interest. The pressure differences across the wall and the water deposition rates in a watertightness test protocol should be related to specific climates or locations so that wall design and performance can be better matched to local conditions.

In developing testing protocols or relating protocols to real climate events two climatic parameters are significant[3]:

1. The deposition rate - the amount of water impinging on the wall, related to the wind speed and rainfall intensity
2. The pressure difference across the wall - related to the wind speed

The relative importance of these two parameters on water entry depends on the size of openings in the wall. Large openings or gross defects where the trajectories and momentum of individual raindrops could carry them directly to the interior are not considered here. Smaller openings or deficiencies are those that that might occur during construction and might be overlooked or those caused by the normal wear and tear that occurs in-service.

Consider openings of two sizes for a “normal” rain event (i.e., return period of 1 in 2 years) of average intensity and duration (e.g., in Ottawa, 1.8 mm/h and a 4-h duration):

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[3] It should be noted here that neither stack effect nor ventilation pressure is considered in this paper. With regard to stack effect the focus of this paper is on: a) low-rise buildings where stack effects are small and b) wind-driven rain, which tends to occur during warm ambient conditions. With regard to ventilation pressures for low-rise buildings, these pressures are generally small, if they exist at all, in comparison to the wind velocity pressures considered here.

1. A size where the opening may be completely occluded by water in such an event where there is sufficient water to collect at the deficiency (e.g., < 1 mm), and
2. An opening of sufficient size (e.g., > 5 mm) that can only be partially blocked by water in a similar rain event.

Openings of the first type might be considered normal in practice – cracks in stucco, for example – whereas larger openings, of the second kind, are considered deficiencies in construction or design – a missing sealant bead, for example. In the first case where the opening is completely occluded by water, the most sensitive parameter related to water entry is the pressure difference, ΔP, across the wall specimen [2]. In the second case, a partially occluded opening, ΔP, is less important than the rate of water deposition. The potential for water entry is related to the amount present at a deficiency; hence, apart from deposition there is as also the possibility that migration of water to interfaces at penetrations through the wall, such as windows and ventilation ducts, may also pose a problem.

Film formation is related to both the nature of the cladding, porous and non-porous (non-absorbing), and the rainfall intensity and duration of rainfall events. Potentially, this permits differentiating between key and non-significant rainfall events, i.e., will a film of water form on a porous surface and collect at a deficiency or simply be absorbed over the course of the rain event.

Hence, performance testing helps determine the location of vulnerable locations in a wall assembly, the test loads at which penetration occurs, and possibly the relationship between the amount of water entry to specific wall details and simulated climate effects [3]. In this paper two types of tests will be considered, water penetration tests and water entry tests. The difference between them is that when testing for water penetration the walls are "pristine" in that there are no deficiencies, while water entry tests are conducted on specimens with deliberately introduced deficiencies. Water penetration and entry test protocols are concerned with two climate-related parameters. When testing pristine walls without deficiencies the ΔP parameter is most important given a deposition sufficient for a film to form. When testing typical deficiencies, however, the deposition rate becomes key. In assessing the watertightness performance of a wall, a protocol should reflect the effect of ΔP as well as deposition rate.

This paper provides the rationale for a performance test for the wall-window interface based on a knowledge of existing watertightness testing standards, a review of key climate parameters such as driving rain wind pressure and water deposition rates. The rationale provides a means to directly relate key climate parameters to specified locations in North America and their expected return periods. This in turn provides a useful measure to extract information for testing wall-window assemblies and their interfaces to simulated climate loads. As well, the proposed methods permit locating geographical areas having higher or lower risk of water entry given the likelihood of occurrence and the degree of intensity and duration of specified rain events.

Overview of Selected Watertightness Testing Standards

The British code of practice, BS 8104:1992 [4], prescribes a method for assessing the exposure of walls to driving rain. The criteria chosen for exposure were quantity and duration of driving rain impinging on a wall rather than the driving rain wind-pressure. The intensity and duration of wet spells are defined as a specific threshold of the driving index that continues without periods of interruption over a given length of time (dwell period). The return periods for these wet spells are provided. The choice of criteria reflects the type of wall construction considered, which is typically masonry in the UK.

Another approach to watertightness is to assume that a film of water will form on the wall. The pressure difference across the wall is increased until failure occurs. The testing pressures are related to the frequency of occurrence of wind and rain in the environment. Examples of this approach are embodied in the Canadian standard for Windows installation (CAN/CSA A440-00 [5]) and the *North American Fenestration Standard* (NAFS-1 [6]). The CSA A440 is a standard that encompasses many aspects of window performance including water penetration performance, a summary of which follows.

Windows are tested at given spray rate under increasing pressure differences. The spray rate is 3.4 L/min-m^2 and conforms to the standard *Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference* (ASTM E 331-00) and the standard *Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference* (ASTM E 547-00). Since the windows are assumed to have no gross defects, the standard assumes that ΔP is the most sensitive parameter. It is sufficient to ensure a large enough quantity of water be supplied to form a film on the windows and allow water to collect at vulnerable points. The pressure steps, ΔP, proceed in increments from 0–700 Pa, 0 for storm window ratings and 700 for highly exposed commercial windows. Windows are rated accordingly up to the maximum pressure step at which they pass, failure occurring if water penetrates the window. In developing the standard climatology of driving rain wind pressure was produced [7]. The standard contains tables and contour maps giving the 5-year return periods for residential and 1 and 10 year Driving Rain Wind Pressure (DRWP) for commercial at 1.8 mm/h or rain intensity threshold (agreed to be the minimum rain intensity at which a film of water will form on glass). Windows are selected by comparing the test rating with expected driving rain wind pressure for a given climate. For residential windows, Vancouver has a 1 in 5 DRWP of 160 Pa, while for Calgary the expected 5-year return DRWP is 220 Pa. Consequently the requirement for windows in Calgary, a substantially drier place than Vancouver is more stringent.

Standard A440 refers to ASTM E 547. In this standard, and a similar standard ASTM E 331, a water deposition rate (spray rate) is prescribed to be 3.4 L/min-m^2 (5.0 US Gal/ft^2-h), and in both tests methods the procedure specifies a pressure difference of 137 Pa across the wall assembly.

The goal is to develop a test protocol to assess the watertightness of wall systems. The threshold values for the pressure difference across the wall, ΔP, and the water deposition rate are to be related to the likelihood of significant climatic events. Wall systems are rated according to water tightness performance, and the appropriateness of the system testing for different climates is established.

Establishing Climate Parameters for Testing

As previously mentioned, the two key climate parameters related to watertightness testing are:

1. The rate of water-deposition on the wall, i.e., wind-driven rain (WDR)
2. The driving rain wind pressure (DRWP)

Estimating the Effects of Wind Driven Rain (WDR)

Free wind-driven rain is the amount of wind-driven rain passing through an imaginary vertical plane without being buffeted by obstructions or terrain. Generally free wind-driven rain can be calculated from hourly weather in the following manner [4,8,9]:

$$WDR_{free} = DRF * \cos(\theta) * U * R \ (L/m^2\text{-h}) \quad (1)$$

where:

DRF is a driving rain factor related to the diameter of the size of raindrops (s/m); the DRF is inversely proportional to the raindrop size,
θ is the angle of the wind to the outward wall normal,
U is the hourly average wind speed (m/s), and
R is the hourly rainfall intensity (mm/h-m^2)

The wind-driven rain impinging on an exterior wall can be estimated by multiplying the free wind-driven rain by an appropriate aerodynamic factor to account for building geometry and architectural details, terrain, and upstream obstructions [4,9]. For the purpose of this paper, aerodynamic factors will be set to 0.9, generally the highest intensity experienced near the top corners of a typical building. Other approaches based on computational fluid dynamic simulations exist, and the results are in general agreement with the approach used here, although the studies do shed some light on the effects of short duration events and the granularity of weather data [10,11].

Effects of Driving Rain Wind Pressure (DRWP)

One purpose of water penetration trials is to test the watertightness performance of pristine walls, i.e., walls with small deficiencies that would likely be completely occluded by water in a significant rain event. Specimens are assumed to be in pristine condition, i.e., built and tested as designed and/or intended without deficiencies purposely inserted and to function as intended. There should be no large holes, and intrusion may occur through small openings or through the materials themselves. Water penetration through small openings tends to more sensitive to the variation of pressure. In this case the pressure difference ΔP is assumed to be the most important parameter.

The Driving Rain Wind Pressure (DWRP) can be calculated simply as:

$$DRWP = 1/2\ \rho\ U^2 \ (Pa) \quad (2)$$

where:
ρ is the density of air, assumed to be 1.2 kg/m^3, and
U is the wind speed during rain in m/s.

Note that the driving rain wind pressure is not necessarily equal to the pressure difference ΔP across an exterior but the force exerted on the wall by the wind. The actual pressure difference across an exterior is related to the wind speed as well as other factors such as air leakage that may serve to reduce the actual ΔP. In some cases the geometry and building operation may actually serve to increase pressure difference across the wall assembly. For the purposes of this paper the DWRP shall be considered to be the same as the pressure difference across the wall.

The Driving Rain Wind Pressures for Canadian cites[4] are given by Welsh, Skinner, and Morris [7]. These values have been computed for rainfall rate thresholds of 1.8, 3, and 5.1 mm/h

[4] Listed in Appendix.

and for return periods of 1 in 2, 5, 10, and 30 years, respectively. Figure 1 shows the hourly DRWPs for 23 Canadian locations for different return periods at the 1.8 mm/h threshold level. Table 1 provides a location key code for cities charted in Fig. 1. The basis for selecting the pressure steps was the rainfall rate of 1.8 mm/h. This threshold was recommended because the 1.8 mm/h rate corresponded to that of ordinarily experienced rainfall during most storms, and the consensus was that this rate would allow for sufficient water availability for water leakage to be possible [7].[5]

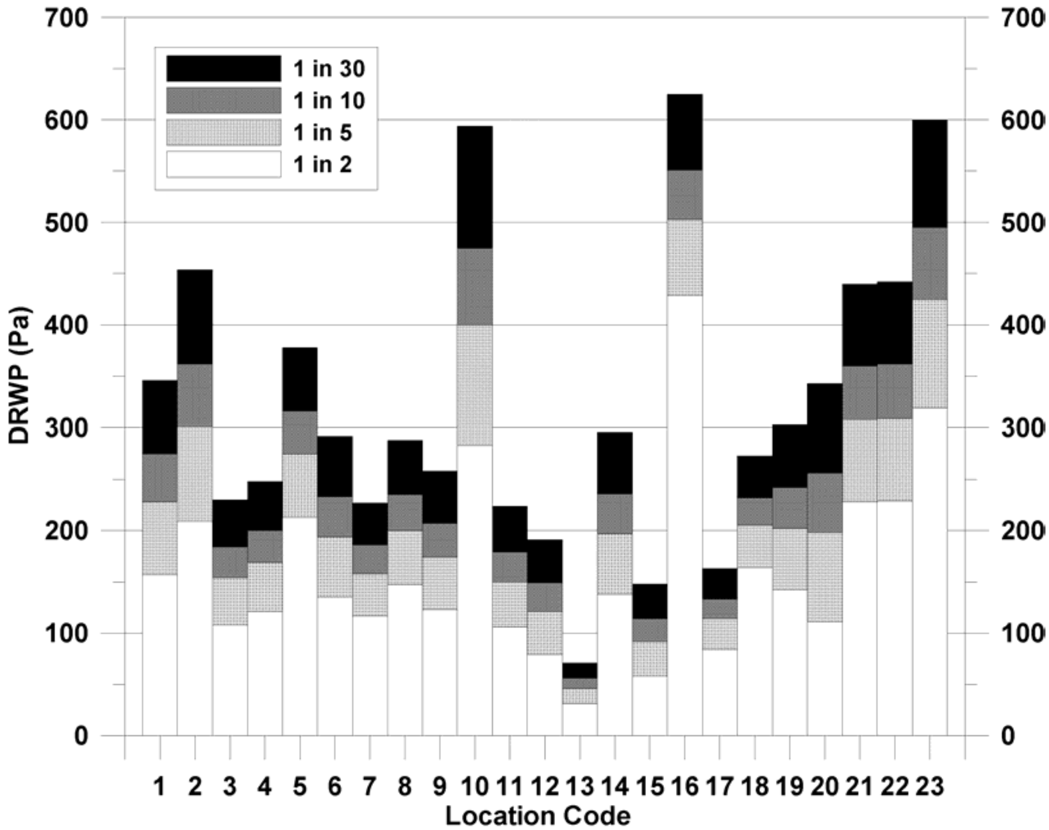

FIG. 1—*A sample of hourly Driving Rain Wind Pressures for several typical Canadian locations for various return periods at the 1.8 mm/h rain intensity threshold.*

TABLE 1—*Key code for locations cited in Figs. 1 and 3.*

Code	Location	Code	Location	Code	Location
1	Calgary AB	9	Saskatoon SK	17	Victoria BC
2	Charlottetown PEI	10	St John's NF	18	Victoria Gonz Hts BC
3	Edmonton AB	11	Toronto ON	19	Regina SK
4	Fredericton NB	12	Vancouver BC	20	Iqaluit NU
5	Halifax NS	13	Whitehorse YK	21	Sept Iles QC
6	Montreal QC	14	Winnipeg MB	22	Shearwater NS
7	Ottawa ON	15	Yellowknife NT	23	Port Aux Basques NF
8	Quebec QC	16	Sandspit BC		

[5] See [7], pp. 8 and 9.

From Fig. 1 it can be seen that the 50 Pa DRWP level is below the 1 in 2 threshold for all the locations except Whitehorse in the Yukon. The 75 Pa pressure level is below the level found for the majority of cities examined. It is noteworthy because it conforms to many other standards for characterizing air-leakage. The 150 Pa pressure level appears to provide the maximum level that could be expected for most Canadian locations at the 1 in 2 threshold. Failure here would be unacceptable for the rest of the country. A pass here would be adequate for all but Coastal climates. The 300 Pa pressure level would seem to be a pass-fail for all but the windiest locations (e.g., Port Aux Basques NF, Sandspit BC) for a 1 in 2 return period. For occurrences of 1 in 2, all locations are covered at 500 Pa. For 1 in 5 return periods the 300 Pa pressure level seems to be an adequate test pressure for all Canadian locations except the Coastal locations, 500 Pa being an upper limit for the 1 in 5 return period. The 700 Pa pressure levels seem to be an adequate threshold to cover most of the DRWPs experienced in Canada for return period of up to 1 in 30. (Exceptions include, e.g., St Andrews NF, Spring Island BC).

Spray Rates

For the water penetration testing, the pressure was deemed to be the most important variable. Spray rates were selected to be the maximum that could be realistically experienced for a given return period. The purpose of water entry testing is slightly different. The focus during water entry testing is how much water, if any, penetrates the assembly and at what rate. The purpose of this kind of testing is to establish water entry rates to be used for estimating the ability of the assembly to manage accidental water entry that in turn can be used to assess the durability of the assembly.

Here it is assumed that the walls are not pristine but rather have deficiencies, i.e., holes or openings larger than would be expected in pristine walls. The most sensitive testing parameter in water entry testing is the spray rate, directly related to the intensity of wind-driven rain impinging on the wall. It should be noted that the maximum wind-driven rain impinging on a wall would generally not occur at the maximum expected DRWP. The trend is for higher rainfall intensities to be associated with lower wind speeds; hence, the combination of maximum DRWP and higher spray rates will be less likely to occur.

Two methods were used to estimate WDR: Choi's [10] and Straube's [9]. For a given set of climate parameters Choi's method seems to provide consistently less water deposition than Straube's. If Straube's is accepted to be conservative, then Choi's can roughly be assumed to underestimate by about 25 % the amount of water deposition on a wall (at least for Ottawa).

Figure 2 shows the hourly average wind-driven rain for 9 Canadian locations for different return periods.[6] From the figure a spray of 0.2 L/min-m^2 would seem to be too low to cover most of the normal in-service conditions, 1 in 2, for locations surveyed, whereas a rate of 0.4 L/min-m^2 would seem to be adequate. For extreme in-service conditions a rate of 0.8 L/min-m^2 will cover most Canadian locations except for 1 in 30 events. A rate of 1.6 L/min-m^2 will cover most locations of interest in Canada. A spray rate of 3.4 L/min-m^2 is unlikely in Canada for hourly rates for a 1 in 30 return period. However, this rate would probably be sufficient if North American locations are considered, the higher spray rates being more likely in the southern United States (Wilmington, NC and Miami FL, for example).

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[6] Listed in Appendix.

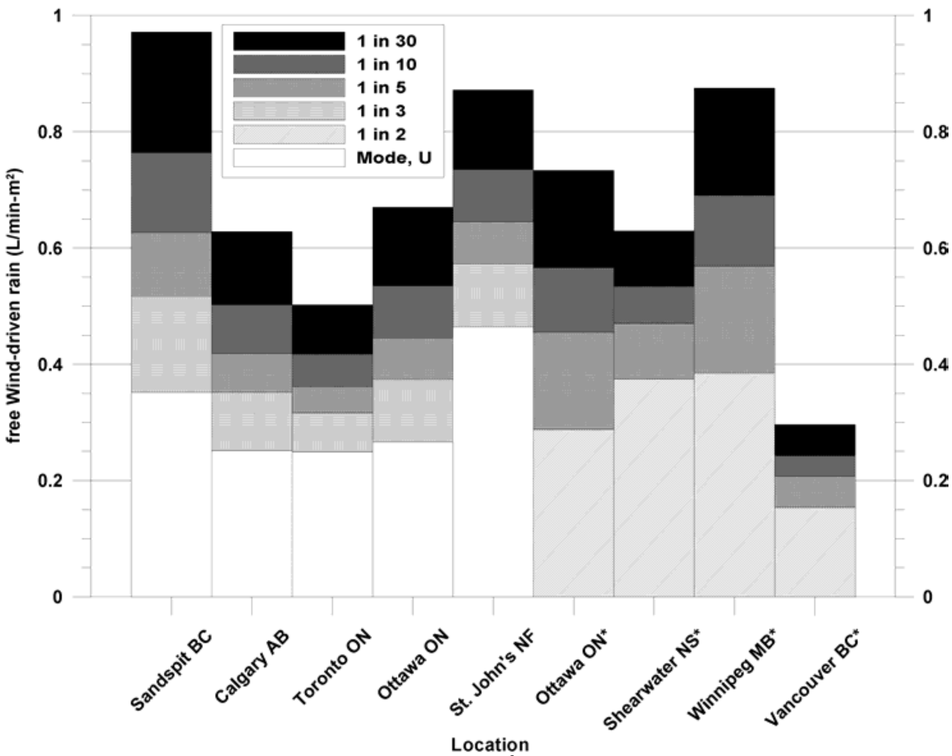

FIG. 2—*A sample of spray rates in L/min-m^2 based on hourly driving rain averages for several typical Canadian locations for various return periods. Choi's method [10] was used to calculate the free WDR except for locations followed by an asterisk, where Straube's method [9] was used.*

Duration and Intensity

Only hourly events have been considered so far, specifically hourly DRWPs and hourly rainfall intensities. For events having durations shorter than one hour the rainfall may be more intense and the wind speed higher. Factors for converting hourly wind speeds to averages over 1, 3, 5, and 10 minutes have been extracted from *The Guide to the Use of the Wind Load Provisions of ANSI A58.1*[7] [12] and are given in Table 2. These factors must be squared when applied to wind pressures. Hourly wind pressures can be used to estimate the corresponding return period values for shorter averaging times using the factors below in Table 2.

TABLE 2—*Factors to convert hourly wind speeds to shorter averaging times.*

Averaging Time	10 min	5 min	3 min	1 min
Factor on speed	1.07	1.11	1.14	1.25
Factor on pressure	1.14	1.23	1.30	1.56

Factors for converting hourly rain intensities falling vertically onto a level surface to shorter averaging periods have been suggested by Choi[8] [10]:

$$\{R(t)\} \;/\; \{R(60)\} = [60/t_i]^{0.42} \text{ (mm/h)} \tag{3}$$

[7] Graph on page 106 [12].
[8] Page 12 [10]

where:

t_i is the averaging time of time of interest (min),
R(t) is the rain intensity for averaging time of interest (mm/h), and
R(60) is the hourly rain intensity in (mm/h).

For example, for an averaging time of 5 min:

$\{R(5)\} / \{R(60)\} = [60/5]^{0.42} = \mathbf{2.84}$. For 10-min averages, the factor is 2.12.

When considering shorter averaging times for the DRWP it was assumed that the rainfall intensity remains constant throughout the hour. What is the effect of considering shorter averaging times on the test protocol threshold limits for pressure? A 5-min averaging time increases the wind pressures by 23 %. Figure 3 shows the 5-min average DRWPs for 23 locations for different return periods at the 1.8 mm/h threshold. For normal service conditions, 1 in 2, 150 Pa suggested by the hourly wind pressures moves up to 200 Pa. At 300 Pa, the threshold seems to cover all areas examined except coastal areas with exceptions (Calgary at 350 Pa) for in-service conditions. The 500 Pa DRWP level covers all Canadian locations except Coastal regions for longer return periods, such as 1 in 5 and 1 in 10. At 800 Pa all Canadian locations are covered for shorter duration extreme events.

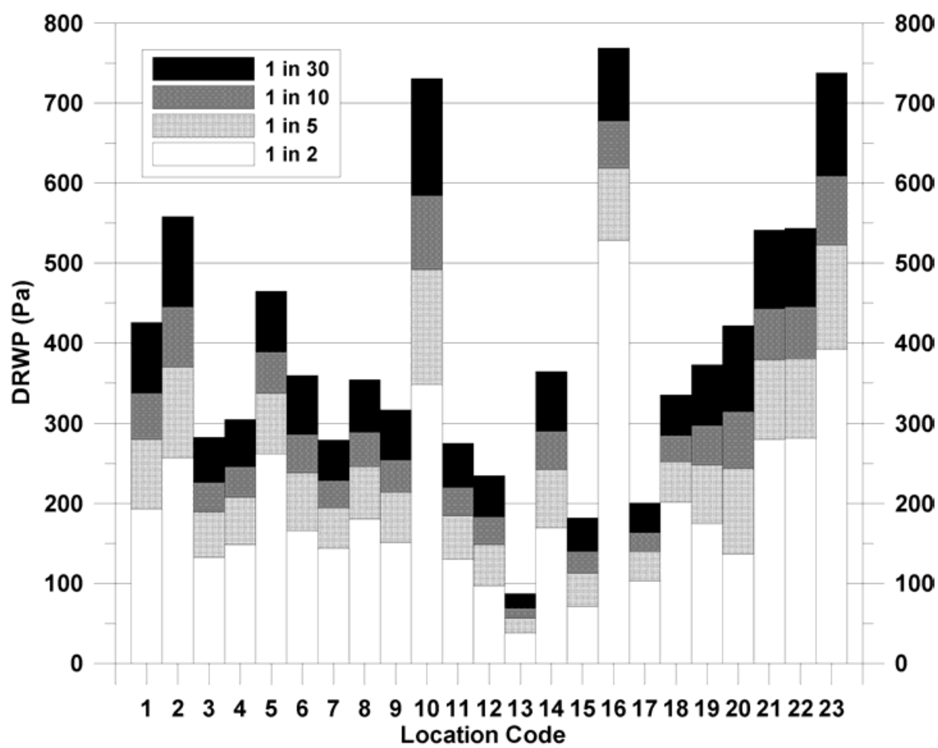

FIG. 3—*A sample of Driving Rain Wind Pressures averaged over 5 min for several typical Canadian locations for various return periods at the 1.8 mm/h rain intensity threshold.*

When considering shorter averaging times for wind-driven rain, the process is more complex. The amount of free wind-driven rain is related to the terminal velocity of the raindrops, which in turn is related to the size of the raindrops. Generally the higher the rainfall intensity, the larger the size of raindrops, and consequently the lower the driving-rain factor (DRF) that in turn results in lower amounts of free wind-driven rain. A conservative estimate is simply obtained by multiplying the time averaging factor by the wind-driven rain calculated on an hourly basis. The assumption here is that wind speed remains constant at the hourly average. For example, the 1 in 30 maximum hourly wind-driven rain for Ottawa is 48.9 L/h-m^2 (0.82 L/min-m^2) that for the top corner of a building yields a spray rate around 0.73 L/min-m^2. Increasing the spray rate by a factor of 2.84 increases the spray rate for an extreme 5-min event to 2.1 L/min-m^2.

Figure 4 shows the 5-min average wind-driven rain for 23 Canadian locations for different return periods. The effect of using 5-min averaging times is that a rate of 0.8 L/min is the lowest threshold for normal in-service conditions except relatively exposed coastal regions.

At 1.6 L/min-m^2 all locations are covered for normal in service conditions (1 in 2) but not for more extreme service conditions, such as one in five and one in ten. However, a spray rate of 3.4 L/min-m^2 covers all the locations examined for the most extreme events (1 in 30).

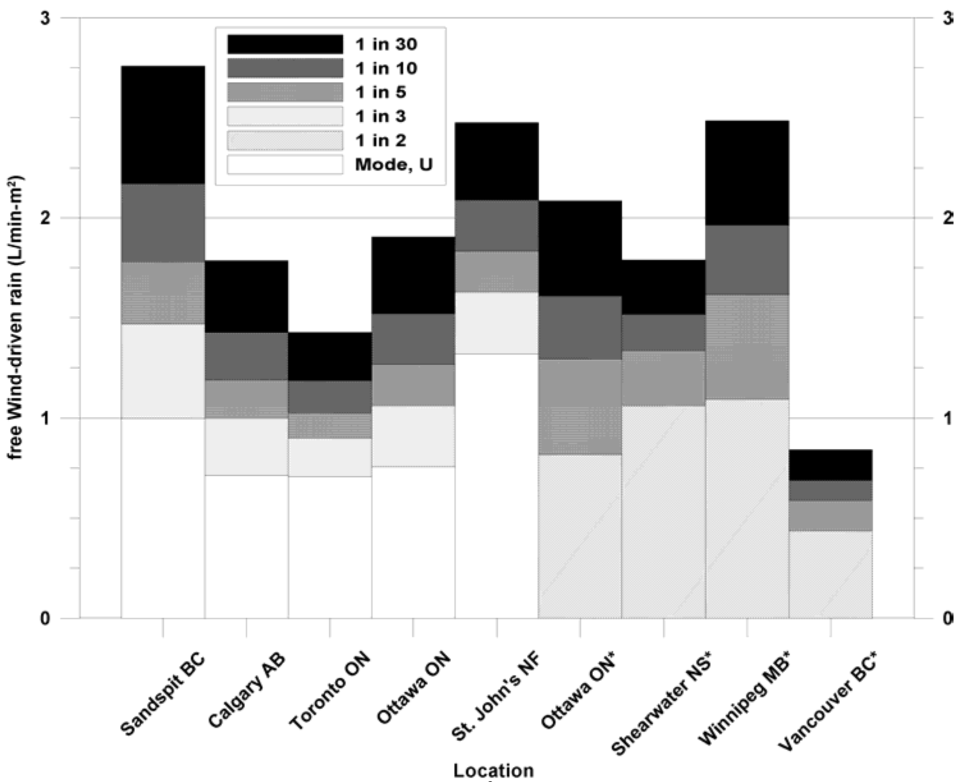

FIG. 4—*A sample of spray rates in L/min-m^2 based on driving rain with a 5-min averaging time for several typical Canadian locations for various return periods. Choi's method [10] was used to calculate the free WDR except for locations followed by an asterisk where Straube's [9] method was used.*

Outline of a Protocol for North American Climates

Any protocol for testing the watertightness of wall systems should vary the two significant parameters: the pressure difference and the water deposition rate. An approach similar to that given in the CSA A440 is proposed here. Both the pressure differences (ΔP), significant for pristine walls, and the water deposition rate, significant when larger deficiencies are present, will be varied. Two levels of service are also considered: extreme events and expected or normal conditions. For extreme events, a level of 1 in 5 (at least) should be imposed for wall systems. For normal in-service conditions, events having a return period of 1 in 2 years should be considered (i.e., 50 % percent chance of recurrence). As in the CSA A440, a given threshold performance level is thus related to the climate. Climate loads are given in Table 3 as levels. The levels represent the combination of water deposition in the form of wind-driven rain and driving-rain wind pressure. Level 1, for example, represents a very low load on the cladding in terms of low driving rain intensities and low driving rain-wind pressures. Level 5, on the other hand, represents the opposite end of the spectrum. North American locations can thus be categorized with respect to these two climate parameters. A notional map is shown in Fig. 5. Each map is constructed for a particular return period in much the same fashion as intensity-duration-frequency charts for rain are generated. Using this approach, an estimate of the in-service conditions and extreme wind-driven rain loads can be obtained and appropriate building envelope claddings designed.

Based on the preliminary analysis of wind-driven rain events for some selected locations, a possible protocol that can be readily related to climate can be developed. For example, the suggested pressure steps could be:

0 Pa Initial wetting
75 Pa Baseline
150 Pa The maximum levels that could be expected for most continental locations for the 1 in 2 threshold.
200 Pa Covers all locations except windiest and coasts for 1 h and 5 min average for 1 in 2.
300 Pa Covers all locations except windiest and coasts for 1 h and 5 min average for 1 in 5 (except Calgary).
500 Pa Covers all location except Coasts for in 1 in 10.
700 Pa Covers all except windiest (St John's, Port Aux Basques, Sandspit) 1 in 30.
1000 Pa Covers the most extreme locations.

While the suggested spray rates could be:
0.4 L/min-m^2 Normal in-service conditions for hourly averages
0.8 L/min-m^2 Normal in-service conditions for 5-min events and most extreme in service conditions for hourly averages except 1 in 30.
1.6 L/min-m^2 Covers all hourly average extreme events; covers some locations to 1 in 10 except windiest and Winnipeg for 5 min events
3.4 L/min-m^2 Covers all hourly and 5 min events.

TABLE 3—*A proposed test protocol with notional performance levels.*

Pressure Differential (Pa)	**Spray Rate (L/min-m^2)**					
	0.1	**0.2**	**0.4**	**0.8**	**1.6**	**3.4**
0						
75	**Level 1**					
150						
200	**Level 2**					
300						
500	**Level 3**					
700	**Level 4**					
1000	**Level 5**					
Rating		Level 1	Level 2	Level 3	Level 4	Level 5
Wind driven-rain intensity		very low	low	moderate	high	very high
Key						

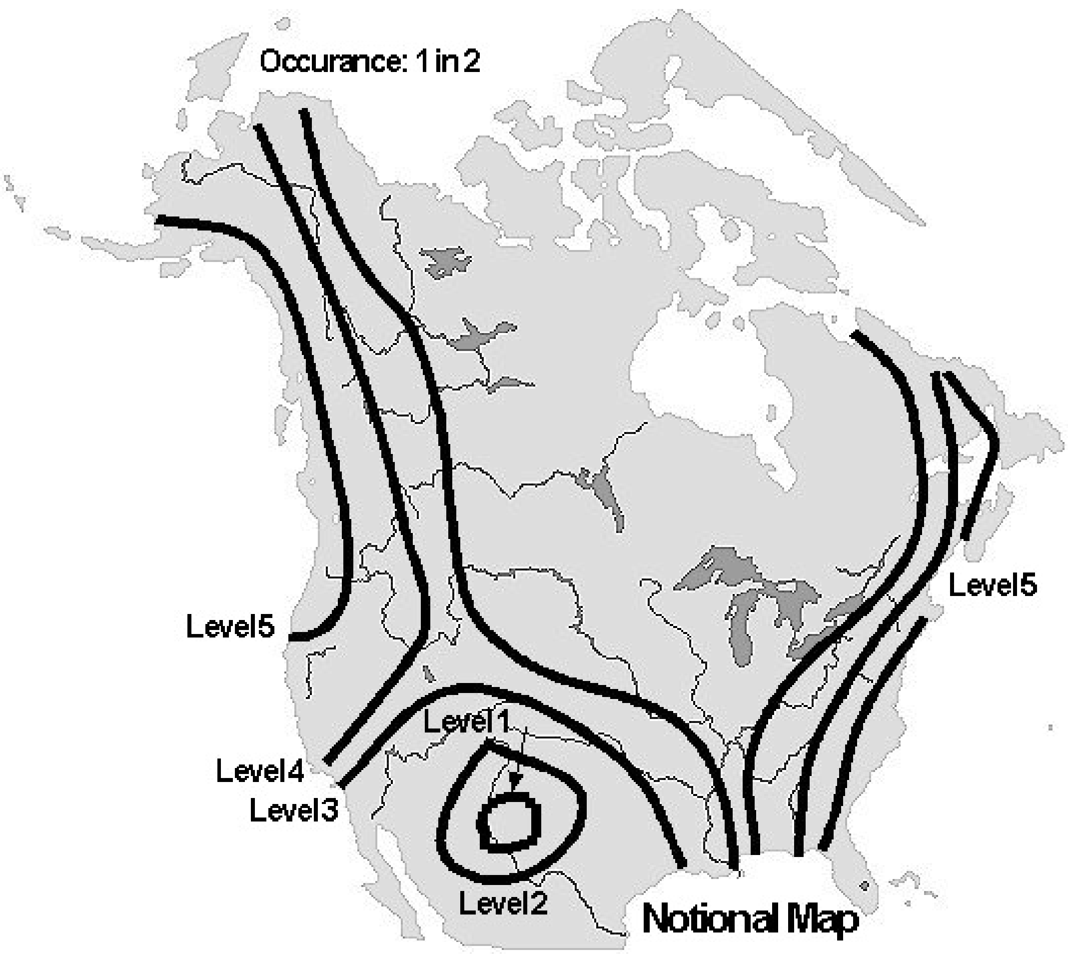

FIG. 5—*A notional climatology of North America based on protocol performance levels.*

Additional Refinement of the Protocol

A refinement of the protocol would relate and adjust the protocol thresholds to reflect expected conditions for the United States. The next step would be to build on the work of Underwood [13] to a produce a climatology of WDR for Canada to complement the DRWP climatology of Canada developed in [7] for CSA A440. Subsequently, the current work would be extended by producing return periods for wind driven rain and generating Intensity-Duration-Frequency relationships similar to rainfall intensity maps but for wind-driven rain.

Another enhancement would be a better statistical treatment for WDR for North America in regard to the co-occurrence of wind and rain. A statistical treatment would allow for joint probabilities of WDR and DRWP to be estimated so that maximum water deposition rates could be determined given that wind-driven rain does not generally occur at maximum rainfall intensities or maximum wind speeds. This would be beneficial for determining pressure difference and spray rates to simulate specific climate events in a test protocol (see Figs. 6 and 7).

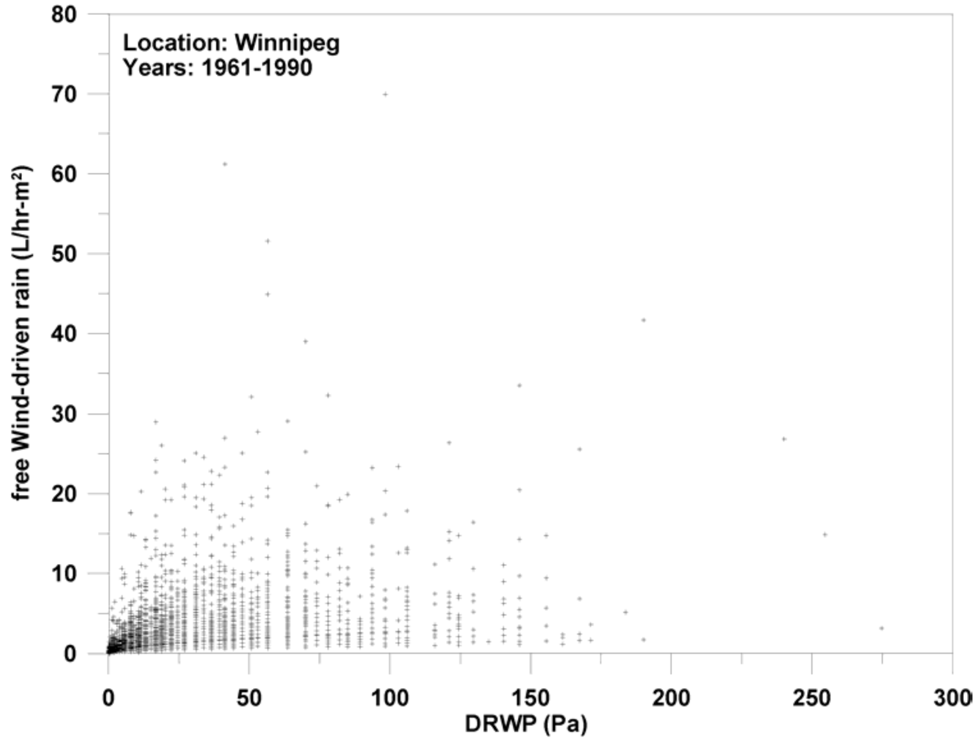

FIG. 6—*Wind-driven rain events for Winnipeg MB, covering 30-year period from 1961 to 1990 with the coincident hourly driving rain wind pressure. The peak values for wind-driven rain occur in the middle of the range of DRWP.*

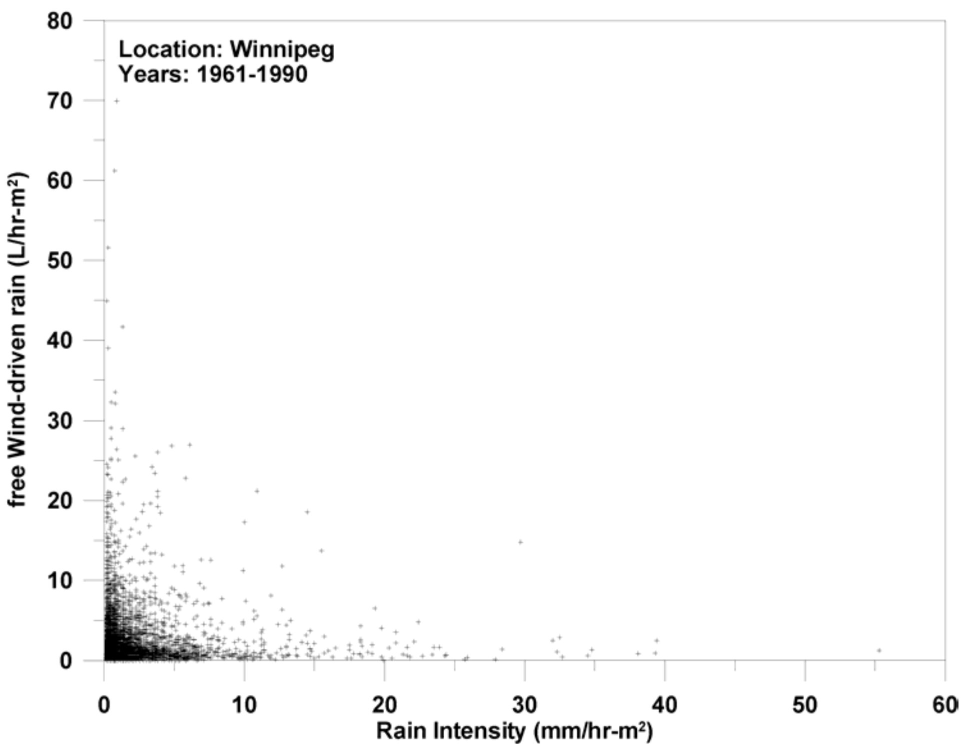

FIG. 7—*Wind-driven rain events for Winnipeg MB, covering 30-year period from 1961 to 1990 plotted against the average hourly rain intensity during the event. The peak values for wind-driven rain occur in the lower range of rain intensities at smaller raindrop diameters.*

Obtaining more detailed information on coincident rainfall, wind speed, and wind direction potentially offers better estimates of intensities of shorter duration events as well as profiles of typical events. This is particularly desirable since in the case of porous claddings rainfall events of short duration may not be of much significance in terms of potential for water entry, as most of the water could get absorbed during the event.

Presently, test methods have an initial wetting period to saturate the cladding. A protocol based on actual weather data or some idealization of typical events, such as rain events associated with frontal activity or convective type events, would give indications of wall performance under simulated conditions closely matching real events. To mimic real weather in a test apparatus would require such a level of fine-grained data.

Finally, the duration of events such as wet spells and dry spells also comes into play especially with regard to porous claddings. Estimates for the likelihood of wall saturation based on wet spells, expressed as an occurrence of the quantity of driving-rain index, could be derived for massive porous claddings. The exposure assessment provided in BSI 8104 is modeled on this approach.

Summary

A test protocol is described that relates to existing protocols, such as the CSA A440 window standard, and explicitly to climate or expected climatic events. Based on such a protocol, the performance of wall systems can be rated through testing and related to climatology to determine the appropriateness of systems to perform in different climate regions. The challenge is to simulate real weather conditions or events in terms of wind-driven rain in a test apparatus that are related to the likelihood of actual events for specified geographic regions. Parameters such as spray rate, pressure differences, and test duration (dwell times) and cycles should be related to expected in-service conditions as well as extreme events.

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Appendix

Average hourly Driving Rain Wind Pressures for 23 Canadian locations in (Pa) from [7].

Location	1 in 2			1 in 5			1 in 10			1 in 30		
	Rain mm/hr			Rain mm/hr			Rain mm/hr			Rain mm/hr		
	1.8	3	5.1	1.8	3	5.1	1.8	3	5.1	1.8	3	5.1
Calgary	157	139	97	228	214	174	275	264	226	346	340	304
Charlottetown	209	163	94	301	244	151	362	297	189	454	379	246
Edmonton	108	81	65	154	114	100	184	137	123	230	170	158
Fredericton	121	106	74	169	140	114	200	163	141	248	197	182
Halifax	213	209	192	275	273	245	316	316	279	378	380	332
Montreal	135	108	67	194	162	109	233	197	137	292	231	179
Ottawa	117	96	74	158	142	120	186	174	150	227	221	197
Quebec	147	105	67	200	156	105	235	189	130	288	239	167
Saskatoon	123	101	77	174	150	132	207	182	169	258	231	224
St John's	283	257	208	400	308	271	475	341	313	594	392	376
Toronto	106	88	66	150	133	108	179	164	135	224	210	177
Vancouver	79	63	38	121	84	57	149	98	69	191	119	87
Whitehorse	31	16	12	46	29	25	56	37	35	71	49	48
Winnipeg	138	113	88	197	170	137	236	208	170	296	266	219
Yellowknife	58	39	25	92	78	54	114	103	74	148	141	103
Sandspit	429	366	256	503	465	399	551	531	493	625	631	636
Victoria	84	56	39	114	80	58	133	96	70	163	120	90
Victoria Gonz Hts	164	104	68	205	160	126	232	196	164	273	252	221
Regina	142	106	85	202	163	143	242	201	182	303	258	240
Iqaluit	111	72	40	198	123	76	256	156	99	343	206	135
Sept Iles	228	193	132	308	270	194	360	321	235	440	399	297
Shearwater	229	209	168	309	286	242	362	338	292	442	415	367
Port Aux Basques	319	283	224	425	345	290	495	386	334	600	447	400

Average hourly wind-driven rain intensities, $L/m^2/h$, impinging on a wall assuming the top corner of the facade.

Location	Return Period					
	Mode U	1 in 2	1 in 3	1 in 5	1in 10	1 in 30
Sandspit, BC[a]	0.35		0.52	0.63	0.76	0.97
Calgary, AB[a]	0.25		0.35	0.42	0.50	0.63
Toronto, ON[a]	0.25		0.31	0.36	0.42	0.50
Ottawa, ON[a]	0.27		0.37	0.45	0.54	0.67
St. John's, NFLD[a]	0.46		0.57	0.64	0.74	0.87
Ottawa ON[b]		0.29		0.46	0.57	0.73
Shearwater ON[b]		0.37		0.47	0.53	0.63
Winnipeg ON[b]		0.38		0.57	0.69	0.88
Vancouver BC[b]		0.15		0.21	0.24	0.29

a - Choi's method [10]; b - Straube's method [9]

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