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Towards Development of a Performance Standard for Assessing the Effectiveness of Wall-Window Interface Details to Manage Rainwater Intrusion

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ABSTRACT:

Laboratory water spray testing identifies the performance of a component or assembly under a specified set of simulated wind-driven rain conditions. Well-developed water spray test protocols can also help identify were an assembly is vulnerable to water entry, the test loads at which water entry occurs, and whether the water entry is managed by the installation details in such a way that it does not result in within-wall damage. This paper presents a proposed laboratory test protocol for assessing the effectiveness of wall-window interface details with regard to management of rainwater, and provides a rationale for a performance-based approach to the evaluation method. An overview of the test approach is provided and details of the test apparatus and test specimen are given, including information on implementation of the test method. Examples of testing performed according to the proposed protocol are provided. Finally additional tests for evaluating the performance of installation details are suggested. The additional tests are for field evaluation of installation details, and for laboratory evaluation of installation details with regard to the risk of condensation along window frames.

KEYWORDS: installation details, laboratory testing, performance test, rainwater intrusion, wall-window interface, watertightness,

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Introduction

The issue of water penetration associated with window installations has been a recognized concern for decades. In the United States prior to the establishment of the International Code Council, (which superseded the three regional model code writing agencies), each of the regional model codes (the Uniform Building Code, the Basic Building Code and the Standard Building Code) promulgated that exterior openings be flashed so as to "be weatherproof", "be leak proof", or "prevent entrance or water". The regional codes each promulgated essentially the same general requirement; none of them however provided guidance concerning what constituted an adequate level of leak resistance, nor did they address how an adequate level of leak resistance might be attained.

In Canada, the National Building Code (NBCC) has consistently required protection from precipitation at openings through wall assemblies and in particular the requirement for flashing at the window head. However these performance requirements are likewise provided in general terms similar to those given by the Codes bodies in the United States. The most recent NBCC 2005 edition nonetheless provides significantly more guidance information regarding protection from precipitation relative to past editions. Whereas the NBCC provides the basic guidance on protection from precipitation, such guidance does not constitute a substitute for accepted good practice. In Canada, the CMHC* has often been a useful resource for guidance concerning construction practice. Documents regarding window installation were published by CMHC in the mid to late 80's [1, 2]. The information provided in these documents largely concerned windows of traditional design, and thus did not address installation of windows with mounting flanges (often termed "nail-on" windows). Flanged windows were increasingly being installed in wood frame buildings in the late 80's and the (often inadequate) methods by which they were installed led to a number of construction defect investigations [3].

It was not until the 1990's that issues relating to water penetration at windows began to be addressed by practitioners in North America [4, 5]. Concerns over water penetration led to the development of an ASTM window installation standard in 2001 [6]; revisions of the standard were issued in 2004 and 2007. The ASTM standard, in any of its versions, states that it "places greater emphasis on preventing or limiting rainwater leakage

* CMHC – Canada Mortgage and Housing Corporation

than on any other single performance characteristic." The ASTM standard, even in its most recent form [7], is however, (by the admission of its developers), an imperfect document, and in need of continued refinement. Unresolved issues concerning installation details for windows remain.

Ongoing concern relating to water penetration associated with window installation methods is reflected in the state of California's recent sponsorship of investigations concerning the level of risk associated with different window installation methods. The work undertaken by Leslie [8, 9] concerned evaluation of installation details pertaining to flanged vinyl windows installed in wood frame walls clad with stucco. Laboratory evaluations nominally permitted evaluating the ability of the different installation methods and use of different components to permit adequate drainage to the exterior of the assembly. The evaluations identified conditions under which observable liquid water leaked to the interior when the test assembly was subjected to simulated rain and leakage events. The work concluded that when windows leak, additional design elements are necessary to manage the water entry. Given the unpredictable amounts of and locations for water entry, pan sill drainage was considered essential. Additionally, it was found that an effective interior air barrier is required around window perimeters. Finally, in regard to testing, it was suggested that performance standards are needed for assessing the performance of window installations in different wall assemblies that are "realistic" and supported by field data and "validated models" [9].

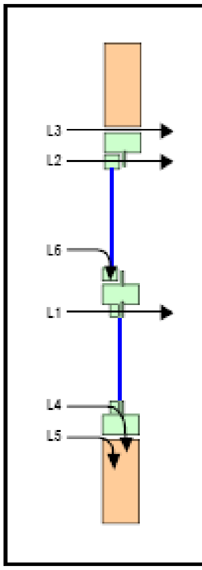
In Canada, the utility of the CSA standard specification for windows [10] has recently been brought into question. Ricketts [11, 12] focused on assessing the watertightness of windows and the wall-window interface on behalf of CMHC*. Results indicated that the two principal paths for problematic water leakage are associated with the wall-window interface. The principal paths (Figure 1) were found to be through the window assembly to the adjacent wall assembly (path L4), and through the window to wall interface with the adjacent wall assembly (path L5). The risk associated with leakage via these two paths reflects that moisture within the stud space of the wall cannot readily be dissipated (by either drainage or evaporation), and therefore is likely to cause damage. Water that moves through the window assembly and is visible on the interior (paths L1 to L3 in Figure 1) may cause damage to interior finishes, but is less likely to cause damage to components within the wall.

Ricketts [12] indicated that the criteria for water penetration addressed in the CSA A440 specification [10] is unlikely to address leakage via the L4 path, and will not address leakage via the L5 path. An estimate of the

* CMHC – Canada Mortgage and Housing Corporation

applicability of the test procedure cited in CSA A440 to detect leakage via the different leakage paths is provided in Figure 1; the Figure indicates that the leakage paths posing the greatest risk of consequential damage are insufficiently addressed by the test methodology cited in the standard. Moreover, this standard concerns selection of the units themselves; it does not address installed performance, which is of ultimate importance. Some recommendations that followed from the reports [12, 12] included:

- Assessment of in-service and micro-exposure (at window proximity) conditions
- Provision for redundancy in water penetration control through the installation of sub-sill drainage.
- Consideration of the durability of water penetration control performance
- Development of a water penetration testing protocol for the window to wall interface



Leakage Paths	Risk of Consequential Damage Rating	Applicability of A440 Testing to Leakage Path
L1 - Through fixed unit to interior	Moderate	Good
L2 - Around operable unit to interior	Moderate	Good
L3 - Through window to wall interface to interior	Moderate	Never
L4 - Through window assembly to adjacent wall assembly	High	Sometimes*
L5 - Through window to wall assembly interface to adjacent wall assembly	High	Never
L6 - Through window assembly to concealed compartments within window assembly	Minor	Good

* Depends on where window frame is attached to test frame

Figure 1 – Schematic of water entry points following Ricketts [11].

Given the level of interest in window performance and installation details, the Institute for Research in Construction (IRC) undertook work to assess the capacity of different wall-window interface installation details to manage rainwater intrusion. Several publications have been produced of selected results [13, 14, 15, 16]. The work primarily focused on window installations typical of North American low-rise wood frame construction; this work at the IRC is continuing.

The investigations undertaken at the IRC provided a basis for proposing a standardized approach to the performance evaluation of window installations in a laboratory setting. This paper provides a rationale for the proposed approach, details on the implementation of the test method, and information regarding instrumentation of specimens. Brief examples of testing performed following the protocol are provided. These examples are for test specimens representative of typical low-rise wood frame construction. The test protocol can also be adapted to commercial installations. Additionally, proposals for standard tests directly related to the proposed air and watertightness test protocol are offered; such tests include assessing the risk of condensation along window frames for given installation details, and a method for the evaluation of installation details in the field.

Approach to Evaluating Water Management of Window Interface Details

Performance Assessment Through Testing

It is useful to draw linkages between performance and durability, given that performance assessments are useful in helping ensure the durability or long-term performance of an assembly. Indeed, durability implies satisfactory performance of the basic functions of a wall and its components when subjected to environmental loads and other factors that may have a deteriorating or degrading effect [17]. However, the useful life of a material or component always relates to the particular combination of environmental factors to which it is subjected, so that durability must always be related to the particular conditions involved [18]. When consideration is given to assessing the performance of the assembly, it evidently is dependent on the performance of individual wall components. Hence, it is necessary to understand how wall components as well as wall assemblies respond to the range of climatic conditions to which they will be exposed. However, the manner in which the continuity of building envelope is implemented at junctions and penetrations such as windows, ventilation ducts, electrical outlets and pipes, is necessarily important. Unquestionably, the long-term performance of the assembly depends on providing functional details at these vulnerable points of the assembly [19, 20]. Hence to achieve functional performance of the assembly, the installation details themselves must meet a similar degree of acceptable performance as the components incorporated in the assembly

Laboratory water spray testing establishes the degree to which a component or assembly performs under a given set (or given sets) of test conditions. Laboratory water spray testing also helps to determine the location of vulnerable points in a wall assembly. If testing is conducted at a number of different loads, the loads at which water entry either occurs or does not occur can be identified. A test protocol may furthermore be designed so as to discern water entry than can be managed, from water entry that will result or is likely to result in damage. For purposes of this manuscript, laboratory spray testing performed according to a well-developed protocol is termed "performance testing". Performance testing may be used to relate the response of a test specimen to specific details under loads that simulate design conditions in a specified climate. Results derived from performance tests may provide useful insights for estimating the long-term performance of products when combined with knowledge of in-service conditions and information on the performance of similar products in the field.

Current Weathertightness Standards

In North America, the preeminent standard specification that addresses the weathertight performance of fenestration is the North American Fenestration Standard - Specification for windows, doors, and skylights [21]. This standard was developed jointly by the AAMA*, WDMA† and the CSA‡. The North American Fenestration Standard (NAFS) defines watertightness testing requirements for windows according to four performance classes designated R, LC, CW, and AW. The class descriptions are given in Table 1. The test method referenced in NAFS is ASTM E331-00 [22]. The differential air pressures at which water penetration resistance tests are performed are based on the design pressure (DP) associated with the performance grade, where the minimum test pressure for R, LC, and CW windows is specified as being 15% of the DP, and for AW windows is specified as being 20% of the DP. The standard further specifies the minimum water penetration resistance test pressure as 140 Pa (2.9 psf) and the maximum test pressure as either of 580 Pa (12.0 psf) (for U.S. applications), or 730 Pa (15.0 psf) (for Canadian applications).

The term "water penetration" is defined narrowly in ASTM E331; water that passes inward beyond a plane defined by the innermost edges of the fenestration unit's frame is classified by the standard as "water penetration". Given this narrow definition of "water penetration" water that leaks through a unit's frame and enters the wall below the unit would not be deemed "water penetration" unless the water happened to also spill to the interior of the wall (past the vertical plane defined by the innermost edges of the unit's frame).

Table 1 — Summary of information relating to watertightness testing provided in North American Fenestration Standard (NAFS) [21]

* AAMA American Architectural Manufacturers Association;
† Window and Door Manufacturers Association;
‡ Canadian Standards Association

Product Specification	Test method for window watertightness	Water penetration resistance test pressure Pa (psf)			
		R**	LC	CW	AW
AAMA/WDMA/CSA 101/I.S.2/A440-08	ASTM E 331-00 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference	140 (2.9)	180 (3.75)	220 (4.5)	390 (8.0)

** **Window performance class**

R: Commonly used in one- and two-family dwellings; design pressure (DP): 720 Pa (15.0 psf)

LC: Commonly used in low-rise and mid-rise multi-family dwellings and other buildings where larger sizes and higher loading requirements are expected; DP: 1200 Pa (25.0 psf)

CW: Commonly used in low-rise and mid-rise buildings where larger sizes, higher loading requirements, limits on deflection, and heavy use are expected; DP: 1440 Pa (30.0 psf)

AW: Commonly used in high-rise and mid-rise buildings to meet increased loading requirements and limits on deflection, and in buildings where frequent and extreme use of the fenestration products is expected; DP: 1920 Pa (40.0 psf)

Existing standard test methods for evaluating the weathertightness of installed fenestration include AAMA 501 [23], AAMA 504 [24], and ASTM E1105 [25]. AAMA 501 [23] relates primarily to testing of curtain walls, storefronts, and sloped glazing. Given that this paper primarily concerns qualifying the installation of fenestration in low-rise wood frame construction, AAMA 501 largely concerns installations outside this paper's scope. AAMA 504 [24], which is the "Voluntary Laboratory Test Method to Qualify Fenestration Installation Procedures", references ASTM E331 together with other test methods. This method, in contrast to ASTM E331, calls for identification of water penetration between the window perimeter and the rough opening (or, more specifically, lack thereof). The performance criterion for this method regarding watertightness requires that no water penetration be evident through the installation system or into the wall cavity around the fenestration product perimeter at the specified test pressure. The utility of ASTM E1105 [25], is primarily to determine the resistance of fenestration units to water penetration. The scope section of the standard indicates that the test method "can also used to determine the resistance to penetration though joints between the assemblies and the adjacent construction," but the means by which this might be accomplished are not outlined in the standard. Moreover, the definition of "water penetration" in ASTM E1105 is identical to that in ASTM E331, and thus is narrow. The proposed test protocol outlined in this manuscript more closely approximates AAMA 504 than any other standard test method.

Although AAMA 504 specifies a minimum test load and suggests that more severe loads can be applied to the test specimen, it does not outline means for adjusting test conditions to simulate climate loads. Additionally, it does not outline means for measuring water penetration via various paths through the assembly. The test method specifies that test specimens be subjected to "durability cycling," the assumption being that assemblies will or should essentially retain watertightness after the durability cycling. In contrast, it can be argued that the watertightness of all components and assemblies will eventually deteriorate, and thus that robust installation procedures will by definition accommodate some degradation of watertightness of the components or assemblies. The test protocol being proposed in this manuscript follows this line of reasoning, specifically that deficiencies in watertightness of components and assemblies will eventually occur.

Estimating the long-term performance for new or innovative products is challenging, given the need to obtain results in a time frame considerably smaller than the expected life of the product. Key elements to consider when developing performance test protocols include:

- Understanding the behaviour of component parts of an assembly in relation to the performance of the system. This also involves;
- Consideration of performance of products when installed according to in-service conditions;
- Knowledge of environmental loads and the manner in which these affect the assembly or components; specifically, having information on the intensity, duration and frequency of occurrence of key climate parameters affecting the assembly.

In this manner, interfaces of adjacent products are delineated, details defined, and in-service conditions estimated. On the basis of test results, key elements that help ensure the long-term performance of the component or assembly can be recognized.

Overview of Approach

The proposed test protocol is intended to provide information on whether different window installation details can adequately manage rainwater intrusion. It provides quantitative information on the degree to which the various approaches manage rainwater in relation to simulated climate loads. Under the protocol, the range of loads may be selected as being representative of "design" loads for the region or locale of interest. Hence information on the primary test parameters is provided in which the basis for the selection of values for test conditions is given.

Thereafter, information is given on the test apparatus and generic configuration of the specimen. The proposed protocol is adaptable to different types of assemblies. It can be carried out by many test facilities that currently perform watertightness tests.

In regard to the configuration, mention is made of the overall size, the location of the window specimen and details regarding the test set-up. As indicated previously, an inherent part of the protocol is the assumption that over time windows will leak and given that there is leakage, the wall-window installations details should be designed and implemented such that inadvertent water entry is contained and drained to the exterior of the assembly. To verify that this is achieved, and the capacity of the installation design to manage water entry at different test loads, deficiencies are purposely introduced in the window assembly thus permitting water entry to the sill area; this is further described in the generic description of the test specimen.

Two important aspects of the approach are that water entry be observed and be quantified. To meet these goals the test specimens incorporate transparent sheathing components, (to permit observation of water presence behind the sheathing membrane), and means for collection and measurement of water that penetrates between the window and the rough opening, and of water that leaks into the stud cavity.

Primary Test Parameters—The key climatic factor that affects the severity of a wall assembly's exposure to water that may penetrate the assembly is the wall's exposure to wind-driven rain. Although drying potential after rain events also has an effect on the long-term performance of the wall, wind-driven rain is the factor that influences water penetration. Knowing the intensity, duration and frequency of rainfall along with coincident wind conditions at a locale provides a means of characterizing wind-driven rain exposure at the locale. As regards simulation of wind-driven rain in laboratory testing, the two primary test parameters are air pressure difference and water spray rate. Combinations of pressure differential and water spray would ideally be based on known climate parameters. Pressure differentials during spay testing correspond to wind speeds coincident with rain, whereas water spray rates correspond to rainfall rates.

If the likelihood of occurrence of values of both wind speed coincident with rain fall and rainfall rates are known for specific climate regions, then one can assess the extent to which window-wall systems attaining specific performance levels might perform in a given region. The selection of a specific set of differential pressure and water spray rate combinations would permit establishing the level of performance at which assemblies can function. The proposed protocol involves subjecting specimens to different levels of simulated wind-driven rain of increasing severity, such that the limit below which systems can adequately perform can readily be determined. From the test protocol then, a specified window-wall assembly is subjected to specific combinations of simulated wind-driven rain by application of pressure differentials across the wall assembly and water spray onto the cladding. The set of combinations is chosen such that these encompass the range of values of simulated wind-driven rain that might be expected to occur at the geographic location within a specified return period. A notional set of test combinations is provided in Table 2; these were derived from a review of wind-driven rain events in North America as reported by

Cornick and Lacasse [26]. Spray rates may vary between 0.4 and 3.4 L/min.-m^2 and pressure differentials between 75 and 1000 Pa. Rates of water penetration at no pressure differential (0) are also determined to help understand the effects of water entry when the force of gravity alone is acting. Such effects would be evident when water cascades onto window-wall interfaces from adjacent building elements in the absence of a significant pressure differential (i.e. <5 Pa).

Table 2 – Notional set of test combinations for assessing the water management performance of the window-wall interface

Pressure Differential (Pa)	Spray rate (L/min-m^2)			
	0.4	0.8	1.6	3.4
0				
75				
150				
200				
300				
500				
700				
1000				

Proposed Laboratory Test Protocol

The proposed protocol involves full-scale testing of installed fenestration units in wall sections that incorporate a cladding system. What is meant by "full scale" is that the wall test sections are of single-storey height, and have a length equal to their height. The wall sections are representative of complete constructed walls in buildings, except for incorporation of transparent interior and exterior sheathing materials (in lieu of opaque gypsum wallboard or opaque wood-based or gypsum sheathing respectively), and for incorporation of collection devices to quantify water penetration at various locations within the wall. In the protocol, the air leakage characteristics of the wall sections are determined before spray testing is commenced. The protocol also allows for determination of air pressure profiles (pressure levels at the various layers within the wall sections), at various levels of pressure differential across the wall. The air leakage and pressure distribution characteristics are likely to influence the potential for water entry via various paths during spray testing. Knowledge of the air leakage and pressure distribution characteristics of the wall section can thus be helpful in interpretation of spray test results. In cases where there is a significant "plane" of air leakage restriction on the interior side of the wall, the air leakage characteristics of the test wall section may (as described later in this manuscript) be modified (adjusted). Modification to the airtightness of the wall may have an appreciable influence on the watertightness of the installation. Details relating to the apparatus and the instrumentation needed to conduct the protocol are addressed in the following sections.

Description of Test Apparatus—The proposed protocol requires an apparatus capable of subjecting a full-scale test specimen (e.g. 2.4-m by 2.4-m; 8-ft. by 8-ft.) to simulated wind-driven rain conditions. The required capabilities of the test facility with regard to exertion of air pressure differentials and spray rates depend on the local climatic conditions being simulated. Table 2 indicates a range of capabilities that would allow simulation of essentially the full range of conditions that may be anticipated across North America. As implied previously, the apparatus would incorporate instrumentation that allows the air leakage characteristics of the specimens to be identified. The water spray system should be pressure regulated, and should deposit water evenly across the front of the specimen through an array of spray nozzles. As will be discussed later in this manuscript, there are cases in which water application in a "cascade" mode (as opposed to application through an array of nozzles) can be instructive.

Generic Description of Test Specimen—An example of the generic step-up for a test specimen is shown in Figure 2, in which both a vertical sectional view and an elevation view of the specimen are provided. The figure shows a test configuration for a single window and related interface details. The application of simulated wind-driven rain conditions, characterized by water spray and pressure difference across the test assembly (ΔP), are depicted on the sectional view as is the notional location for water entry points representing possible deficiencies in the cladding or window. A notional path for water leakage and accumulation to the sill is shown in the elevation view. The generic configuration also provides the location of a water collection trough as a means of quantifying water entry to or drainage from the sill.

As indicated previously, the introduction of deficiencies, (at the interface between the window and cladding or in the window proper), is a key element of the protocol. For example, the introduction of deficiencies at window corners, depicted as points of water entry in Figure 2, can be achieved by boring small openings (e.g. < 1-mm diam.) in the window frame, providing direct access to the sill area. Such deficiencies mimic failed or improperly sealed window frame joints. In this manner, tests can first be conducted with no deficiencies and thereafter with deficiencies introduced in the interface or at the window. A specimen having no deficiencies would be representative of a recently installed window assembly, whereas a specimen with deficiencies incorporated in it

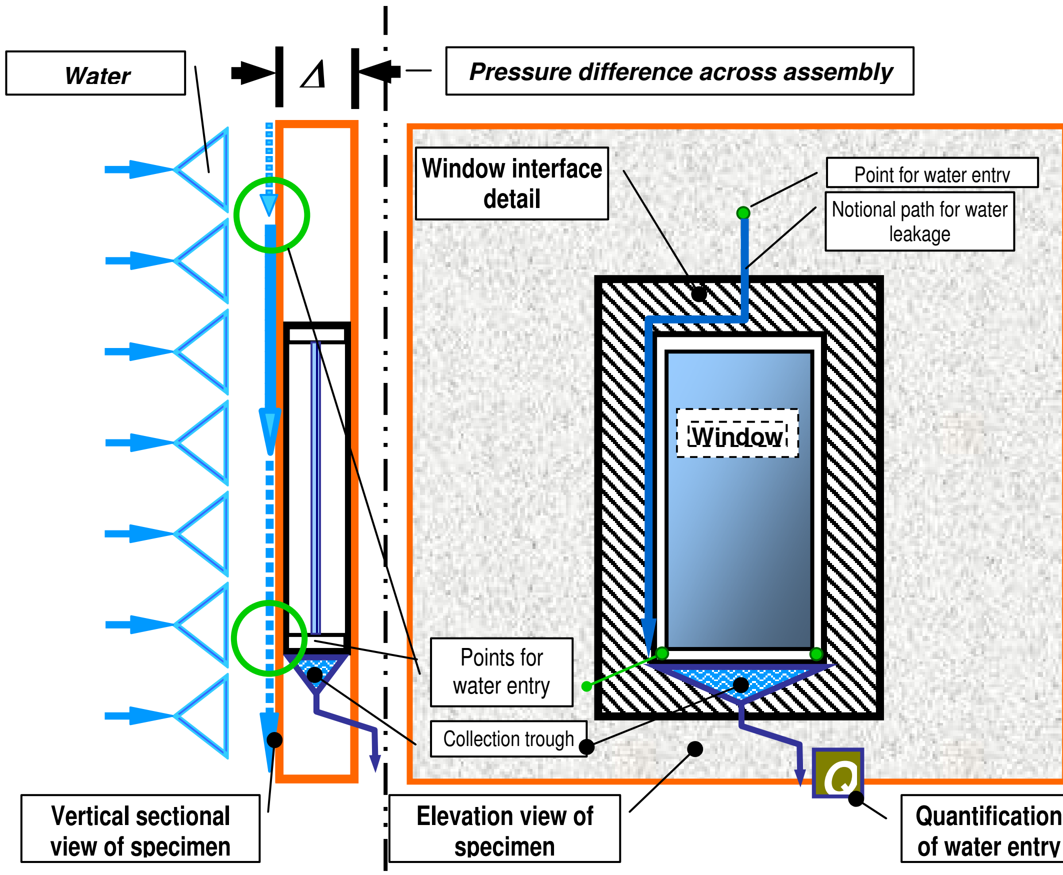


Figure 2 – Schematic of test assembly showing vertical and elevation views and actions of simulated wind-driven rain on specimen; also provided are locations of window, collection trough and notional points for water entry and leakage in assembly.

would represent either a prematurely failed system or one that over time developed entry paths for rainwater. In either case, the introduction of deficiencies permits discerning the vulnerability of the assembly to water entry, or conversely, the extent to which specific installation details may provide robustness to the installation.

Inclusion of a single large window opening in a test specimen would be useful when investigating installation details for mulled windows. In mulled installations two or more window units are joined to form a single assembly; these assemblies are vulnerable to water entry at the joints between units.

If comparison between details of individual windows is of interest, the width of the window can be reduced, and side-by-side comparisons are then possible. An example of a specific configuration for two side-by-side window installation details is provided in Figure 3. These types of configurations were used in previous studies to compare the comportment of alternate design details to simulated conditions of wind-driven rain [13, 14, 15, 16].

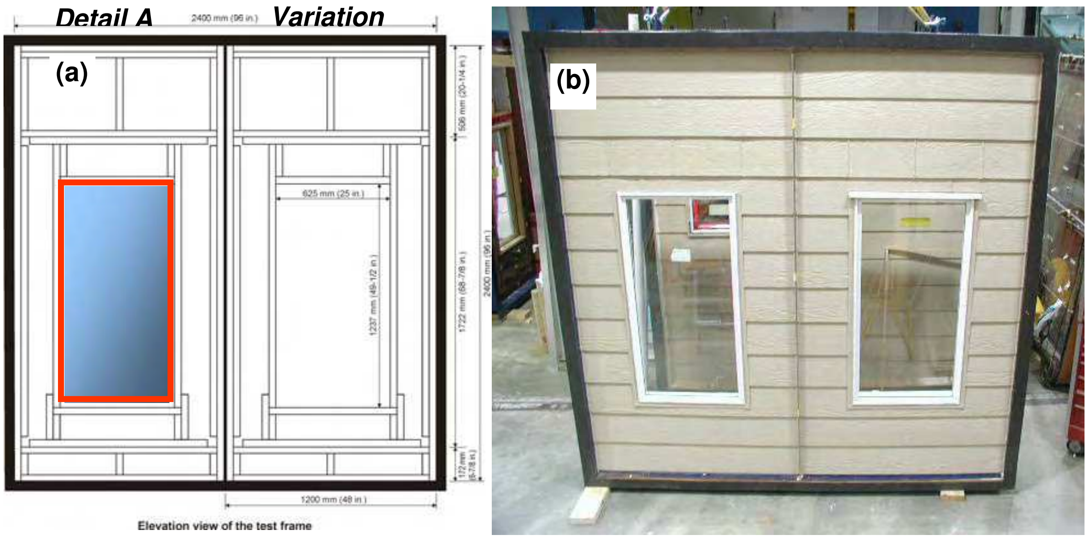


Figure 3 — (a) schematic of front elevation of 2.44-m by 2.44-m (8-ft. by 8-ft.) specimen showing location of 600 mm by 1200 mm (2-ft. by 4-ft.) windows and adjacent wood framing studs. Detail "A" might be representative of installation details used in current practice whereas detail "V" a variation on that practice; (b) photo of a completed specimen clad with hardboard siding.

Summary of Test Protocol—The protocol provides values for spray rate (water deposition rate) on the cladding and pressure difference across the assembly [26]. The essential elements of the protocol are:

1. Characterization of air leakage and pressure equalization potential of the wall assembly;

2. Water spray testing without deficiencies in the test specimen, over a series spray rates and over a series of static differential pressures at each spray rate. The most extreme combination of spray rate and differential pressure may be chosen to simulate the expected design load (rainstorm) over a specified return period (usually ten years or more) for the geographic locale.

3. Water spray testing with a deficiency or deficiencies in the test specimen over the same series of conditions as in the second step (listed directly above).

Specimens are thus subjected to simulated wind-driven rain conditions for specified periods of time. The conditions are intended to replicate the main features of rain events. During spray testing, the rate of water entry behind the cladding and the rate of drainage from the sill area of the rough opening, are to be determined by measuring water collected from troughs.

Criteria for performance assessment—The test protocol is designed to identify the potential for water entrapment within the wall assembly. More specifically, the protocol addresses the management of water that may enter the space between the window frame and the rough opening. Water that enters this space typically finds its way to the sill area of the space. The expectation is that a robust installation will allow drainage of water from this area to a place where it is evacuated from the wall assembly. Hence in conducting tests, observations are made as to whether water is present at the sill area of the rough opening, and whether water accumulates in the sill area or drains from it. Collection of water in specialty troughs permits determining whether the rates of entry to the sill are less than, equal to, or greater than rates of drainage from the sill; evidently if rates of entry exceed those of drainage, accumulation at the sill occurs and spillage into the stud cavity may occur. Such threshold conditions for which entry exceeds the drainage capacity of the design are critical points that set the limits as to the expected performance of the installation method. This condition may occur at a particular set of test conditions or over a series of conditions, but in every instance this would be noted over the course of the test. From a series of such tests, acceptable levels of performance of the installation method may be determined.

Instrumentation of Specimens

The test protocol requires that both the pressure differential across the assembly and water spray rates on the cladding be maintained at prescribed conditions over selected periods of time. Hence the minimum required instrumentation to assess performance would include:

- Pressure sensor to monitor the pressure differential imposed on the specimen
- Water flow meter in line with the spray rack capable of measuring rates of flow to the nearest 0.5 L/min.;
- Water collection troughs for quantifying water entry to the sill space, and drainage from it.

Each of these items will be briefly discussed in turn.

Pressure Sensors

Conducting tests up to 1000 Pa covers a substantial pressure range. Selection of sensors over this threshold would reduce the level of accuracy at the pressure differentials most commonly associated with wind-driven rain events in North America, although it would provide for measurement of pressures associated with hurricane-force winds (i.e. 104 to 131 km/h; 65 to 82 mph). Inasmuch as the vast majority of rainstorms in North America are not accompanied by hurricane-force winds[3], choice of a pressure sensor having a maximum range of at least 1 kPa with ±10 Pa accuracy (1% full scale) will for most cases be adequate.

[3] Severe thunderstorms may produce rain accompanied by hurricane-force winds, but the duration of these rain events at any given location at or near the ground is typically quite short.

Water Flow Meter

In respect to the spray rack and water deposition on the cladding surface, the most commonly referenced test method (ASTM E331) specifies a default water deposition rate of 3.4 L/min-m^2. For a specimen of ca. 6 square meters (ca. 8-ft.^{2}) this would amount to a nominal flow rate of 20 L/min. If the rain conditions to be simulated are as high as the default condition specified in E 331, a flow meter capable of measuring beyond 20 L/min (say 30 to 50 L/min.) is needed. We recommend a flow meter accuracy of 0.5 L/min or better. Typically, the spray is applied with specialty nozzles. The operational features of such nozzles are such that they are performance rated at specific water pressures. Hence the provision of pressure gauges along spray rack water delivery lines is useful for monitoring the line pressure over the course of testing to ensure that the spray is being evenly applied.

Water Collection Troughs

As indicated previously, a defining characteristic of the test protocol is its ability to assess the rate of drainage from the sill area of the space between the window and the adjacent wall. This is accomplished with specially constructed collection troughs.

Examples of different collection troughs are provided in Figure 4. Figure 4 (a) shows a photo of a trough used for collection of water draining from the sill area, and the related vertical sectional view. The photo of the trough is taken prior to installation of the cladding overtop the trough. Water collected in this trough is channelled through a tube (shown in photo) to a collection vessel located beneath the specimen, where rates of collection can be measured. Figure 4 (b) shows an alternative configuration for a trough to collect water draining from the sill area. It contains a front elevation photo of the collection trough and the related vertical sectional view. The sectional view indicates that drainage from the sill area is collected in a trough beneath the sill area. Water from this trough is evacuated to a vessel located beneath the specimen, (in this case through a tube on the interior face of the specimen). The accompanying photo shows a yellow diamond meshed component used to funnel water to the collection trough. Figure 4 (c) shows a photo of a trough used to collect water that penetrates past the window, and moves fully to the interior. This trough is shown in the related vertical sectional view, (along with two other troughs). In the sectional view, the trough located at the bottom of the assembly collects water that may accumulate at the base of the wall behind the cladding.

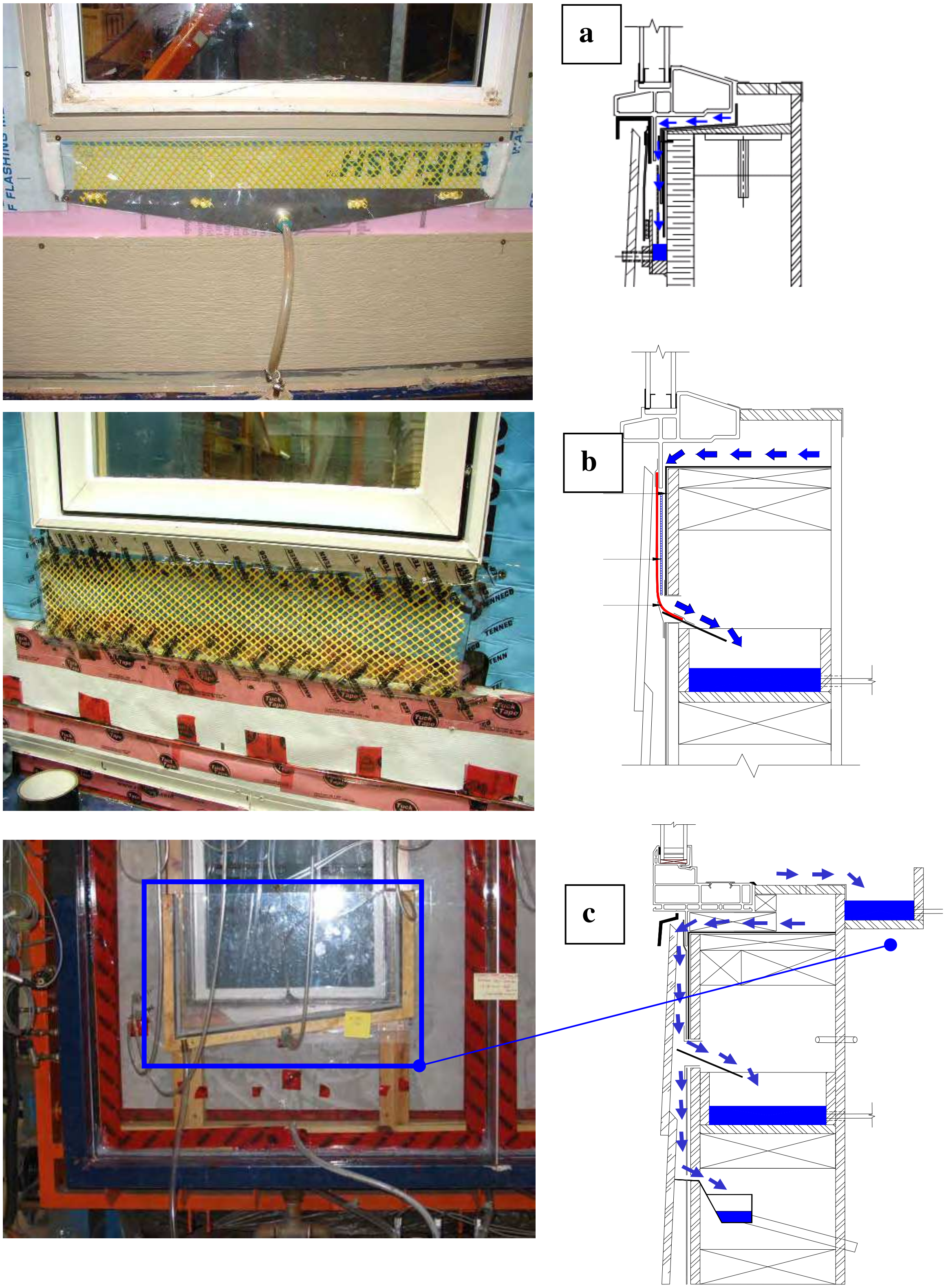


Figure 4 – Examples of water collection troughs; (a) collection trough for water draining from sill; (b) alternative trough configuration - water draining from sill; (c) collection trough for water that penetrates window (photo) and collection troughs for water penetration past the window, for drainage from the sill space, and for water drainage to the base of the wall (sectional sketch).

The collection troughs are evacuated to collection vessels located beneath the specimen. Each of the collection vessels is equipped with a capacitive level sensor. These sensors monitor the height of water in their respective vessels. Monitoring water levels in the vessels over time allows calculation of volumetric rate of collection, and its fluctuation over the course of a test. Our experience is that the capacitive sensors have appreciable accuracy. Provided that the collection vessels are not too large, rate flow readings with an accuracy of ± 2 mL/min. can be attained. .

Useful Additional Sensors

Additional pressure sensors can permit measurement of pressure differentials at points within the assembly. This can identify driving potentials for water entry at locations in proximity to the pressure tap.

Implementation of Test Protocol

The proposed test protocol, as previously described, follows a series of test sequences that include: (i) Air leakage determination; (ii) Pressure response characterization (optional); (iii) Watertightness evaluations. The test is carried out in sequential steps the first of which is determining the air leakage of the test specimen. This ideally is followed by a step in which the pressure response of the specimen is identified. The final step of the protocol is the conduct of watertightness (spray) testing. Details for each of these steps are provided below.

Air leakage

Determining the air leakage characteristics of the assembly and of the window (by use of masking techniques) permits assessment of the window's contribution to the overall air leakage across the assembly. This can indicate whether the primary water entry paths for wind-driven rain are expected to be through the window or through other paths in the assembly Although masking techniques can be instructive, we do not propose that they necessarily be included as part of the protocol.

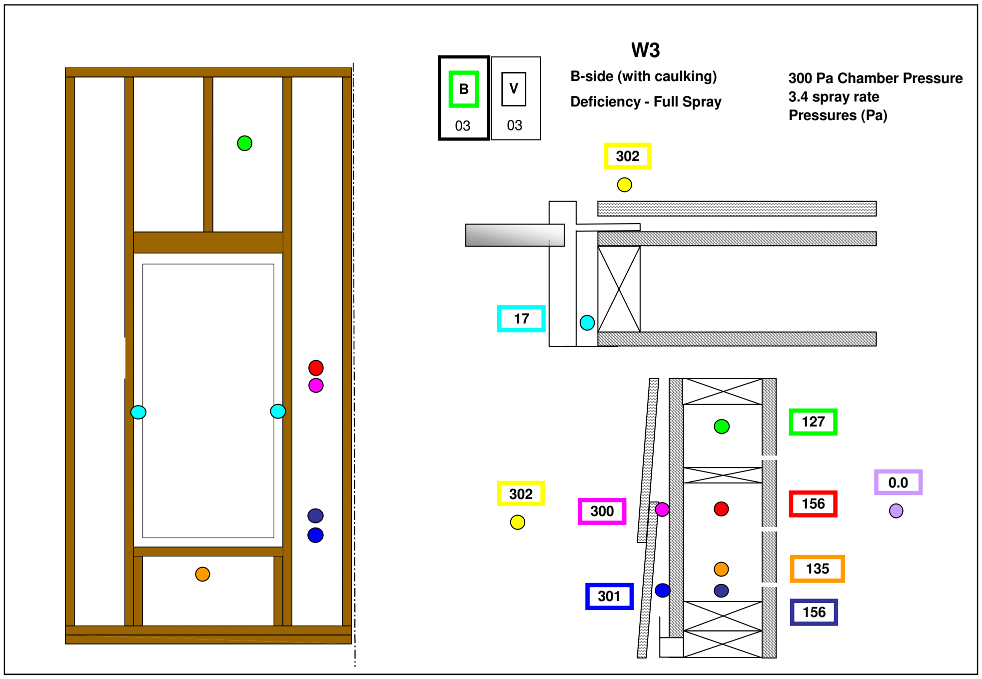
The degree of tightness of an air barrier system (ABS) located at the interior finish to window frame interface is likely to affect the degree of driving pressure at the exterior interface. Hence characterizing the degree of air leakage of wall assemblies having an interior ABS can provide significant insight with regard to interpretation of spray test results.

In walls with an interior ABS, we have been able to regulate the air leakage characteristics of the system by introducing a series of pluggable[4] openings in the "plane" of airtightness of the ABS (with the pluggable openings located near the perimeter of the window). The airtightness "plane" in the test specimens with which we have the most experience was the interior finish, which was a clear acrylic sheathing panel. Nominal leakage rates of 0.3 and 0.8 L/s-m^2 through test specimens could be achieved by boring an array of small openings through the acrylic sheathing near where it interfaced with the interior surfaces of the window frame. The nominal values for air leakage (0.3 and 0.8 L/s-m^2) are those achieved at 75 Pa; they were derived from air leakage tests over which pressure differences across the specimens ranged from 50 to 700 Pa. The value of 0.3 L/s-m^2.are considered representative of a "tight" assembly whereas that of 0.8 L/s-m^2 would be representative of an assembly with substantially lesser airtightness (but likely more closely representative of the degree of airtightness obtained in typical construction practice).

Pressure response

In regard to pressure response, should there be a series of pressure sensors monitoring pressure in the different layers of the assembly, e.g., behind the cladding, in the stud cavity, or in the interstitial space between the window frame and window opening, then obtaining pressure differences at these different locations in the dry condition provides some idea of the range of expected pressure differences at given driving pressures during spray testing. This in turn, offers some measure of the anticipated driving pressures across the respective layers and thus provides some idea of the expected comportment of the assembly prior to testing under wet conditions. An example of such a pressure response diagram is provided in Figure 5 in which the pressure response at a differential pressure of ca. 300 Pa is shown for two window installations each contained in a single test specimen. The configuration of the test specimen was as shown in Figure 3. On the B-side (a) of the specimen, the head and jamb flanges of the window had been bedded in sealant ("caulking"), whereas on the V-side (b) of the specimen, there was no sealant behind the window flanges. The different locations at which pressure differentials were measured are shown in the elevation views (left), and also in the corresponding sectional views. The upper sectional views depict the horizontal cross-sections, showing the pressure in the space between the window and window opening; the lower sectional views depict vertical cross–sections. The sectional views indicate pressure levels (relative to the interior) at the respective taps. Comparison of results between different installation details can readily be made; e.g. differences in pressure differential at the window mounting flange are evident as greater differences ($\Delta P = 302 - 17 = 285$ Pa) are obtained for the detail with caulking applied as compared to when no caulking is applied ($\Delta P = 72$ Pa) to the back of the flange. Such type of information provides insights into vulnerability of different details and the magnitude of water leakage rates to and drainage from the sill.

[4] Pluggable holes allow the specimen to be tested in a relatively airtight mode (with holes plugged), or tested in a relatively non-airtight mode (with holes unplugged). The ability to re-test at different air leakage conditions permits determination of watertightness at different air leakage conditions over a series of different spray rates.



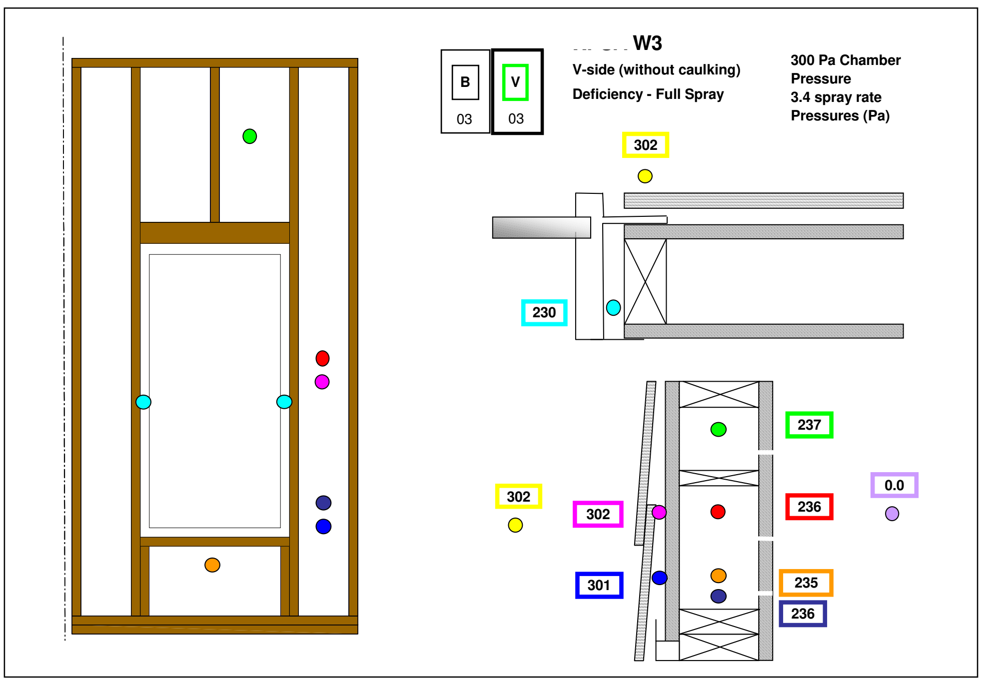


Figure 5 - Pressure response on each of two sides of a wall assembly with each side having a window installed in an opening. The pressure responses are at ca. 300 Pa driving pressure, showing pressures (Pa) at specified locations in elevation view (left) and corresponding sectional views (top- horizontal x-section; bottom-vertical x-section) (a) Sample pressures on B-side having caulking behind window flange at head and jamb; (b) Sample pressures on V-side without caulking behind window flange.

Watertightness Evaluations

Proposed Test parameters—To be consistent with the most commonly used test procedure for assessing watertightness (ASTM E331 [22]), the evaluations would be carried out at a water spray rate of 3.4 L/min-m^2 (5 US gal/ft^2-hr). Considerable insights into the range of expected performance of an assembly may however be gained by conducting tests at different spray rates.

For example, by initiating tests at lower spray rates, threshold values for water entry can potentially be determined. This permits assessing the lowest level at which adequate performance can be achieved. For a comparison of the relative performance of different installation details, identification of the level for each at which adequate performance can be achieved is likely to be more instructive that testing each at a single fixed level of water spray, (particularly when the test level is as high at the default rate specified in ASTM E331). Adjusting the spray rate to a value that simulates an expected climate load may also be more instructive than testing at the default spray rate.

An example of a set of test conditions is given in Table 3. In this example, test trials are first conducted without and thereafter with deficiencies incorporated in the assembly. The example is for a specimen with an interior Air Barrier System (ABS) whose air leakage rate can be adjusted. The tests are carried out with the ABS adjusted to leak a at a low leakage rate (0.3 ABS) and then at a greater leakage rate (0.8 ABS).

Table 3 — Proposed Test Parameters for Evaluating Wall-Window Interface Details to Manage Water Intrusion

Test Trial	**Deficiency**	**ABS* L/s-m^2**	**Spray rates / condition L/min-m^2**	**Differential pressure Pa**							**Test interval min.**
				0	**75**	**150**	**300**	**500**	**700**	**1K**	
1	No	0.3	0.8 full-spray	●	●	●	●	●	●		15
2			1.6 full-spray	●	●		●		●		15
3			3.4 full-spray	●	●	●	●	●	●		15
4			3.4 cascade spray	●	●			●	●	●	15
5	No	0.8	0.8 full-spray	●	●	●	●	●	●		15
6			1.6 full-spray	●	●		●		●		15
7			3.4 full-spray	●	●	●	●	●	●		15
8			3.4 cascade spray	●	●			●	●	●	15
9	Yes	0.3	0.8 full-spray	●	●	●	●	●	●		15
10			1.6 full-spray	●	●		●		●		15
11			3.4 full-spray	●	●	●	●	●	●		15
12			3.4 cascade spray	●	●			●	●	●	15
13	Yes	0.8	0.8 full-spray	●	●	●	●	●	●		15
14			1.6 full-spray	●	●		●		●		15
15			3.4 full-spray	●	●	●	●	●	●		15
16			3.4 cascade spray	●	●			●	●	●	15

* Nominal air barrier system (ABS) leakage of 0.3 and 0.8 L/s-m^2 at a pressure differential of 75 Pa

For each test trial, and at each water spray rate, starting with the lowest rate of deposition (0.8 L/min-m^2), tests are initiated with no pressure differential applied across the specimen, following which the test sequence follows in increasing pressure levels up to 700 Pa, or 1kPa. Test intervals, as noted, are nominally 15 minutes in duration. The use of cascade spray as compared to full-spray conditions provides a means to better understand the features of the assembly that might affect the water load on the window corners. More information on the difference between cascade and full-spray conditions is provided in the subsequent section (i.e. § *Choice of water deposition*).

Choice of water deposition on cladding—Water deposition in a test sequence is idealized as being representative of rainfall deposition on a façade; water is evenly sprayed across the entire specimen surface typically with a series of water spray nozzles arranged in a regular array that permits a reasonably even distribution of water, as illustrated in Figure 6. The "full-spray" configuration, depicted on the left of Figure 6, results in water being deposited evenly across the height of the specimen, however, the resulting water load due to migration downward along the face of the cladding increases in proportion to the wall height, the maximum effective load being located at the base of the wall. The load on the wall at any given height can be estimated from knowledge of the average spray rate over the wall and the wall height*. Certain types of cladding have non-absorptive surfaces and water quickly accumulates on the surface and runs down its face. For claddings having a porous surface, water first needs to saturate the surface of the cladding sufficiently for a film of water to form; thereafter, water naturally cascades down the cladding.

Provision can be made for testing assemblies with water applied in a cascade mode; this is accomplished by providing for a supply of water at the head of the specimen (illustrated in Figure 6 on the right). In cascade mode, specimens with non-absorptive cladding are not exposed to cumulative water loads at lower locations on the specimen, (as would be the case in full-spray mode). In cascade mode, the water load on specimens with non-absorptive claddings is, in principle, independent of vertical location on the specimen.

Expected range of values from watertightness tests—Examples of some results for water tightness tests that provide the expected range of water collection rates are provided in Figures 7 and 8. In Figure 7, rates of water collection at the window are given in relation to the pressure differential across the specimen (0 to 700 Pa); variations in collection rates (maximum values ranging from ca. 10 to > 80 ml/min) relative to the water spray load on the specimen (0.8 to 3.4 L/min-m^2) are clearly evident. It can also be seen that collection rates increase with increasing pressure difference and that rates of entry of different assemblies (i.e. A and W) can also be differentiated.

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* Water deposition load $S_r(x)$ at height, x, from top of wall, $S_r(x) = (x/\boldsymbol{h})\cdot 2S_r$; where $\boldsymbol{h}$ is height of wall; S_r is average spray rate (L/min.-m^2) over wall height.

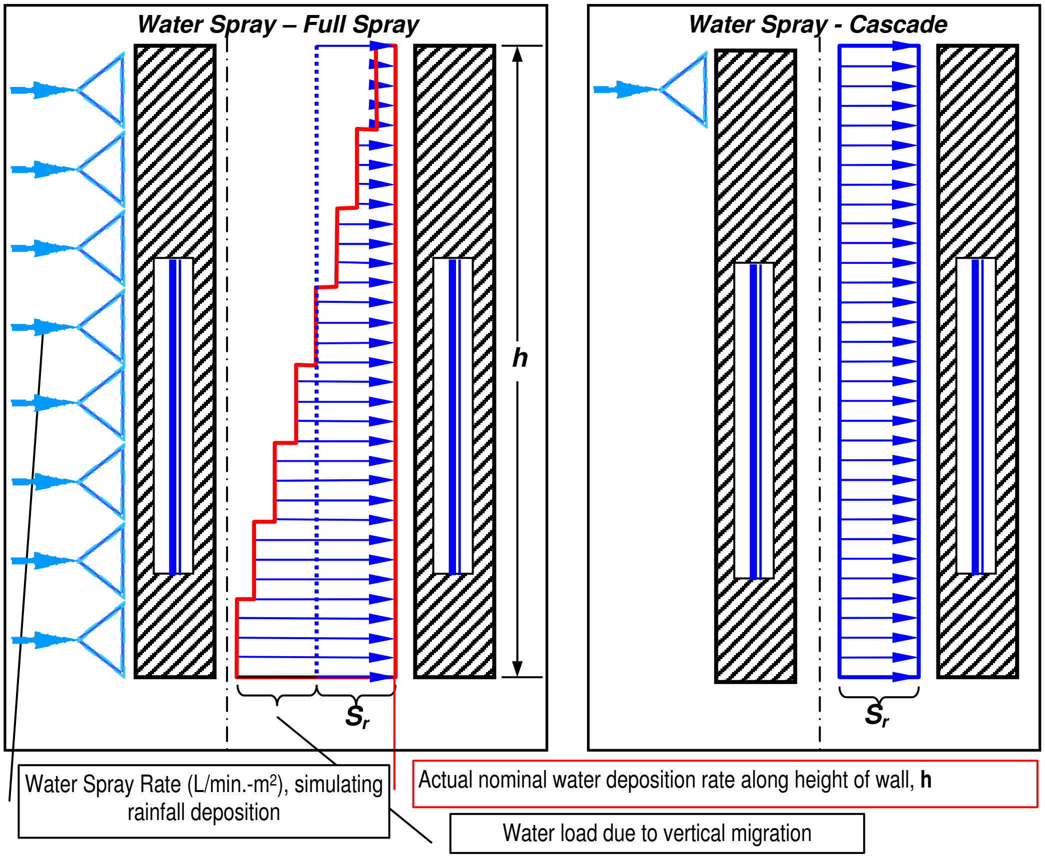

Figure 6 –Difference in relative water load along height of specimen when applying full-spray as compared to cascade water deposition loads on cladding

Figure 8 provides an example of test results, showing how the rate of water collection for drainage from the sill area below each of two installed windows (each in the same test specimen) related to spray rate and to pressure differential across the specimen. Collection rates in this example ranged from as low as approximately 10 ml/min to rates substantially in excess of 1000 ml/min. Collections rates in this instance were largely insensitive to applied pressure differential but were highly dependent on water deposition (spray) rate.

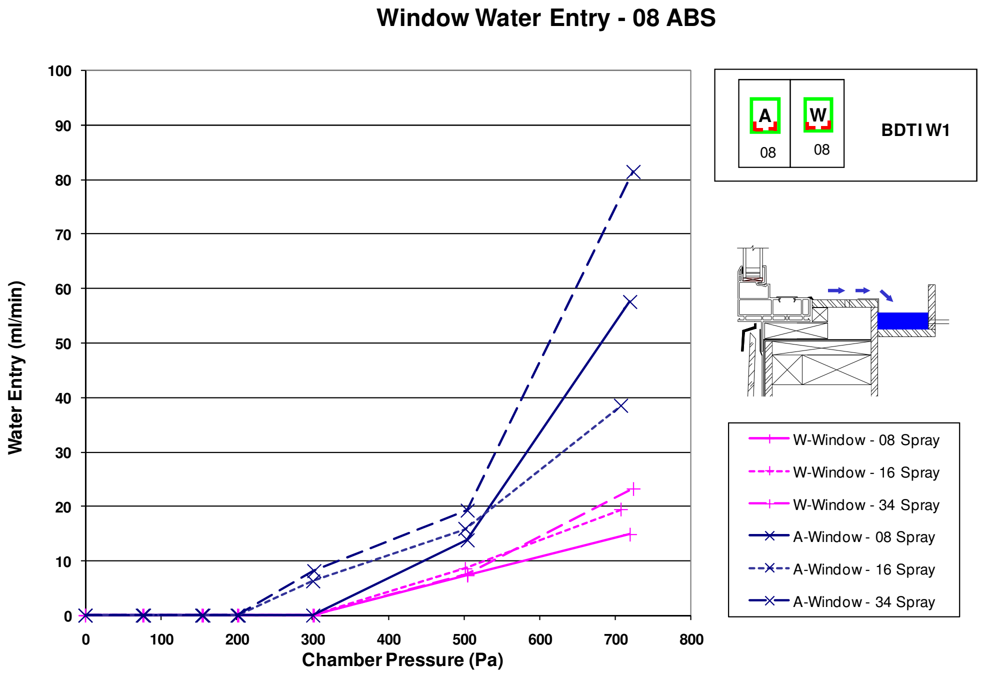

Figure 7 – Rate of water collection at window in relation to pressure differential across specimen; variations in collection rates in relation to the rate of water spray load on the specimen are clearly evident; collection rates increase with increasing pressure difference; rates of entry between different assemblies, A and W, are also evident

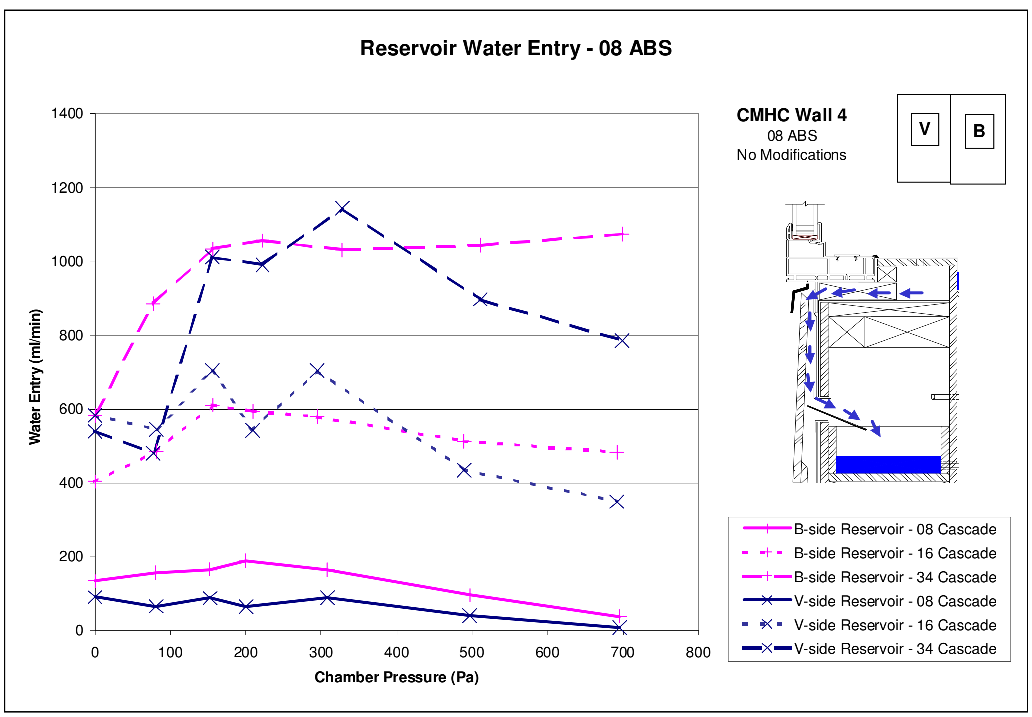

Figure 8 – Rate of water collection for drainage from sill in relation to pressure differential across specimen; variations in collection rates in relation to the rate of water spray on the specimen are evident; collection rates are not dependent on pressure difference but on water spray loads; similarities between rates of entry of different assemblies, V and B, are also evident.

Proposed Related Tests

Additional tests that relate to evaluation of window installation methodology are worthy of consideration, specifically a field test for evaluation of installation methods, and a test to determine the risk of condensation associated with a given set of installation details. Notional aspects related to the completing each of these tests are provided below.

Field Test

Parameters for field testing can be derived from the laboratory test protocol, and could be applied in-situ once a window installation method has been tested in the laboratory. Requirements for such a test would be similar to that for other field tests, such as that provided in: ASTM E1105 [25] (Field Determination of Water Penetration of Installed Exterior Windows by Uniform or Cyclic Static Air Pressure Difference) or ASTM C1601 [27] (Field Determination of Water Penetration of Masonry Wall Surfaces). Control of the water flow rate to the spray rack would require a flow meter, and control of the pressure difference across the window would require the room to be depressurized to a specified level (e.g. 75 Pa). The test would need to be carried out prior to completion of the interior finish, as otherwise the observation of inadvertent water entry is not likely to be possible. Field testing without interior finish in place however poses a risk for skewed results. This is because continuity of the air barrier system at the interface between the interior finish and the window is generally needed to ensure adequate watertightness of the installation, and with interior finish absent, continuity of the ABS is doubtful. Means can however be devised to provide a notational ABS for the purposes of testing. Providing a false interior finish, such as a clear acrylic sheet (as in the proposed laboratory test protocol) is an option. The acrylic sheet would be installed temporarily (for purposes of testing); it would have a width of at least a stud space on either side of the window opening.

Risk to Window Condensation at the Window Frame

Depending on the types of windows used and the wall construction into which windows are installed, there evidently are various possible methods for providing drainage; drainage methods are likely to vary primarily with regard to cladding type. The various drainage details may affect air leakage through the assembly. The provision of adequate thermal protection at the window-wall interface, as is currently recommended in building practice, may contradict recommended (or required) details for moisture management. Some approaches to window installation chosen with regard to their ability to manage water penetration may thus raise the risk of formation of condensation on the windows. Hence there is a need to determine if, under cold weather conditions, the approaches do in fact pose a potential for problematic condensation.

There exist a number of standard laboratory test methods for determining the potential for the formation of condensation on windows, e.g. ASTM C1199-00 Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods [28], and AAMA 1503-98 Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections [29]. The essential elements of the methods, briefly described, consist of testing a window assembly in a hot (i.e. room-side, interior) and cold (i.e. exterior) box environmental chamber across which there is a specified temperature differential (e.g. 70˚F; ca. 38˚C), measuring the window and frame surface temperatures at specified locations on the window, and calculating a weighted average of the interior surface temperature on the window. If from testing the window, the estimated room-side surface temperature on the window is less than a specified dew point temperature (selected to be representative of "normal" indoor conditions) then condensation on the window is expected.

Existing test methods for evaluation of condensation potential of windows could be adapted for evaluating the relative risk of condensation associated with various window installation methods. The test results are likely to be most meaningful when performed on wall assemblies that include cladding systems. As well, one may be able to adapt the test methods to determine the effects of air infiltration on the potential for window condensation for specific installation details.

The extent to which windows actually perform when installed is not well understood irrespective of the fact that the same windows may have been subjected to rigorous testing and evaluation following commonly used standard practice to evaluate thermal performance. Tests that help evaluate the risk of condensation at the window frame given specified installation details may prove useful in offering a more complete solution to the window installation conundrum.

Conclusion

A protocol for a laboratory test method on assessing the watertightness performance of window installation details is proposed. Information is provided on the specimen configuration, tests parameters, instrumentation, and performance criteria. Examples have been provided for the implementation of this test protocol, and the interpretation of test results from the examples have been discussed. Finally, information is a provided regarding additional proposed test methods for evaluation of window installation details, specifically a notional field test and a test for assessing the risk of condensation at the window frame.

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