NRC Publications Archive Archives des publications du CNRC

A review of climate loads relevant to assessing the watertightness performance of walls, windows and wall-window interfaces

Cornick, S. M.; Lacasse, M. A.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. / La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

For the publisher's version, please access the DOI link below. / Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:

<https://doi.org/10.1520/JAI12505>

Journal of ASTM International, 2, Nov/Dec. 10, pp. 1-16, 2005-11-01

NRC Publications Archive Record / Notice des Archives des publications du CNRC :

<https://nrc-publications.canada.ca/eng/view/object/?id=60ea8bec-0f43-4943-abcc-c220a113ae9a>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=60ea8bec-0f43-4943-abcc-c220a113ae9a>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

<http://irc.nrc-cnrc.gc.ca>

National Research Council Canada

A Review of climate loads relevant to assessing the watertightness performance of walls, windows and wall-window interfaces

NRCC-47645

Cornick, S.M.; Lacasse, M.A.

**A version of this document is published in / Une version de
ce document se trouve dans :**

**Journal of ASTM International, v. 2, no. 10, Nov/Dec.
2005, pp. 1-16**

Doi: [10.1520/JAI12505](https://doi.org/10.1520/JAI12505)

National Research
Council Canada

Conseil national
de recherches Canada

Canada

S. M. Cornick¹ and M. A. Lacasse²

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

REFERENCE: S. M. Cornick and M. A. Lacasse, “*A Review of Climate Loads Relevant to Assessing the Watertightness Performance of Walls, Windows and Wall-Window Interfaces*,” *Performance and Durability of the Wall-Window Interface: ASTM STP xxxx*, B. G. Hardman, C. R. Wagus and T. A. Weston, Eds., ASTM International, West Conshohocken, PA, 2004

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, the test loads at which penetration occurs, and possibly, relating 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

¹ Associate Research Officer, National Research Council Canada, Institute for Research in Construction, 1200 Montreal Road, Building M-24, Ottawa, ON, K1A 0R6 Canada

² Senior Research Officer, National Research Council Canada, Institute for Research in Construction, 1200 Montreal Road, Building M-20, Ottawa, ON, K1A 0R6 Canada

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.

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 E241-00) 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 entry 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 significant³:^[SC1]

- (1) The deposition rate - the amount of water impinging on the wall, related to the wind speed and rainfall intensity, and
- (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 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/hr and a 4-hour duration):

- (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 as deficiencies in construction or design, for example, a missing sealant bead. 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 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

³ It should be noted here that neither stack effect or 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 with the wind velocity pressures considered here.

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 was 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 in the UK is typically masonry.

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 E331-00) and the standard *Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference* (ASTM E547-00). 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 to 700 Pa, 0 for storm window ratings and 700 for highly exposed commercial windows. Windows are rated accordingly up 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/hr 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 the ASTM E547. In this standard, and a similar standard ASTM E331, a water deposition rate (spray rate) is prescribed to be 3.4 L/min-m² (5.0 US Gal/ft²-hour) 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) and
- (2) The driving rain wind pressure (DRWP).

Estimating the Effects of Wind Driven Rain (WDR)

Free wind-driven rain is 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]:

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

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)

R is the hourly rainfall intensity (mm/hr-m²)

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 purposes of water penetration trials is to test the watertightness performance of pristine walls i.e. walls with small deficiencies that would likely to 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 (DRWP) can be calculated simply as:

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

where:

ρ is the density of air, assumed to 1.2 kg / m³

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 DRWP shall be considered to be the same as the pressure difference across the wall.

The Driving Rain Wind Pressures for Canadian cities⁴ 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/hr 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/hr threshold level. Table 1 provides a location key code for cities charted in Figure 1. The basis for selecting the pressure steps was the rainfall rate of 1.8 mm/hr. This threshold was recommended because the 1.8 mm/hr rate corresponded to that of

⁴ Listed in Appendix

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.

From Figure 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 indicate 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 location except the Coastal locations, 500 Pa being an upper limit for the 1 in 5 return period. The 700 Pa pressure levels seems 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).

Table 1 – *Key code for locations cited in Figures 1 and 2*

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 Pages 8 and 9 [7]

Figure 1 – A sample of hourly Driving Rain Wind Pressures for several typical Canadian locations for various return periods at the 1.8 mm/hr rain intensity threshold

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 under estimate 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 periods⁶. From the figure a spray of 0.2 L/min-m² 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-m² would seem to be adequate. For extreme in-service conditions a rate of 0.8 L/min-m² will cover most Canadian locations except for 1 in 30 events. A rate of 1.6 L/min-m² will cover most locations of interest in Canada. A spray rate of 3.4 L/min-m² is unlikely in Canada for hourly rates for a 1 in 30 return period.

Even if 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). [SC2]

Duration and Intensity

Only hourly events have been considered so far, specifically hourly DRWPs and hourly rainfall intensities. For events having duration's 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.

⁶ Listed in Appendix

⁷ Graph on page 106 [12]

Figure 2 – A sample of spray rates in L/min-m² 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.

Table 2 – Factors to convert hourly wind speeds to shorter averaging times

Averaging Time	10 minutes	5 minutes	3 minutes	1 minute
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 Choi⁸, [10]:

$$\{R(t)\} / \{R(60)\} = [60/t_i]^{0.42} \text{ (mm/hr)} \quad (3)$$

where:

t_i is the averaging time of time of interest (min)

$R(t)$ is the rain intensity for averaging time of interest (mm/hr)

⁸ Page 12 [10]

$R(60)$ is the hourly rain intensity in (mm/hr)

For example for an averaging time of 5 minutes:

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

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-minute averaging time increases the wind pressures by 23%. Figure 3 shows the 5-minute average DRWPs for 23 locations for different return periods at the 1.8 mm/hr 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 longer duration extreme events.

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/hour-m² (0.82 L/min-m²) that for the top corner of a building yields a spray rate around 0.73 L/min-m². Increasing the spray rate by a factor of 2.84 increases the spray rate for an extreme 5-minute event to 2.1 L/min-m².

Figure 4 shows the 5-minute average wind-driven rain for 23 Canadian locations for different return periods. The effect of using 5-minute 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-m² 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 3.4 L/min-m² covers all the locations examined for the most extreme events (1 in 30).

Outline of a protocol for North American Climates

Any test 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 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 be thus categorized with respect to these two climate parameters. A notional map is shown in Figure 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.

Figure 3 – A sample of Driving Rain Wind Pressures averaged over 5 minutes for several typical Canadian locations for various return periods at the 1.8 mm/hr rain intensity threshold

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 hour and 5 min average for 1 in 2.
300 Pa	Covers all locations except windiest and coasts for 1 hour 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.

Figure 4 – A sample of spray rates in L/min-m² based on driving rain with a 5-minute 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.

While the suggested spray rates could be:

0.4 L/min-m² - Normal in-service conditions for hourly averages

- 0.8 L/min-m² - 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-m² - 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-m² - 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						

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 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 Figures 6 and 7).

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 absorb 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.

Figure 5 – *A notional climatology of North American based on protocol performance levels*

Finally the duration of events such as wet spells and dry spells also come into play especially with regards 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.

Figure 6 – Wind-driven rain events for Winnipeg MB, covering 30 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

Figure 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

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 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.

References

1. Carll, C. (2001), Rainwater Intrusion in Light-Frame Building Walls, Proceedings of the 2nd Annual Conference on Durability and Disaster Mitigation in Wood-Frame Housing: November 6-8, 200, Madison, WI, Forest Products Society, Madison, USA, pp. 33-40.
2. Lacasse, M.A., O'Connor, T., Nunes, S.C., Beaulieu, P., Report from Task 6 of MEWS Project : Experimental Assessment of Water Penetration and Entry into Wood-Frame Wall Specimens - Final Report, *Research Report, Institute for Research in Construction, National Research Council Canada*, 133, pp. 1 v. (various pagings), Feb. 2003 (IRC-RR-133)
3. Lacasse, M.A., "Recent studies on the control of rain penetration in exterior wood-frame walls," BSI 2003 Proceedings (15 Cities across Canada, 2003-10-07), pp. 1-6, Oct. 2003
4. BSI. British Standards Institution, BS 8104:1992 Code of practice for assessing exposure of walls to wind-driven rain, British Standards Publishing Limited, UK
5. CSA A440 *Windows* (CAN/CSA A440-00)
6. 101/I.S. 2/NAFS-02 (ANSI/AAMA/WDMA) Voluntary Performance Specification for Windows, Skylights and Glass Doors (ANSI Approved), American Architectural Manufacturers Association, 2002
7. Welsh, L. E., Skinner, W. R., and Morris, R. J. *A Climatology of Driving Rain Pressure for Canada*, Climate and Atmospheric Research Directorate Draft Report, Environment Canada, Atmospheric Environment Service. 1989.
8. Lacy, R. E., "Driving-Rain Maps and the Onslaught of Rain on Buildings", *Proceedings of the RILEM/CIB Symposium on Moisture Problems in Buildings*, Helsinki Finland, 1965.
9. Straube, J.F. and Burnett, E.F.P., (2000), "Simplified prediction of driving rain deposition", *Proceedings of International Building Physics Conference*, Eindhoven, September 18-21, pp. 375-382.
10. Choi, E. C. C. "Criteria for Water Penetration Testing," *Water Leakage Through Building Facades*, ASTM STP 1314, 1998
11. Blocken B., and Carmeliet, J., "Driving rain on buildings envelopes - II. Representative experimental data for driving rain estimation" *Journal of Thermal Envelope and Building Sciences*, 2000, **24**, 2, 89-110
12. ASCE 7-88 (Formerly ANSI A58.1 1988) Minimum Design Loads for Buildings and Other Structures ed. Kishor Mehta, American Society of Civil Engineers, 345 East 47th Street New York, NY 10017-2398.
13. Underwood, S. J., and Meentemeyer, V., "Climatology of Wind-Driven rain for the Contiguous United States for the Period 1971 to 1995", *Physical Geography*, 1998, **19**,6:445-462.

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, $L/m^2/hr$, 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	1 in 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]						

Page: 3

[SC1]Reviewer #1 comment #2

Page: 9

[SC2]Reviewer #2 comment # 8