WATER PENETRATION CONTROL FOR WINDOWS – A SERVICE LIFE APPROACH

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INTRODUCTION

Building envelope performance problems and their close link to poor window and window to wall interface performance is a recurring theme in Canada and elsewhere over the last 40 years. In *Glazing Design - Canadian Building Digest #55 (CBD55)* [1] published in July 1964 it is stated that '*Rain penetration is a major problem with glazing and must be controlled…*'. A more recent study Rain Leakage of Residential Windows in the Lower Mainland of British Columbia – Building Practice Note No. 42 published the Division of Building Research, National Research Council of Canada in November 1984 [2] begins with *'Many inquiries concerning rain penetration of exterior wall are received by the B.C. Regional Station of the Division of Building Research and are focused on window installation practices'*. The problems are not restricted to BC either. Building Research Note No. 210 (BRN No. 210) [3] also published in 1984 reports on window performance problems in Atlantic Canada.

The A440 series of window performance standards [4][5] were developed in part to help provide a basis for evaluating and categorizing rain penetration control performance. More recently, installation practices have also been addressed through the creation of a new standard in the A440 series (A440.4 Window and Door Installation)[6].

Despite the various studies that have identified performance problems associated with windows, and the introduction of new standards to improve quality, windows and window to wall interfaces continue to be major contributors to moisture problems in buildings. This paper introduces an approach to achieving acceptable water penetration control with installed windows over their intended service lives.

This paper is based on two projects [7][8] undertaken by RDH Building Engineering Limited that were sponsored by Canada Mortgage and Housing Corporation, The Homeowner Protection Office of British Columbia and British Columbia Housing and Management Commission.

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OBJECTIVES

The basic objective for effective water penetration control associated with windows seems simple enough: A window and it's interface with adjacent wall assemblies must resist or accommodate water penetration over the intended service life of the window without unforeseen maintenance, repairs or renewals so that materials that comprise the window and wall do not deteriorate. The wide range of exposure conditions (from rarely wet, to frequently wet and subject to high winds) as well as varying design configurations and sizes results in most windows being unique product applications. Therefore unlike many other manufactured products, windows cannot really be considered a mass produced assembly line product with one design where relatively simple quality control measures are required to ensure acceptable performance. For windows, achieving the basic water penetration objective involves a complex set of decisions related to determination of exposure conditions, selection of a water penetration control strategy, choice of components and materials, interface design and verification of performance.

CURRENT APPROACH AND LIMITATIONS

At the present time, the 1995 National Building Code (NBC-95) [9] provides very little specific guidance regarding water penetration resistance of windows and the window to wall interface. Part 5 of NBC-95 identifies objectives for water penetration control that are applicable to all building envelope assemblies and components, including a basic requirement that water penetration not occur to the point where it is likely to cause damage. It draws attention to the fact that junctions between assemblies (window to wall interface) need to be appropriately designed to prevent water penetration. The Appendix notes also provide warnings with respect to the difficulties in achieving a perfect surface-sealed barrier (face seal), and the need to consider service lives of assemblies, components and materials in the design of a building envelope.

These building code objectives are consistent with the basic objective for water penetration control associated with windows as stated in the previous section, however there is little guidance provided in the code with respect to how to achieve these objectives. Note that it is not generally the intent of the code to provide guidance regarding how to achieve performance objectives. Our identification of limitations may therefore reflect a need for this guidance to be provided through other documents.

Specific limitations of the NBC-95 requirements are as follows:

- Although Article 5.2.1.1 identifies the needs to consider the exterior environmental loads and references climatic data for different locations, it does not acknowledge the micro climate effects of building form, and local topography which impact on the frequency and time of wetness due to rain.

- Although Article 5.6.1.1 addresses water penetration, it does not provide (nor do the Appendix notes) any guidance on design and selection of appropriate water penetration control strategies for various exposure conditions.
- Although Articles 5.6.2.1, 5.6.2.2 and associated Appendix notes address the need to consider building interfaces, they do not provide any guidance on design and selection of appropriate water penetration control strategies for various exposure conditions.

Similar limitations exist within Part 9 of NBC-95 although the prescriptive nature of this Part of NBC-95 results in some rather simplistic statements regarding control of water penetration.

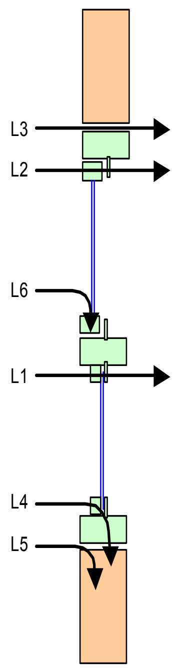
NBC-95 does require windows to comply with the appropriate window manufacturing standards, CSA A440.0 and A440.1. The use of A440.4 standard is not mandated by NBC-95.

The A440-00 Windows standard, special publication A440.1-00 User Selection Guide, and standard A440.4-98 Window and Door Installation all contain requirements relevant to water penetration control. A440-00 and A440.1-00 apply to the manufactured window component and therefore do not contain requirements for the window to wall interface. They rely on the evaluation of water penetration control performance for windows through the use of a standard ASTM test protocol (E547). Test pressure differentials are based on geographic location and building height. The B Ratings (test pressure differentials) help to ensure that the window is capable of resisting a wind driven rain pressure that has a one chance in ten of being exceeded in a year. This represents a peak rain exposure event and is significant in the context of relatively infrequent wind driven rain. A key question is whether this test requirement is relevant in the context of service life performance of the installed window.

Specific limitations of A440-00 and A440.1-00 with respect to water penetration control include:

- The A440 and A440.1 standards are fundamentally intended for evaluation of manufactured components and therefore do not consider water penetration resistance of installed window assemblies. They therefore do not require the evaluation of the performance of the interface between windows and adjacent wall assembly. Figure 1 clearly indicates that the leakage paths of most concern are not addressed or inadequately addressed by the current test requirements.
- A440 and A440.1 standards do not consider the micro climate effects of building form, and local topography which impact on the frequency and time of wetness due to rain.
- The guide (A440.1) provides a basis for choosing B ratings that are significant in the context of relatively infrequent wind driven rain, whereas micro climate factors are not considered, yet are significant in every rainfall event.
- A440 standards do not reflect any consideration for the durability of the performance achieved in the standard test procedure.
- The evaluation procedure does not reflect the varying long-term risk of water penetration associated with different water penetration control strategies (rainscreen vs. face seal).

- The requirements do not consider performance of combination windows such as strip windows (horizontally coupled) or window wall (vertically and horizontally coupled).
- There are no requirements for ongoing quality control at the manufacturing facility nor is there a mandated requirement for a manufacturer to participate in a certification program.



Leakage Paths	Risk of Consequential Damage	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: Applicability of the A440 Standard to Leakage Paths

The A440.4 standard represents a first attempt at integrating the many issues that need to be considered in the installation of a window into a wall. It also contains some useful guidance and discussion of sound fundamental principles for water penetration control associated with the interface between the window and wall. However the following limitations exist with the current standard:

- The standard currently provides disproportionately few examples illustrating the principles of water penetration control.
- Requirements for rain penetration control are inappropriately included within the air leakage control portion of the guide.
- Several of the figures illustrating concepts are inappropriate for some exposure conditions from a water penetration control perspective.

WATER PENETRATION CONTROL ISSUES

The discussion in the previous section identifies three key limitations of the current mandated approaches in achieving water penetration control associated with windows:

- Need to address in-service exposure conditions
- Need to adequately address water penetration control at the window to wall interface
- Need to address durability of water penetration performance

The following sections outline a rational approach to addressing these key water penetration control issues.

In-Service Exposure Conditions

Consideration of exterior environmental conditions, or exposure, can be thought of in two regimes: a peak exposure event (rainfall together with significant air pressure differential that can be expected to occur relatively infrequently), and a standard in-service exposure event (rainfall with relatively low or no air pressure differential and occurs frequently).

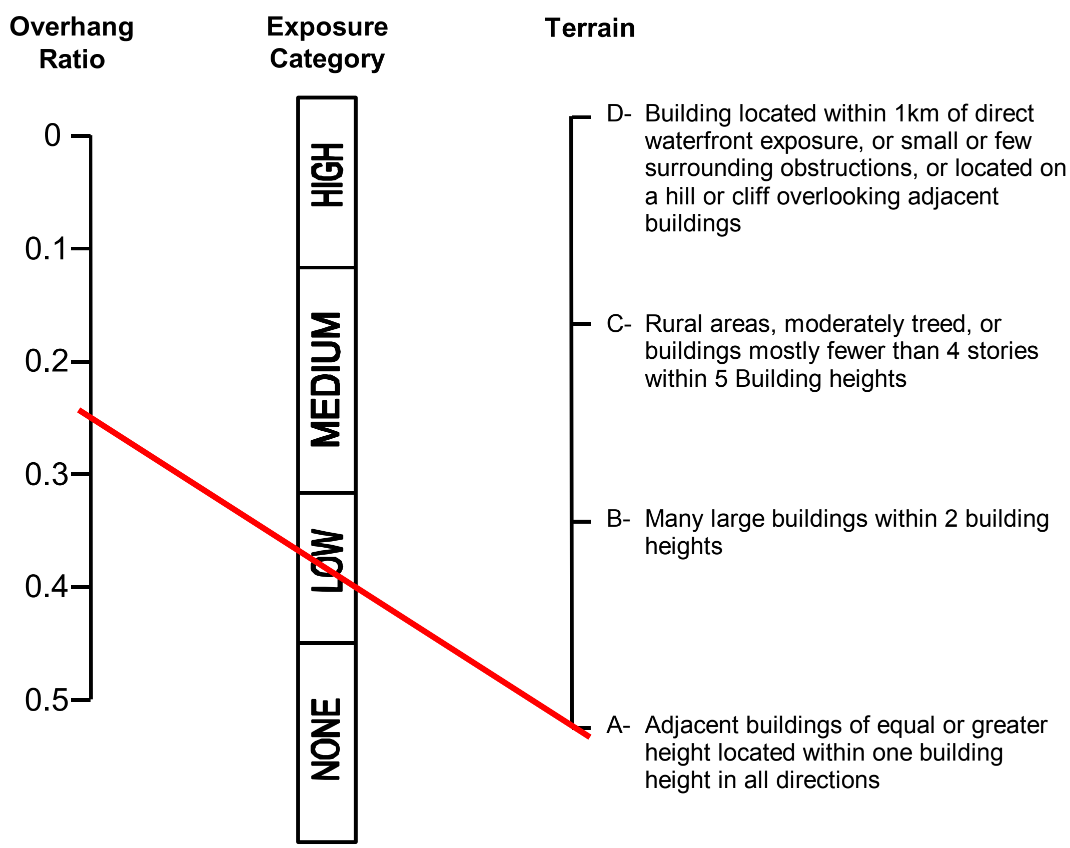
A requirement for a particular B level rating in a CSA A440 mandated water penetration test will help to ensure that the window is capable of resisting a peak event and is therefore significant in the context of relatively infrequent wind driven rain. However, it is not clear that these ratings and the associated testing have any significance with respect to the in-service performance of the installed window. 'Time of wetness' is a concept that may be a more appropriate exposure criterion to consider for the service life of the window.

Time of wetness is a significant variable with respect to water penetration performance and durability because it is a measure of how often, and for what duration a window, and window to wall interface is wet. Time of wetness is impacted by climate, building form, overhangs, and the local terrain and is significant in every rainfall event.

Time of wetness impacts leakage paths that occur regardless of pressure differential due to wind (primarily the driving force is gravity). In fact, much of the leakage activity of concern occurs at low or no pressure differential. Time of wetness also becomes more significant as materials age because the mere presence of water at a hole created by material aging can be a source of water penetration. The most direct way to control time of wetness is through the provision of overhang protection (roofs, balconies, flashing, rebates), with local topography having perhaps a slightly less significant effect.

The assessment of these micro exposure factors to determine a relative exposure category is not currently well defined or supported by research. Certainly the significance of overhangs on wall performance has been documented (Survey of Building Envelope Failures in the Coastal Climate of British Columbia)[10]. An approach to assessing micro exposure conditions has been presented in the Best Practice Guide – Wood Frame Envelopes In the Coastal Climate of British Columbia [11] and is reproduced in Figure 2.

Note that this nomograph was derived based on empirical evidence from coastal British Columbia. It is likely conservative for other parts of Canada and could benefit from some refinement of the procedure based on more quantifiable data related to time of wetness for different geographic locations. However, it is believed that this model represents a reasonable starting point.



Overhang Ratio = $\frac{\text{Overhang Width}}{\text{Wall Height}}$

Where: Wall Height is the height above the lowest affected element (sill of window if considering a window)

Overhang Width is the horizontal distance between the outer surface of the cladding or window and the outer surface of the overhang

Figure 2: Nomograph Relating Overhang Ratio and Local Terrain to Determine Micro-Exposure Conditions (Red indicates the assessment of exposure conditions for a one storey house with 2' roof overhangs)

For example, it may be possible to introduce a micro-climate exposure factor into A440.1, based on the nomograph in Figure 2, that dictates what minimum water penetration control strategy is required. For the low exposure conditions depicted by the red line in Figure 2 a face seal window with relatively simple window to wall interface details may provide acceptable performance. For higher exposure conditions where the window will be regularly exposed to rain, reliable water penetration performance is best achieved through a combination of a window that utilizes a rainscreen water penetration control strategy, as well as a level of redundancy provided through the addition of sub-sill drainage.

The selection of a particular water penetration control strategy can also have a significant impact on the durability of water-tightness for given exposure conditions. This aspect of performance is discussed later in this paper.

Window To Wall Interface

Failures at the window to wall interface is the dominant leakage problem associated with the in-service window assembly. Field test results [8] indicate that all leakage paths shown in Figure 1 are significant, although based on frequency of occurrence and risk of consequential damage, leakage through the window into the adjacent wall assembly and through the window to wall interface to the adjacent wall assembly present the greatest relative risk.

Clearly, while there is a need to create both a window and a wall assembly that are able to accommodate the moisture loads imposed, the interface between these assemblies is equally important. Unfortunately, it is not always clear how to effectively maintain continuity of critical moisture control functions (critical barriers) through this interface. In addition, it is also not always clear what parties are responsible for ensuring that continuity.

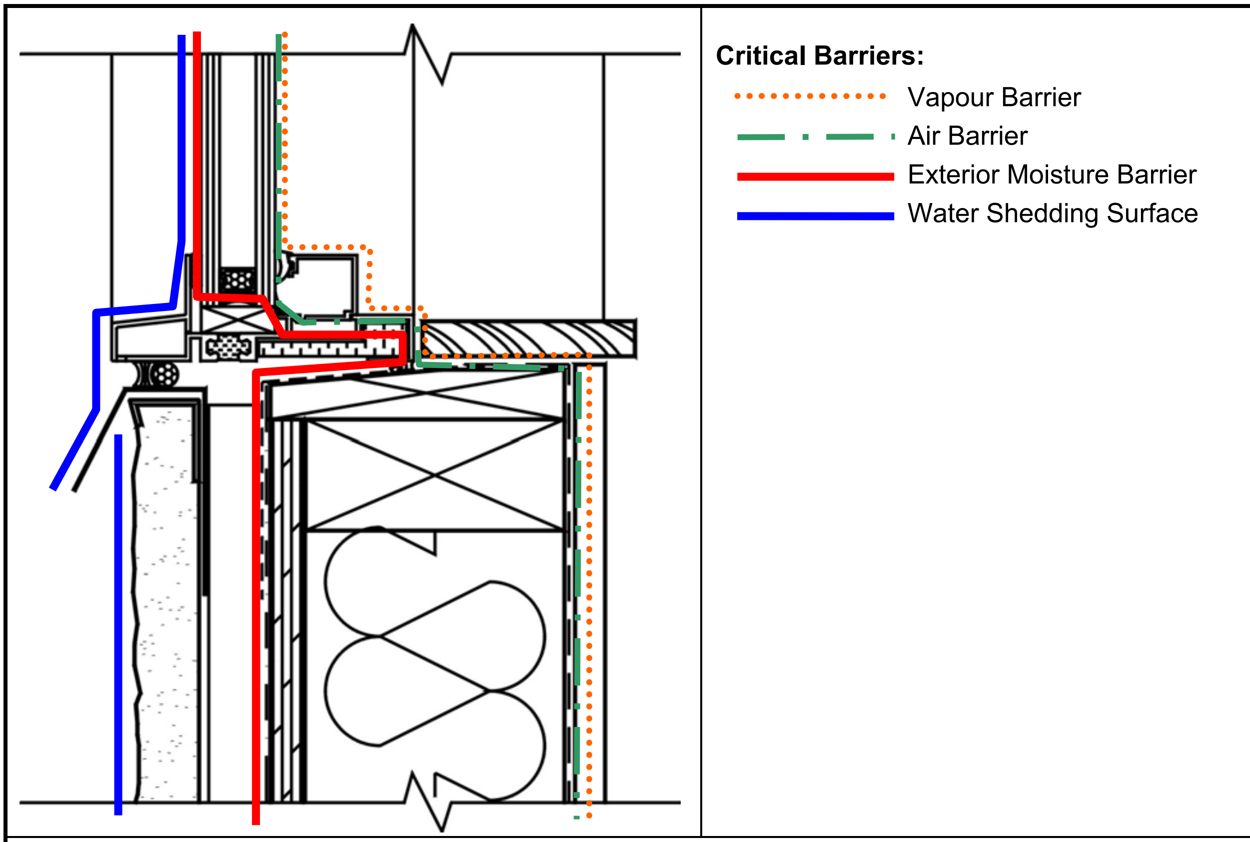
The term “Critical barrier” refers to materials and components that together perform a specific function within a wall or window assembly. All of these functions are ‘critical’ to the successful performance of the assembly however, some of the functions are easier to achieve than others.

It is common to think of, and define, critical barriers within a wall assembly such as a vapour barrier or air barrier. However, two additional barriers are also critical but less well understood or used within the industry. One of these critical barrier terms is the ‘water shedding surface’. The water shedding surface refers to the surface of assemblies, interfaces and details that deflect and/or drain the vast majority of exterior moisture (in the form of liquid water) impacting on the façade.

A second less well understood critical barrier term is the ‘exterior moisture barrier’ (is also referred to as a water resistive barrier). The exterior moisture barrier refers to the surface farthest into an assembly from the exterior that can accommodate some exterior moisture (in the form of liquid water) without causing damage to interior finishes or materials within the assemblies.

These four critical barriers can be used to describe an effective water penetration control strategy for the window to wall interface as shown in Figure 3.

A key aspect of the detail shown in Figure 3 that may not be obvious from the discussion on critical barriers provided below Figure 3 is the fact that both the window and the wall assembly utilize a rainscreen water penetration control strategy. It is much easier to make a rainscreen interface transition between two assemblies that also utilize this strategy. Conversely, it is often more difficult to achieve continuity through the window to wall interface when some incompatibility exists, such as when a face seal window assembly meets a rainscreen wall assembly.



The four critical barriers can be used to describe the different moisture control functions within window and wall assemblies as well as at interfaces between window and wall assemblies. In this example the vapour barrier (resisting vapour diffusion) is provided by materials of low vapour permeability located near the interior of the wall and window assembly and include the polyethylene sheet, window frame, and the interior sheet of glass. The air barrier function (resisting the flow of air in either direction) is provided by the drywall, seal to the sub-sill, seal between the sub-sill and the window frame, the window frame, the seal between the window frame and the glazing, and the glazing. The exterior moisture barrier function is provided by the glazing, the seal between the glazing and the window frame, the seal between the window frame and the sub-sill membrane, the sub-sill membrane, and the exterior sheathing paper. The water shedding surface function consists of the glazing, the glazing tape between the glazing and window frame, the exterior surface of the window frame, the sealant between the window frame and the sill drip flashing, the sill drip flashing and the exterior surface of the stucco cladding.

Figure 3: Continuity of Critical Barriers at Window to Wall Interface

Verification of performance of the window to wall interface is also necessary. Two key aspects of this are quality assurance measures such as field review by the design and construction team and water penetration testing of the installed assembly. The ASTM E1105 testing protocol is appropriate for testing the initial performance of this interface. Other factors must be considered in order to ensure durable service life performance however. These issues are discussed in greater detail in the next section.

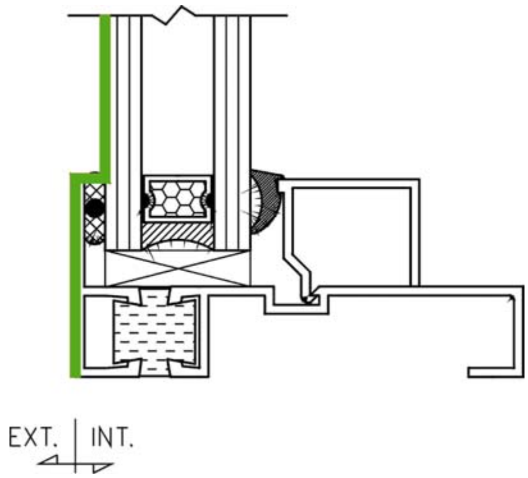
Durability

It is possible to initially achieve and verify the acceptable water penetration performance of a manufactured window (and even the window to wall interface) through testing. However, it is the service life performance, not initial performance, which is the critical element of our water penetration objectives for windows. It is not practical to test for the durability of performance of installed windows, nor is it practical to test all of the installed windows to ensure that they reliably meet the intended performance criteria. For this reason measures must be incorporated into the design of the window and the window to wall interface that provides confidence with respect to in-service performance. In addition to achieving 'durability by design', the mandated use of a certification program that requires on-going testing of windows from the manufacturing plant will help to ensure the ongoing reliability of the manufactured window product.

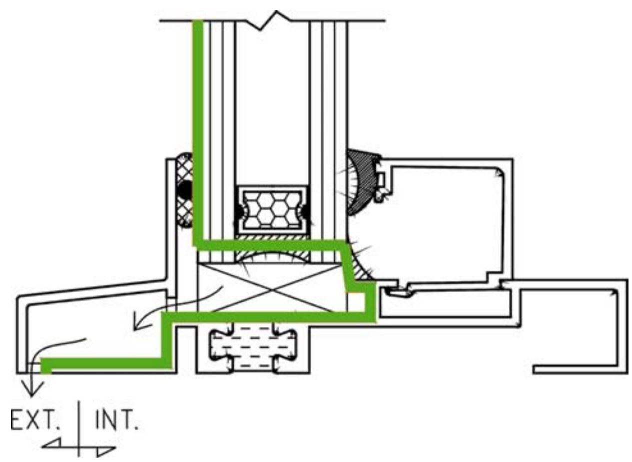
Durability by design involves the use of assemblies and details that incorporate some redundancy. There is a need to incorporate some redundancy in design because all materials deteriorate with age and it is not possible to build with perfection. An exception to this in the case of glazed assemblies might be a Total Vision System (TVS) where the use of very durable materials, and simple design provide acceptable long-term performance of what is essentially a face seal assembly. In addition, TVS systems are generally easily accessible and maintainable. In practice however, residential buildings dictate the use of more complicated combinations of materials and geometry that limit the ability to achieve acceptable performance with face seal (no redundancy) assemblies and interfaces. Even with complicated facades there are exceptions for certain exposure conditions. For example, a poorly installed face seal window located in a protected environment such as under a balcony projection or immediately beneath large roof overhangs will perform well with respect to water penetration because it is rarely wetted.

A rainscreen design strategy incorporates redundancy through the provision of an exterior moisture barrier that is rarely wetted and is therefore more likely to provide good performance. See Figure 4. Providing sub-sill drainage capability for a window essentially assumes that a window will leak at some point in its service life and provides some redundancy through the provision of a second line of resistance (See Figure 3). In fact, both rainscreen design and redundancy created by the use of sub-sill drainage will help control water penetration at peak pressures also, while the initial achievement of a particular B rating may have minimal relevance with respect to the long term water penetration performance of a window or the window to wall interface.

Some materials used in windows are inherently durable (such as appropriately coated aluminum, and glass) while others such as sealants and wood will require maintenance and renewals. However, due to the location of windows on many buildings, access to address these maintenance and renewal needs can be difficult. In addition, the location of some critical seals within a window unit and within the window to wall interface are very difficult to replace or maintain in-service. Window selection and detailing for durable water penetration control must therefore reflect reasonable maintenance and renewals expectations.



Exterior Moisture Barrier Location for a Face Seal Window



Exterior Moisture Barrier Location for a Rainscreen Window

The term face seal describes a window where the water shedding surface is coincident with the exterior moisture barrier and air barrier.

The term rainscreen describes a window where the water shedding surface is not coincident with the exterior moisture barrier and air barrier. The exterior moisture barrier is located to the interior of the water shedding surface and there is an air space between the water shedding surface and the exterior moisture barrier that creates a capillary break. The flow of exterior moisture (rain) through the water shedding surface is minimized and the capillary break facilitates drainage of the minimal water that may penetrate past the water shedding surface into the cavities within the window frame. The exterior moisture barrier and air barrier are usually coincident in a rainscreen window.

Between these two categories (face seal and rainscreen) is a third category referred to as concealed barrier. Similar to the rainscreen approach, the water shedding surface is at a different location than the exterior moisture barrier. However, due to discontinuities in the water shedding surface, a poor air barrier, the lack of an air space between the water shedding surface and the exterior moisture barrier, poor pressure equalization characteristics or a combination of these variables, a more significant amount of water contacts and remains in contact with the exterior moisture barrier. The risk of water penetration for a well designed concealed barrier window (or wall) can fall somewhere between a face seal window (higher risk) and a rainscreen window (lower risk). However, the performance of concealed barrier windows can also be less effective than face seal windows. This is due to the fact that water can be retained inside the frame long after wetting events, and is in contact with sealants thereby adversely affecting the durability of the sealant due to constant water immersion. In addition, because water is sometimes retained within concealed spaces in the frame, frequency and quantity of water leakage through the frame can be more prevalent. The effective performance of concealed barrier windows is therefore dependent on the management of the variables described above (continuity of water shedding surface, location and continuity of air barrier, and drainage capability between the water shedding surface and the exterior moisture barrier).

Figure 4: Water Penetration Control Strategy for Windows

For most situations, the selection of the window and the interface design must therefore balance exposure conditions with water penetration control strategy, some redundancy in detailing, material selection, and maintenance and renewal needs, to achieve acceptable performance.

MANDATING A SERVICE LIFE APPROACH

Although several key principles for effective service life water penetration control have been described in this paper, there is a need to provide greater guidance regarding the application of these principles to manufacturers, building and interface designers, installers and building owners so that the principles are achieved in practice.   In addition, there is a need to mandate some of these requirements before effective performance will be achieved on a consistent basis.

A mandated service life approach must begin with the building code. It should articulate fundamental objectives, define environmental loads, and identify appropriate principles of water penetration control for the range of in-service exposure conditions.

The manufacturing standards must require explicit consideration of durability and service life performance issues through the classification of windows in accordance with their water penetration control strategy and consideration of micro-exposure conditions, in addition to peak conditions. Effective in-service performance must include the establishment of a mandated certification program that requires periodic sampling of products to help ensure on-going quality control is taking place at the manufacturing facility.

The final link in this mandated performance hierarchy involves mandated requirements within the installation standard such as a field testing protocol, installer certification and guidelines for detailing in differing exposure conditions.

This general roadmap for mandating acceptable in-service water penetration control for the window and window to wall interface is shown in Figure 5.

While some elements shown in this roadmap exist in codes, standards and certification processes now, others have yet to be mandated, while some elements require further development before they can be mandated. For example, little quantifiable information is currently available regarding micro exposure conditions, and therefore inclusion of guidelines within the Appendix to the code may be more appropriate at this stage than definitive requirements within the code itself. On the other hand, a simple prescriptive requirement for sub-sill flashings for all windows that are regularly wetted may address many of current window and window to wall interface problems by providing some redundancy.

Classification of windows within the A440 standard by water penetration control strategy may not be a simple task either. The differences between concealed barrier assemblies and rainscreen assemblies can be subtle. At the same time, many windows with the same basic rain penetration control strategy can physically appear quite different.

There is also a wide range of examples for installation details that requiring development for different exposure conditions before they can be included in the A440.4 installation standard.

Despite the challenges that remain, it is believed that we now have an understanding of the key elements of the changes that need to occur to achieve consistent and effective in-service water penetration control for windows.

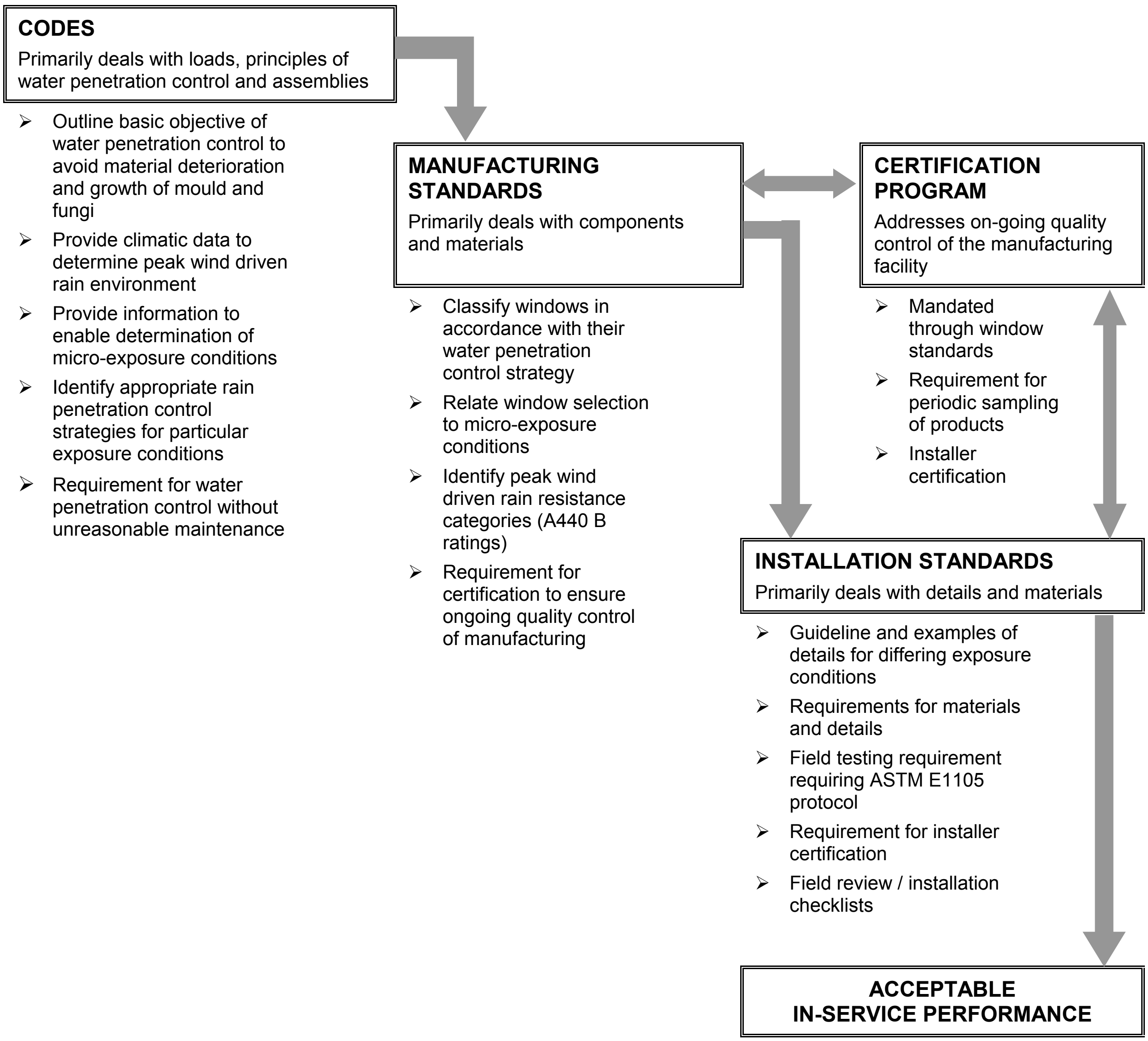


Figure 5: Roadmap for Mandating Effective Water Penetration Control

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