Evaluating the effectiveness of wall-window interface details to manage rainwater. Phase 1: watertightness, air leakage and rainwater management of CMHC specified assemblies

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Client Report

Performance Evaluation of Wall-Window Interface Details Phase 1 – Watertightness, Air Leakage and Rainwater Management of CMHC Specified Assemblies

REPORT: B-1229.1

A Client Report based on the results of the broader Joint CMHC / IRC Research Project on:

Evaluating the Effectiveness of Wall-Window Interface Details to Manage Rainwater

for the

Canada Housing and Mortgage Corporation
700 Montreal Road
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National Research Council Canada
Conseil national de recherches Canada
Canada

Evaluating the Effectiveness of Wall-Window Interface Details to Manage Rainwater

Phase 1 – Watertightness, Air Leakage and Rainwater Management of CMHC Specified Assemblies

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Nomenclature

ABS	air barrier system
ASTM	American Society for Testing and Materials
B-side	base-case side of test specimen
CMHC	Canada Mortgage and Housing Corporation
CSA	Canadian Standards Association
DRF	driving rain factor
DRWP	driving rain wind pressure
DWTF	dynamic wind and wall test facility
NRC	National Research Council Canada
PVC	polyvinyl chloride (as in PVC window)
RO	rough opening (as in window rough opening)
V-side	variation side of test specimen
W1	wall test specimen number 1
W2	wall test specimen number 2
W3	wall test specimen number 3
W4	wall test specimen number 4
WDR	wind driven rain
WWI	wall-window interface

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Mr. Tom Johnston, Atlantic New Home Warranty Program, Nova Scotia
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Mr. Roger Coté, inspector and supervisor for province of New Brunswick

Preface

This report has been compiled based on experimental work carried out in the laboratories of the Institute for Research in Construction, a review of pertinent literature and feedback obtained from different experts and practitioners of window installation. It forms the initial part (Phase 1) of a series of three reports prepared on the "Performance Evaluation of Wall-Window Interface Details". Of the eight chapters provided in this report, the first three provide an introduction to the work in which the approach to the performance assessment process is described, the development and rationale for the test method are given, and a summary description of the test specimens is offered. The four subsequent chapters focus on detailed results obtained from the experimental work of testing four different pairs of wall-window interface details, and the final chapter offers an overview of some of the practical considerations derived from this work. Although a brief description of the interface details and specimen configuration are provided within each Chapter, considerably more detail is given for each of the four specimen pairs in the Appendix in which the installation process is illustrated in a series of photographs. Finally, the hardcopy report also includes a softcopy of the work presented on a CD. In this CD, in addition to all of the information provided in this report, other contributions are included that directly relate to the work carried out in this study that were either previously published in conferences, or are presentations that were made at different meetings, symposia or workshops.

Executive Summary

Inadequate detailing practice and defective installation of windows have accounted for a significant number of premature failures of the building envelope. This has spurred the development of alternative construction details to manage water intrusion at the wall-window interface. However, it is not known how effective these construction details may be over the life expectancy of the wall assembly. Laboratory investigations focused on assessing the effectiveness of wall-window interface details to manage rainwater intrusion in the wall assembly have provided an effective way to obtain useful information on the varying performance of different interface details. Previous studies undertaken to investigate the effectiveness of details typically used in wood frame low-rise wall assemblies have shown the degree to which different details manage rainwater intrusion and the extent of fault tolerance of these systems. The current study was undertaken to investigate the effectiveness of such details, typically used in wood frame low-rise wall assemblies, to manage rainwater.

This report provides results obtained from evaluating the watertightness of a series of four wall-window interface details representative of construction practice across Canada. An overview of the experimental approach is provided and includes the development of the test protocol, a description of the test apparatus and the basis for estimating the effects on specimens subjected to simulated climate loads. The test specimen configuration is described and details of four sets of wall-window interfaces and variations on their implementation are provided. The results of water penetration tests are presented in terms of water entry through deficiencies in the cladding, water collection within the assembly and the severity of the simulated wind-driven rain loads. Results on water entry for the different wall-window interface configurations are given and the effectiveness of different details is discussed.

Chapter 1 — Introduction

Background Information

A key design element for exterior walls is the control of rain penetration. Lack of attention to design principles or failure to implement them in the detailing of wall components may lead to premature deterioration of wall elements. Inadequate detailing and defective installation of windows has accounted for a significant number of premature failures of the building envelope as has been evident across Canada in past years [1, 2, 3, 4]. For example, a survey of building envelope failures in the coastal region of British Columbia indicated that 25% of the moisture problems associated with water ingress into wall assemblies were directly attributed to penetration through the windows or the window-wall interface [3]. However, the issue of building envelope failure is not one that is limited to coastal climates, although it is likely that assemblies are more vulnerable in such climates, but one that has found interest throughout North America and abroad in regions where wood frame housing is also in use such as New Zealand.

For example, the Building Research Association of New Zealand undertook research studies [5] into the weathertightness performance of the installation of windows in cladding for low-rise residential construction in New Zealand, focusing on assessing the performance limitations in weathertightness of the Window Association of New Zealand's Window Installation System for direct-fixed cladding in low-rise residential construction.

More recently, the issue of premature failure of the building envelope has been apparent in Minnesota [6], where it is reported by the building inspection division of the town of Woodbury that homes built since 1990 were experiencing major durability problems. Specifically, 276 of 670 stucco homes built in Woodbury in 1999 have failed (ca. 41%); the primary cause for failure were window leaks, lack of kickout flashing, and improper deck flashing above the wood framing [6]. Clearly the problem of water penetration at window openings persists and not only in coastal areas for which the perception is that climate loads are very severe. Although coastal climates may be severe, details that promote the entrapment of water and are not fault tolerant are likewise susceptible to premature deterioration, even in areas of apparently reduced "climate loads".The state of California has taken interest in understanding the level of risk afforded by different window installation methods and has recently reported on a test program to evaluate the performance of different window installation details [7]. The overall goal was to perform a systematic laboratory evaluation of specifically identified conventional and innovative residential building materials, assemblies, and construction practices. The laboratory evaluations were designed to provide experimental evidence of moisture loading, propensity for mold formation, and potential performance improvements associated with innovative building assemblies and construction practices.

In North America, this more recent interest has spurred a review of existing standards of the American Society for Testing and Materials (ASTM) [8] and in the Canadian context, standards of the Canadian Standards Association (CSA) for assessing the performance of windows [9]. Two studies focused on assessing the watertightness of windows and the wall-window interface were completed by Ricketts [10, 11] on behalf of Canada Mortgage and Housing Corporation (CMHC). Results indicated that although a wide range of causal factors was found to contribute to leakage activity, the principal paths for water leakage are those associated with the wall-window interface. These could occur either through the window assembly to the adjacent wall assembly or through the window to wall interface with the adjacent wall assembly. A review of the CSA A440 B rating performance [9] indicated that the criteria for water penetration control do not identify leakage associated with these leakage paths, nor is there a requirement for testing of the installed window assembly. Additionally, it was found that the selection of windows and the design of the wall-window interface do not consider local exposure conditions as may be provided by the local topography or other building features such as overhang protection.

Some recommendations that followed from these reports included [10 and 11]:

- 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

Given the nature of these recommendations there was a need to obtain useful benchmarking information on the effectiveness of different construction details at managing water intrusion over the life expectancy of the wall assembly. Such information would necessarily benefit building envelope designers, specifiers and expert practitioners. As well, considering that the deterioration of building materials within exterior walls can progress significantly before any symptoms become apparent to the owner, one should not rely solely on feedback from in-situ investigations to assess the effectiveness of the window-wall interface details. Laboratory investigations can provide an effective way to obtain reliable, insightful information regarding the effectiveness of specific wall-window interface details to manage rainwater intrusion in the wall assembly [12, 13]. Although laboratory studies are short–term tests that do not directly relate to expected long-term performance, these can be used to determine the response of wall assemblies to specific rain events in a given climatic region for which the recurrence period can be ascertained. Establishing the response of wall assemblies to simulated events for which the period of reoccurrence is known is an indirect means of determining the likely risk of water entry over a given period and for a specific region. These may also provide some measure of the expected risk to water entry and the fault tolerance of different installations methods in extreme conditions.

Hence there is widespread interest in obtaining a better understanding of the comportment of different window installation methods for a range of climate loads. Accordingly, a study was undertaken to investigate the ability of such details, typically used in wood frame low-rise wall assemblies, to manage rainwater the approach and outline of which is provided in the subsequent section.

Experimental Approach To Evaluating Water Management of Window Interface Details and Report Outline

The current test program, which is described below, has sought to evaluate different wall-window interface details and their ability to manage rainwater entry and as well, provide a means of assessing the robustness of specified design by, for example, considering what occurs when jointing products fail or construction has reduced airtightness. In addition, a test program having a specified test protocol nominally permits benchmarking "performance" of proposed interface design details. As well, the development of a "standards" approach in a laboratory setting offers potential as a precursor to a field certification protocol that is currently lacking.

What follows is a brief outline of the report that also provides a synopsis of the experimental program including the basic objective, development of the specimen configuration and test protocol. Information is given on the nature of results and practical considerations derived from them as well as a summary of the contents of the respective Appendices.

Objective

The objective of the experimental work was to compare the ability of different wall-window details to manage rainwater. Given the many different combinations of windows, wall cladding systems and related interface details that could be assessed, importance was placed on establishing specifications to which all test specimens would nominally be fabricated, including:

- Overall size of specimen (determined by maximum size permissible in test apparatus)
- Size and location of windows
- Type of windows and cladding
- Type of sheathing board, sheathing membrane and interior finish

Development of Test Specimen Configuration

Accordingly, the configuration of test specimens was established that nominally permitted comparisons among the different details when subjected to simulated wind-driven rain conditions. Wall specimens were designed to permit side-by-side comparison of two wall-window interface details (Figure 1-1). Hence, each 2440 mm by 2440 mm wall specimen included two half-specimens, each with large openings of 635-mm by 1245-mm, and in each of which was placed a 610 mm by 1220 mm window together with a set of wall-window interface details. These details include those located at the head, the jambs and the sill. One half of the specimen included a "selected practice detail", the other a "variation", which typically could be an "upgrade" of the interface detail that may or may not be common but nonetheless presented a research interest. Entry of water around either window opening was collected in troughs located beneath the respective sills. Water was also collected at the window, just beneath the sill level, on the interior side of the specimen. Thereafter, a choice was made as to which wall-window combinations to evaluate based on regional considerations of current practice and variations thereof. A summary regarding the test specimen configuration specific to the results reported are provided in Chapter 2 (Summary description of test walls) and further details are provided in the Appendix A (Detailed Description of Walls).

Development of Test Protocol and Use of the Dynamic Wind and Wall Test Facility (DWTF)

The (DWTF), previously used to subject similar specimens to simulated wind-driven rain conditions, has been shown to offer a reproducible method for subjecting specimens to simulated wind-driven rain [14]. A test protocol was developed based on previous work [14], and also took into consideration existing North American water penetration test standards such as ASTM E331 [8] and CSA A440 [15]. The protocol established parameters for spray rate (water deposition rate) on the cladding and pressure difference across the assembly [12]. Specimens were thus subjected to simulated wind-driven rain conditions for specified periods of time; these conditions replicated the main features of rain events. Rates of water entry at the subsill and behind the cladding were determined by measuring the rate of water collected from these locations as well as that portion that entered the window at the interface between the window lite and frame. The use of the facility together with the test protocol permitted comparisons of water entry results among the different wall-window interface details. Both the apparatus and protocol are described in Chapter 3 (Performance Assessment of the Wall-Window interface).

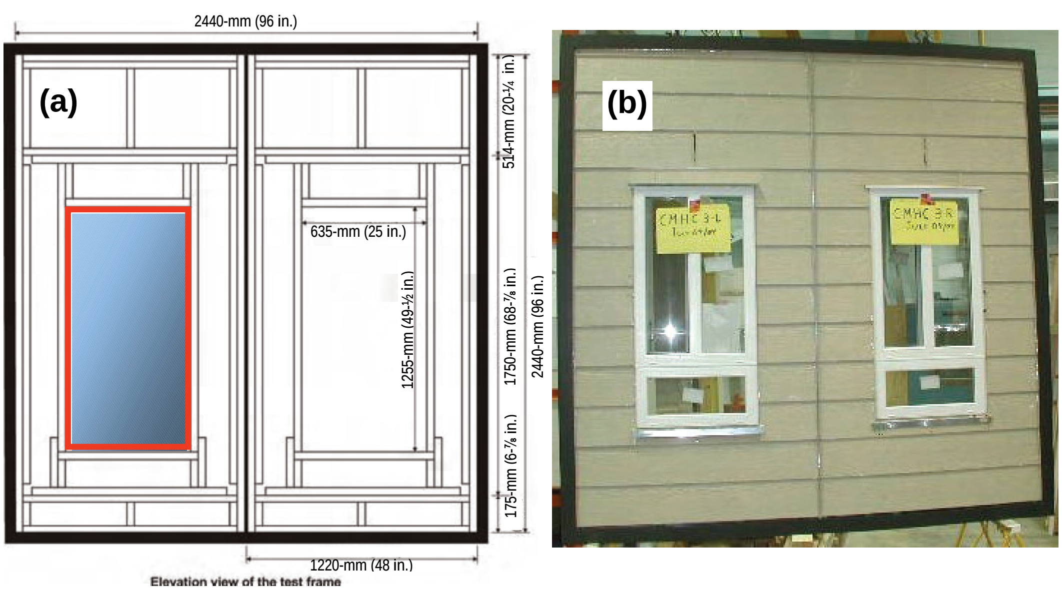

Figure 1-1: (a) schematic of front elevation of 2.44-m by 2.44-m specimen showing location of windows and wood framing studs. Detail "A" might be representative of installation details used in current practice whereas detail "V" a variation on that practice; (b) photo of completed specimen clad with hardboard siding.

Results From Watertighness Testing of Four Sets of Wall Assemblies

Chapters 4 to 7 provide the results of watertightness tests of four sets of wall-window interface details (W1 to W4) configured for:

- Fixed or combination PVC window units,

- With and without mounting flanges, and
- Installed in a rainscreen or direct applied wall assembly.

Interface details of the various approaches to window installation are given and the effectiveness of different details in managing rainwater entry is discussed in terms of the degree of drainage from the sill, the amount of water present behind the cladding, and the capacity of the installation system as a whole to manage rainwater entry. Drainage was estimated from the collection of water in purposely built troughs from which water collection rates were measured in relation to simulated wind-driven rain conditions and other test parameters affecting the degree of entry at the interface including the degree of air leakage across the test assembly and the incorporation of deficiencies in the cladding, window, and air barrier system.

Practical Considerations

Chapter 8 offers a summary of the practical considerations derived from testing the four (4) wall sets as these relate to: (1) the design and selection of components for the wall-window interface, and; (2) installation. Practical concerns that relate to design and design decisions, may, for example, take into account the selection of window details in relation to climate loads, the choice of flanged or box windows, the significance of flat sills or sills that incorporate slopes. Other considerations in respect to the selection of material may include the importance of jointing products; self adhered flashing membranes and the use of tape to help seal the interface from water entry and air leakage. These items are discussed in the context of how the choice of product may affect water management at the wall-window interface as based on the results obtained in the experimental study. Regarding installation practice, emphasis is placed on demonstrating the importance of proper and adequate care of installation of components as these necessarily relate to offering the respective installation details an adequate degree of robustness. Whether the discussion focuses on the design and selection of components or installation practice, reference is made to the experimental results that sustain the findings derived in this study.

Appendices

The report includes a number of appendices of which one is included in this report and the broader list is included in the accompanying CD as these were quite numerous and more easily accessible in electronic format.

Included in this report is “Appendix A – Detailed Description of the Wall Specimens”, in which is given both horizontal and sectional views of the various wall assemblies and as well, offers details in respect to the sequence of installation of individual components.

In the electronic version of this report two additional appendices are included, specifically:

- Appendix B, copies of papers or articles published in recent conferences are provided and cover information on selected results from tests or draw upon key findings of the work as described in this report.
- Appendix C – Presentations, in which copies of presentations are provided that were made reporting on selected results.

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Chapter 2 —
Summary Description of Test Specimens

Introduction

The following section provides a summary description of the test specimens in which some background information on regional construction practice for low-rise wood-frame homes in Canada is outlined, as is window usage and installation practice across Canada. The rationale for the selection of different details is provided, as are the nominal assembly details for each of the four test specimens. Additionally, information is given on test variations, modifications made to the assemblies that include deficiencies through which water was introduced, and methods for incorporating troughs in the assemblies for the collection of water.

A more detailed description of the respective full-scale test specimens is provided in the Appendix (Detailed Description of Walls), in which horizontal and vertical cross sectional views are given as well as photographs taken during their fabrication that illustrate the installation of individual components of the assembly.

The intent of this section, apart from offering the rationale for the selection of the components and detailed assembly of the specimens, is to provide some measure of understanding of the different variations and the manner in which these are assessed through the use of modifications to the cladding or interior finish as well as the approach adopted to collect water and retrieve information insightful to assessing their respective performance in managing rainwater entry.

Review of Wall-Window Detailing

A team of Canadian building envelope specialists provided input into what is currently best practice and typical practices of detailing the wall-window interface of wood-frame residential buildings in their respective geographical region of practice. Commercial, institutional and industrial window installation practices were not considered. Specific, though not exhaustive, information was obtained on regional practice of the West Coast, the Prairies (i.e. Alberta, Saskatchewan, Manitoba), Quebec and Atlantic Canada. This exercise highlighted significant differences in regional practices across Canada for detailing the wall-window interface and wall assembly that are given below. These differences can be related to climate severity as well as traditional practice.

- On the West Coast PVC flanged windows are predominantly used and the cladding (particularly traditional stucco) tends to be installed over a 10 to 19-mm cavity created by the installation of vertical furring strips. Best practices include installing a water-resistant membrane over the rough framing of the opening (i.e. rough opening) and a waterproof membrane on the subsill*, which is intended to drain into the cavity behind the cladding. Thermal insulation is usually not placed in the 12-15 mm (1/2 to 5/8 in.) void between the window frame and the rough opening.
- In the Prairies, PVC flanged windows are also predominantly used and the cladding is typically installed directly against the backup wall. Typically no attempt is made to drain the subsill or protect the rough opening materials against water absorption. Best current practice includes the addition of water-resistant membranes over the materials of the rough opening.
- In Quebec, box frame (non-flanged) windows are common and the trend is to install the cladding over a cavity. The gap between the window frame and the rough opening is usually filled with thermal insulation. Best current practice includes the installation of a water-resistant membrane on the material making up the rough opening and a waterproof membrane on the subsill. The subsill is intended to drain into the cavity behind the cladding.
- In the Atlantic Provinces, vinyl siding is the most common type of exterior cladding and is usually applied directly over the sheathing membrane (water resistive barrier). The use of PVC flanged windows is typical. The most commonly used sheathing membrane is polymer based. At the wall-window interface, it is customary to use construction tape to seal the sheathing membrane to the window flange at its perimeter when the window is installed before the sheathing membrane. Another practice is to place strips of sheathing membrane over the sheathing board at the sill and jambs before then installing the window. Another practice is to fold the sheathing membrane inside the rough opening prior to installing the window. Insulation fills the gap between the rough opening and the window frame; either spray-in-place polyurethane foam is used or batt insulation. The incorporation of a drip cap flashing at the window head is not a common practice.
- In Ontario, PVC flanged windows are commonly used. The siding is usually directly installed onto the sheathing membrane (water resistive barrier). Spray-in-place polyurethane foam is predominantly used to fill the gap between the rough opening and the window frame in retrofit applications; variations on the joint between the sheathing membrane and window frame are similar to the range of variations of the Atlantic Provinces.

Following a review of the information obtained from the regional experts and a review of manuals, standard guides and research studies related to window installation [1, 2, 3, 4, 5, 6, 7, 8, 9, and 10], the selection of wall-window interface details was based on:

- Current industry issues related to water management at wall-window interfaces, including:
  - Shielding the window junctions from rainwater loads using end dams at both extremities of the window head flashing,

* Reference is made throughout the text to the terms: rough opening, subsill and windowsill. Refer to the Appendix A for definitions used in this report pertaining to these terms.

  - o Allowing redundancies in the assembly for the collection and evacuation of water that may get beyond the first line of defense (i.e. cladding),
  - o Designing the details based on the assumption that the window frame was not completely watertight and would leak sooner or later, thus allowing water inside the wall assembly.

- Representation of best as well as typical regional Canadian practices. Practices varied by region and the project aimed at providing information on the comparative performance of a diverse array of practices.

Common Features of Wall Specimens Subjected to Tests

The primary features of the test specimen, as shown in Figure 2-1, were in part determined from the need to accommodate a 2.44-m by 2.44-m test frame that fits to the DWTF test apparatus. Given one of the objectives of the experimental work was to compare the ability of different wall-window interface details to manage rainwater entry, the wall specimens were designed to allow side-by-side comparison of two wall-window interface details. Each 2.44-m (8 ft) by 2.44-m (8 ft) wall specimen included two large openings, each of which accommodated a window together with a set of wall-window interface details for the head, the jambs and the sill. Hence, the size of windows (610 mm wide by 1220 mm high) permitted accommodating two sets of wall-window installation details in the wall specimen. As well, a window height of 1220 mm allowed for about 610 mm of opaque wall above the window, thereby permitting water to run off over the window head.

Using this configuration, half of the specimen included a wall-window interface detail that was a “practice of interest” or “base case” technical solution (B-side) whereas the other half a variation (V-side) on the interface details that may or may not have been common but nonetheless presented a research interest. Throughout the report, mention is made of B-side and V-side details as described above. Both horizontal and vertical details for each of these are provided when reporting on the results from performance tests on the respective wall assemblies.

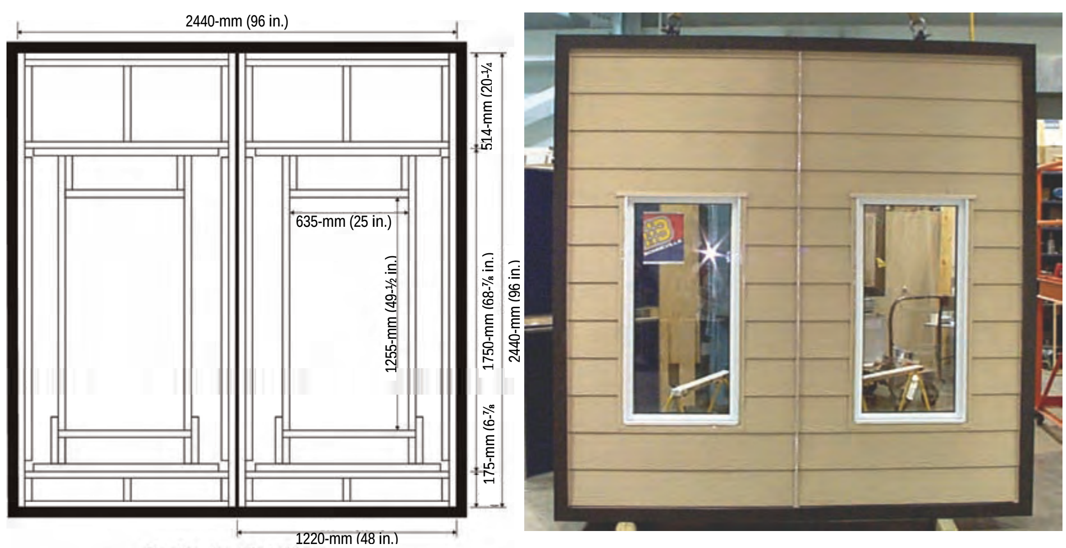


Figure 2-1: Typical layout of the wall specimen for comparative investigation of the water management response of two side-by-side wall-window interface details (left). Elevation view of the exterior cladding of the specimen completed (right).

The configuration of the walls was intended to be representative of low-rise residential construction with the exception of changes for clear sheathing materials. As such, the specimen consisted of: 38 by 138-mm (nominal 2-in. by 6-in.) wood studs, transparent acrylic sheet on the inside as the designated element of the air barrier system (ABS), two acrylic sheets installed with a 3-mm gap at mid-height of the specimen on the exterior of the wood frame acting as the sheathing board, spun-bonded polyolefin membrane or asphalt impregnated paper serving as sheathing membrane and an exterior horizontal hardboard siding installed on vertical furring strips for one set of test runs and directly against the back-up wall for a second set. Clear acrylic sheets were used instead of common building materials given that their transparency provided a means to trace water entry from behind the sheathing board. The expectation was that the location and timing of water ingress could readily be observed using this technique.

Summary Of Wall-Window Interface Variations Tested

In respect to the windows, these were selected on the basis of regional variations regarding window-framing features that might affect the detailing of the wall-window interface for water management. Various types of PVC windows were used in the project and included:

- Non-finned ("box") window frame, fabricated in Canada;
- Fixing flange integral to the frame, fabricated in Canada.

As well, both fixed and operable sliding windows were used and where operable windows were utilized, these formed the upper part of a combination operable-fixed window.

A summary of the different wall-window combinations including information on window frame and type, wall and siding types and variations of interface details is provided in Table 2-1

Table 2-1: Summary of wall-window cladding combinations selected for testing

Speci-men	Window Frame	Window Type*	Wall Type / Siding Installation	Variation (determine effect of)
W1	Box (Non-flanged)	Fixed	Rainscreen wall – clear cavity behind siding	Extra seal at junction of jambs and head of window R.O.**
W2	Flanged	Fixed	Concealed barrier wall – no clear cavity	Changes in protection of R.O.; back dam at subsill
W3		Combination - Operable sliding (upper) / Fixed (lower)	Rainscreen wall – clear cavity behind siding	Two subsill drainage methods for flat sill
W4			Concealed barrier wall – no clear cavity	Sealing sheathing membrane to window flange

*All windows were fabricated of PVC**R.O.: rough opening

Deficiencies Incorporated in the Cladding

As shown in Figure 2-2, three (3) sets of deficiencies were incorporated at the interface between the exterior cladding and the window frame and included: (1) 90-mm vertical slit (ca. 2-mm width) above window heads; (2) 90-mm missing length of sealant and backer rod located at the horizontal joint along the lower and outer corner of the window frame, at the junction of the window frame and the sill flashing, and; (3) a 90-mm long by 6-mm wide missing sealant and backer rod in a vertical joint at mid-height of the outer window jamb. Each of these locations is identified in Figure 2-2.

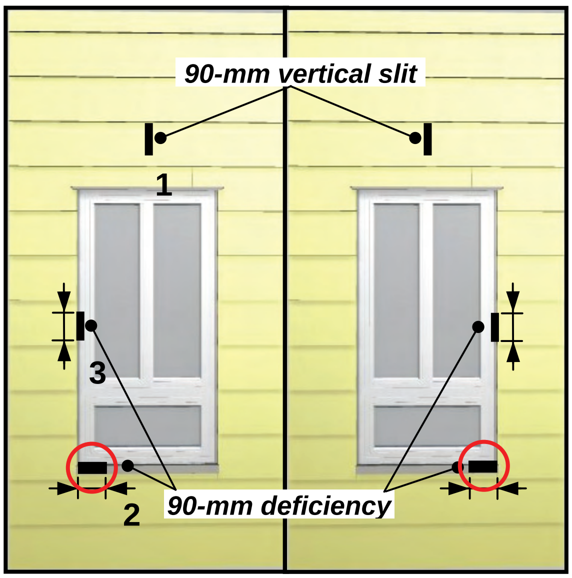


Figure 2-2: Front elevation of 2.44-m by 2.44-m specimen (cladding exterior) showing location of 90-mm deficiencies (missing sealant, backer rod at specimen face)

Water Collection Troughs

Water penetration at the window proper, entering unintended openings in the cladding and interface, or entering through deficiencies, was collected in troughs located at the base of the wall and beneath the window subsill as shown in Figure 2-3 (a). The use of troughs as shown in Figure 2-3 (b), evolved from an initial set of two troughs used in specimen W1 and W2, ultimately to the use of four troughs as depicted in the figure.

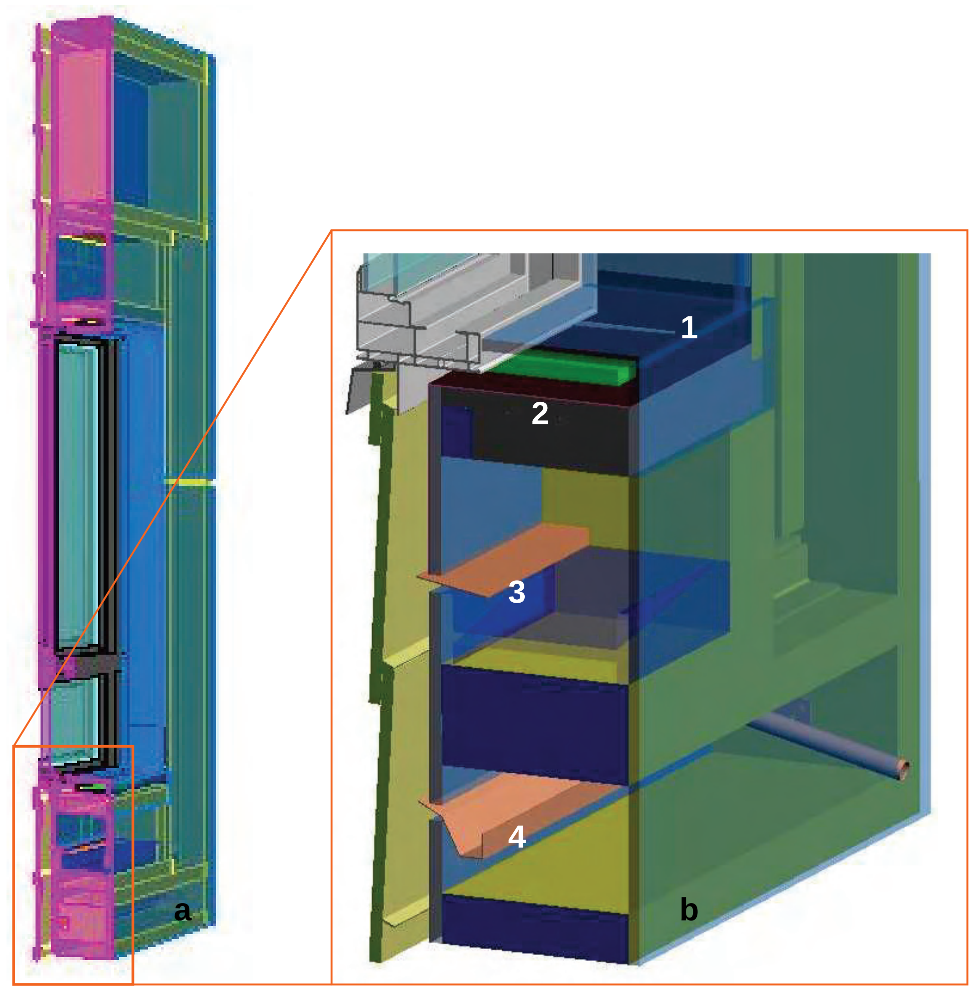


Figure 2-3: Vertical wall sections facing interior (a and b) showing location (b) of water collection troughs at (1) window on interior side of test specimen, (2) beneath window in false subsill; (3) beneath subsill for collection of water drained from subsill (see Fig. 4) and, (4) lower most trough for collection behind siding.

A trough located at (1) in Figure 2-3 (b) was intended for the collection water that would penetrate the window between the lite and window frame; a picture of such a trough affixed to the back of the specimen, is shown in Figure 2-4. Such a trough, or variations thereof, was used for all four wall specimens.

Water accumulating at the subsill could be collected in a removable trough at (2); this trough was used for subsill collection in specimens W3 and W4. A trough located beneath the subsill at (3) was intended for measuring water drainage from the subsill to the trough; this trough was present for all specimens. Water finding its way behind the cladding would be collected near the base of the wall in the trough at (4); this trough was used in specimens W3 and W4.

Figure 2-4: Collection trough used for the collection of water penetrating the window

The use of all four troughs nominally permitted quantifying the amount and rate of water entry along different paths and differentiating the significance of these paths given different test conditions.

For example in assembly W3, water entering the subsill area, as shown in Figure 2-5, would drain from the subsill down the front of the waterproof membrane and be directed into collection trough (3) beneath the subsill. As shown in the figure, water was redirected to this trough using a protruding metal plate that was placed in a horizontal opening, a narrow slit, located ca. 180-mm below the sill edge.

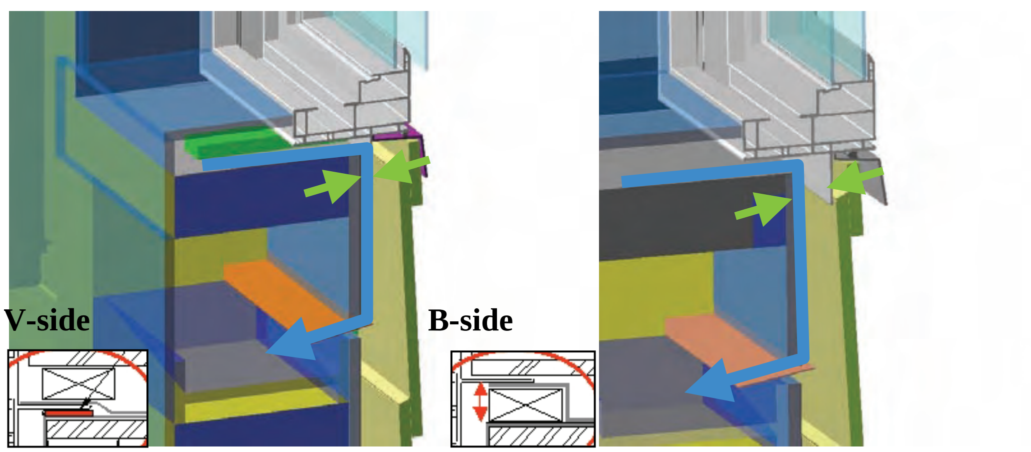


Figure 2-5: Expected direction of water drainage from subsill to collection trough (3) for variation (V-side) and base-case (B side) portions of specimen W3

A description of the method used to determine water collection rates for the respective troughs is given in Chapter 3 (see § Calibrated water collection vessels).

Wall-Window Detailing for W1

The effect of certain design features on the water management at the wall-window interface was investigated and included:

- Levels of drainage in place at the subsill of the rough opening (for box and flanged window frame installations);
- Levels of redundancy in the seals installed at the wall-window interface (for box frame window installation).

The reference assembly, representative of the Quebec region, is a pair of box frame windows installed in a wall with a clear drained cavity of 19 mm depth behind the cladding. Figure 2-6 provides the wall-window details for the "Base Case" half of the test specimen and the "Variation" half of the test specimen (Side "V"). The difference between the two details is an additional seal joining the window frame to the sheathing board, at the jambs and head of the rough opening for the "Variation" half of the test specimen. This creates an additional level of redundancy in the event that the external seal becomes deficient during its service life.

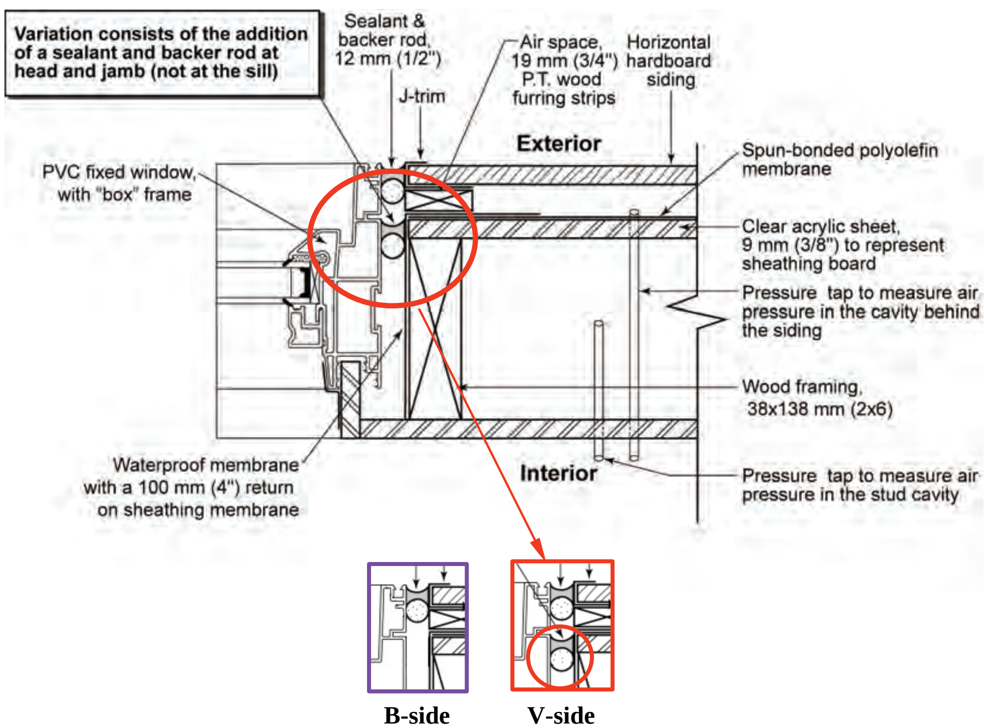


Figure 2-6: Specimen W1: horizontal section showing Base Case representing "practice of interest" and Variation on "Base Case".

Wall-Window Detailing for Specimen W2

These installation details focused on the installation of windows that included integral mounting flanges when installed in a non-rainscreen concealed barrier wall. In particular, there was interest in gaining some perspective on two different approaches to the protection of the wood-based components at the rough opening and whether a back dam at the subsill would provide an additional degree of protection against water entry.

Of the two different installation methods, the specified practice ("base-case"; "B-side") of Specimen W2 (Figure 2-7) included a back dam at the interior face of the rough flat sill, the sill being overlaid with a self-adhered bituminous-based waterproofing membrane, that was lapped over the sheathing membrane, as well as a self-adhered waterproofing membrane to seal the sheathing board to the window flange at the jambs and head. The flat sill on the V-side was not protected and the sheathing membrane was lapped under the window flange at the rough sill, and lapped over the window flange at the jambs and head.

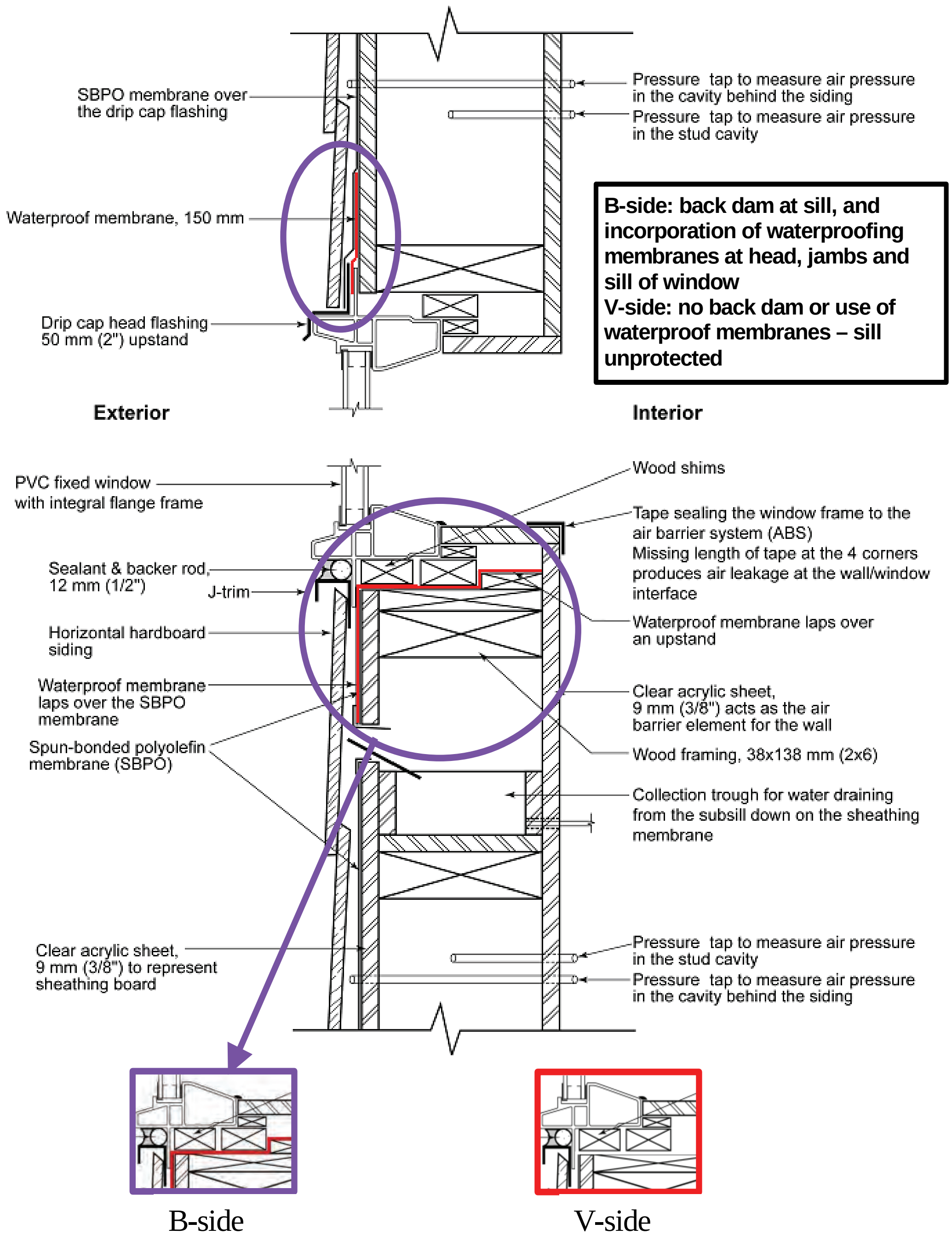


Figure 2-7: Vertical sectional views of specimen W2 at the wall-window interface showing the (a) selected practice side (B-side; base-case) and (b) Variation (V-side) specimen configurations.

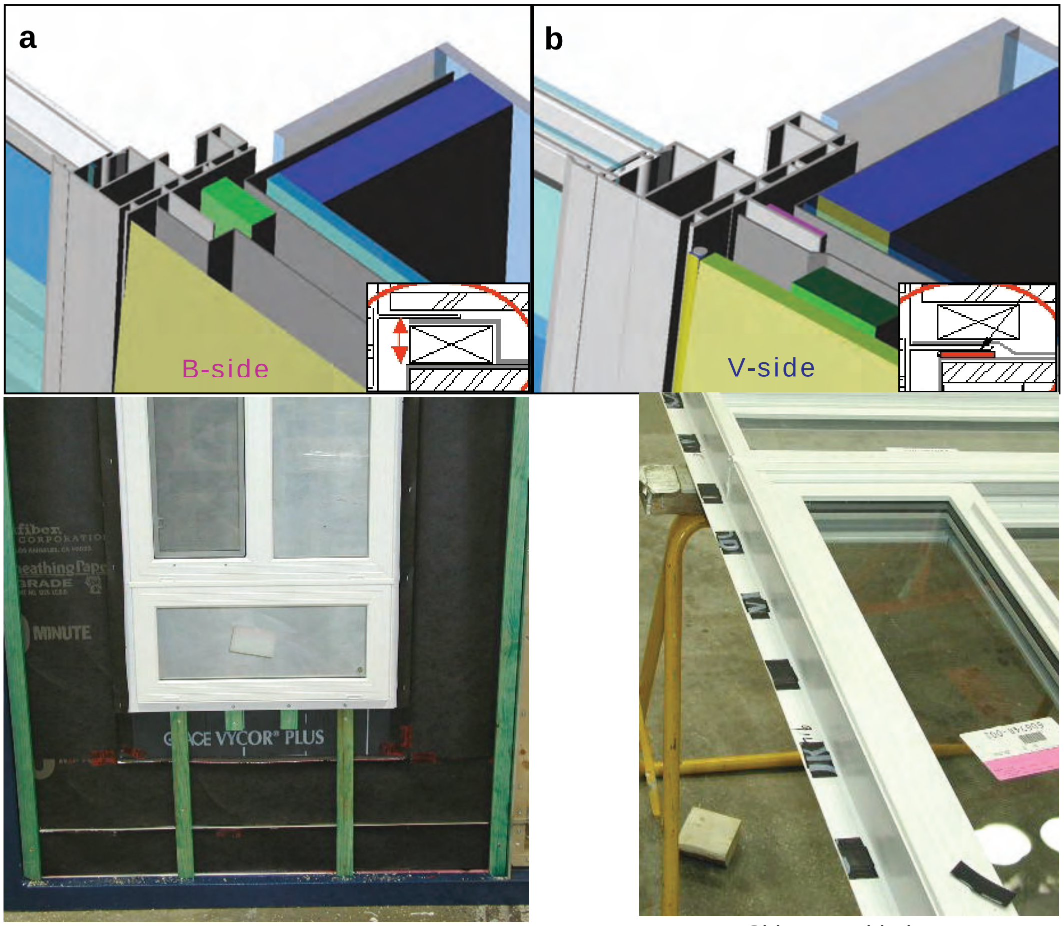
Wall-Window Detailing for Specimen W3

These installation details focused on the installation of windows that included integral mounting flanges and solutions for detailing such windows when incorporated in a rainscreen wall. The use of PVC windows having integral mounting flanges is typical in new construction practice but is increasingly being used when reconstruction of damaged facades is required. Given that for reconstruction there is also interest in applying a rainscreen wall solution, focus was placed on evaluating different variations of such installation details. The intent was to determine if, between different approaches, significant differences would be observed in respect to the water management of the respective details. In particular, there was interest in knowing the degree to which the different approaches would permit adequate drainage of the subsill area, and as well whether the mounting flanges would restrict the rate of drainage from the subsill.

Specimen W3 included PVC combination windows[†] having integral mounting flanges that were installed in a rainscreen wall incorporating a 19-mm clear cavity behind the cladding. The hardboard siding was affixed to 19-mm pressure-treated furring strips, the strips fastened to 2-in. by 6-in. (38-mm by 138-mm) wood frame studs. The rough opening at the sill was protected with strips of bituminous-based self-adhered membrane: one membrane covered the rough sill, the bottom of the rough jambs, and extended 150-mm over the sheathing membrane below the subsill. A second strip of self-adhered membrane covered the bottom 150-mm of the rough jambs and a 150 mm wide band of sheathing board. A paper-based asphalt impregnated product used for the sheathing membrane, was also used to protect the remaining portions of the rough opening extending along the height of the jambs and across the head of the window.

Of the two different installation methods, the specified practice ("base-case"; "B-side") included installation of the window flange directly on the furring strips, as shown in Figure 2-8 (a). The variation of this detail ("V-side"), shown in (b), had the window flange mounted to the protected sheathing board on the backside of which were placed shims (shown in photograph) that provided a small space (2-3-mm) between the mounting flange and the board. The shims were made of small portions of bituminous-based self-adhered membrane that had been folded over and applied to the flange at fastener locations. Following the window installation, sheathing membrane was loosely installed (no seal) over the window flange at the head and jambs (additional details regarding the sequence of installation is provided in Chapter 6 – Watertightness Tests on Specimen W3). Drip cap flashing (rigid PVC), not incorporating end-dams, was installed at window heads whereas rigid metal flashing, serving as sill drip cap, was placed at the junction of the window and cladding. The 6-mm joint between cladding and window frame was sealed with a backer rod and sealant.

[†] Horizontal sliding upper portion of 800-mm height, CSA rating B3; fixed lower portion of 400-mm height, CSA rating B4; total assembly not rated



Window installed over furring strips

Shims provided gap

Figure 2-8: Schematic of horizontal section of (a) base-case ("B-side") window and photograph (below) showing window installed on furring strips; (b) variation ("V-side") window and accompanying photograph (below) showing location of membrane shims on backside of mounting flange.

Wall-Window Detailing for Specimen W4

The focus was on the installation of windows that include integral mounting flanges when incorporated in a non-rainscreen concealed barrier wall. There was particular interest in gaining some information on different approaches to the sealing of the sheathing membrane at the perimeter of the window and whether, or not, such approaches would provide adequate protection against water entry should there not be a seal applied at the window perimeter between the cladding and window frame.

In both cases the sheathing membrane was installed after the installation of the window, as is often the case in current wood frame construction practice. However on the B-side, the sheathing membrane was sealed to the window frame at its perimeter using 50-mm wide strips of self-adhered elastomeric membrane whereas on the V-side, the sheathing membrane was lapped over the window frame flange without additional measures to ensure a tight seal.

Horizontal sectional views for the B- and V-sides showing the wall-window interface at the jamb of specimen W4 are provided in Figure 2-9.

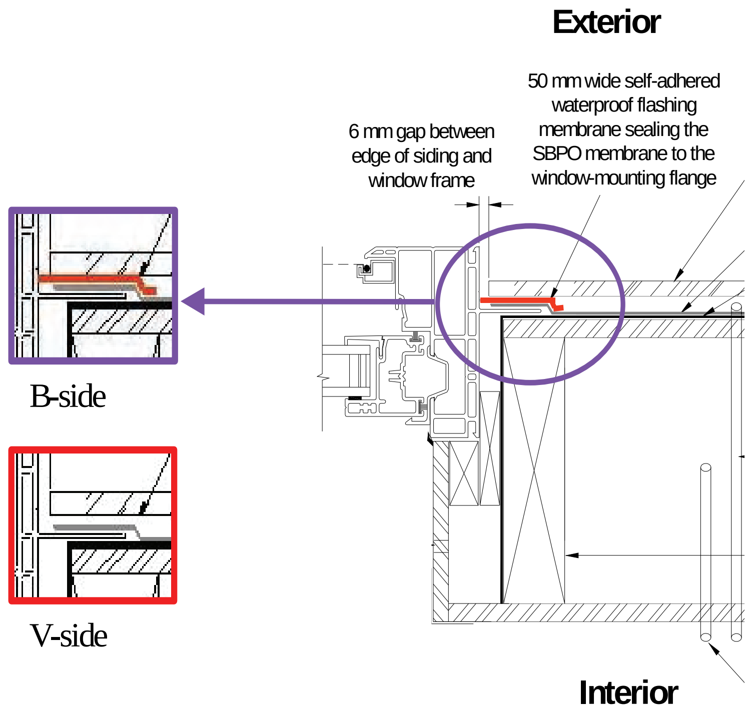


Figure 2-9: Specimen W4: Horizontal Section view of Wall-Window Interface at Jamb – specified practice (B-side, Base-case) and Variation on this practice, V-side Configuration

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Chapter 3 — Approach to Performance Assessment

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 assembly 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 significant*:

(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 and as well the location of the openings on 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/h 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. Assuming that the greatest ΔP occurs at the cladding, and in same plane as the openings, 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, at the opening and that can also be related to the 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, in part, 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.

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* It should be noted here that neither stack effect or ventilation pressure is considered in this approach. With regard to stack effect the focus is on: a) low-rise buildings where stack effects are small and b) wind-driven rain that 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.

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 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 the approach presently outlined, two types of tests were considered: water penetration tests and water entry tests. The difference between them is that when testing for water penetration the walls are "pristine" in that there are no intended deficiencies whereas water entry tests were 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 of water to form. However, when testing typical deficiencies, the deposition rate becomes important. In assessing the watertightness performance of a wall, the test protocol should reflect the effect of ΔP as well as deposition rate.

The following 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 increments in pressure differential, ΔP, proceed 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, the climatology of driving rain wind pressure was produced [7]. The standard contains tables and contour maps giving the 5 year return periods for residential and 1 and 10 year Driving Rain Wind Pressure (DRWP) for commercial at 1.8 mm/h or rain intensity threshold (agreed to be the minimum rain intensity at which a film of water will form on glass). Windows are selected by comparing the test rating with expected driving rain wind pressure for a given climate. For residential windows Vancouver has a 1 in 5 DRWP of 160 Pa while for Calgary the expected 5-year return DRWP is 220 Pa. Consequently the requirement for windows in Calgary, a substantially drier place than Vancouver in respect to total annual rainfall, is nonetheless 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-m^2) (5.0 US Gal/ft^2-h) and in both test methods the procedure specifies a pressure difference of 137 Pa across the wall assembly.

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

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

where:

DRF is a driving rain factor related to the diameter of the size of raindrops (s/m); The DRF is inversely proportional to the raindrop size.

θ is the angle of the wind to the outward wall normal

U is the hourly average wind speed (m/s)

R is the hourly rainfall intensity (mm/m^2-h)

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 study, aerodynamic factors were set to 0.9, generally the highest intensity experienced near the top corners of a typical building. Other approaches based on computational fluid dynamic simulations exist and the results are in general agreement with the approach used here although the studies do shed some light on the effects of short duration events and the granularity of weather data [10, 11].

Effects of Driving Rain Wind Pressure (DRWP)

One purpose of water penetration trials is to test the watertightness performance of pristine walls i.e. walls having small deficiencies that would likely be completely occluded by water in a significant rain event. Specimens are assumed to be in pristine condition, i.e. these are built and tested as designed and are expected to perform as intended. There should be no large openings through which water may intrude, although water intrusion may occur through small openings or through the materials themselves. As was previously discussed, water penetration through small openings is considered more sensitive to variations in pressure. In the instance where a pristine wall specimen is tested, the pressure difference, ΔP, is assumed to be the most important parameter.

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

$$DRWP = 1/2\ \rho \bullet U^2\ (Pa) \tag{2}$$

where:

ρ is the density of air, assumed to be 1.2 kg/m^3
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 wall but the force exerted on the wall by the wind. The actual pressure difference across an exterior wall 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 study the DWRP was considered to be the same as the pressure difference across the wall.

The driving rain wind pressures (DRWP) for Canadian cites are given by Welsh, Skinner, and Morris [7]. These values have been computed for rainfall rate thresholds of 1.8, 3, and 5.1 mm/h and for return periods of 1 in 2, 5, 10, and 30 years respectively. Figure 3-1 shows the hourly DRWPs for 23 Canadian locations for different return periods at the 1.8 mm/h threshold level. Table 3-1 provides a location key code for cities charted in Figure 3-1. The basis for selecting the pressure steps was the rainfall rate of 1.8 mm/h. This threshold was recommended because the 1.8 mm/h rate corresponded to that of ordinarily experienced rainfall during most storms and the consensus was that this rate would allow for sufficient water availability for water leakage to be possible [7]†.

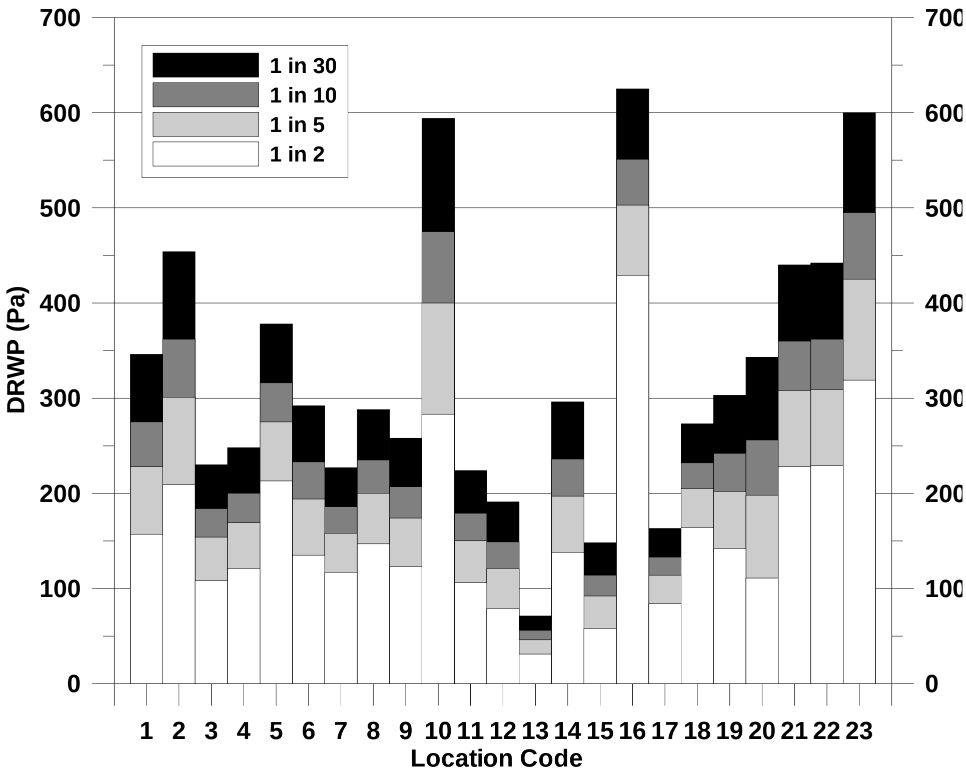

Figure 3-1: A sample of hourly Driving Rain Wind Pressures for several typical Canadian locations for various return periods at the 1.8 mm/h rain intensity threshold

Table 3-1: Key code for locations cited in Figures 1 and 3

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

From Figure 3-1 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

† Pages 8 and 9 [7]

(e.g. Port Aux Basques, NF; Sandspit, BC) for a 1 in 2 return period. For occurrences of 1 in 2 all locations are covered at 500 Pa. For 1 in 5 return periods the 300 Pa pressure level seems to be an adequate test pressure for all Canadian locations except the Coastal locations, 500 Pa being an upper limit for the 1 in 5 return period. The 700 Pa pressure levels 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).

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. Higher rainfall intensities tend to be associated with lower wind speeds hence rainfall events that are a combination of maximum DRWP and higher spray rates 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 3-2 shows the hourly average wind-driven rain for 9 Canadian locations for different return periods. From the figure a spray of 0.2 L/(min-m^2) would seem to be too low to cover most of the normal in-service conditions, 1 in 2, for locations surveyed whereas a rate of 0.4 L/(min-m^2) would seem to be adequate. For extreme in-service conditions a rate of 0.8 L/(min-m^2) will cover most Canadian locations except for 1 in 30 events. A rate of 1.6 L/(min-m^2) will cover most locations of interest in Canada. A spray rate of 3.4 L/(min-m^2) is unlikely in Canada for hourly rates for a 1 in 30 return period. However this rate would probably be sufficient if North American locations are considered, the higher spray rates being more likely in the southern United States (Wilmington, NC. and Miami FL. for example).

Duration and Intensity

Only hourly DRWP and hourly rainfall intensity events have been considered so far. 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

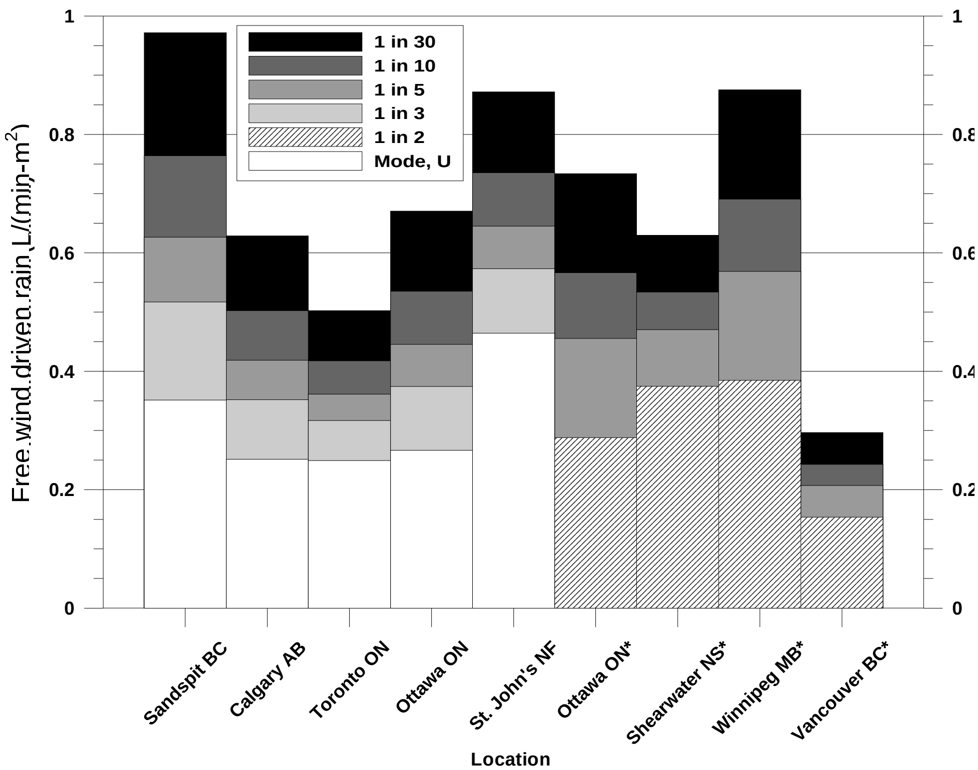

Figure 3-2: A sample of spray rates in L/(min-m^2) based on hourly driving rain averages for several typical Canadian locations for various return periods. Choi's method [10] was used to calculate the free WDR except for locations followed by an asterisk where Straube's method [9] was used.

been extracted from *The Guide to the Use of the Wind Load Provisions of ANSI A58.1*‡ [12] and are given in Table 3-2. 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 in Table 3-2.

Table 3-2: 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 rainfall intensities falling vertically onto a level surface to shorter averaging periods have been suggested by Choi, [10] using the following relationship:

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

where:

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

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

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

‡ Graph on page 106 [12]

For example, given an averaging time of 5 minutes:

$\{R(5)\} / \{R(60)\} = [60/5]^{0.42} = \mathbf{2.84}$. 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 3-3 shows the 5-minute average DRWPs for 23 locations for different return periods at the 1.8-mm/h threshold. For normal service conditions, 1 in 2, 150 Pa suggested by the hourly wind pressures moves up to 200 Pa. At 300 Pa the threshold seems to cover all areas examined except coastal areas with exceptions (Calgary at 350 Pa) for in-service conditions. The 500 Pa DRWP level covers all Canadian locations except Coastal regions for longer return periods, such as 1 in 5 and 1 in 10. At 800 Pa all Canadian locations are covered for longer duration extreme events.

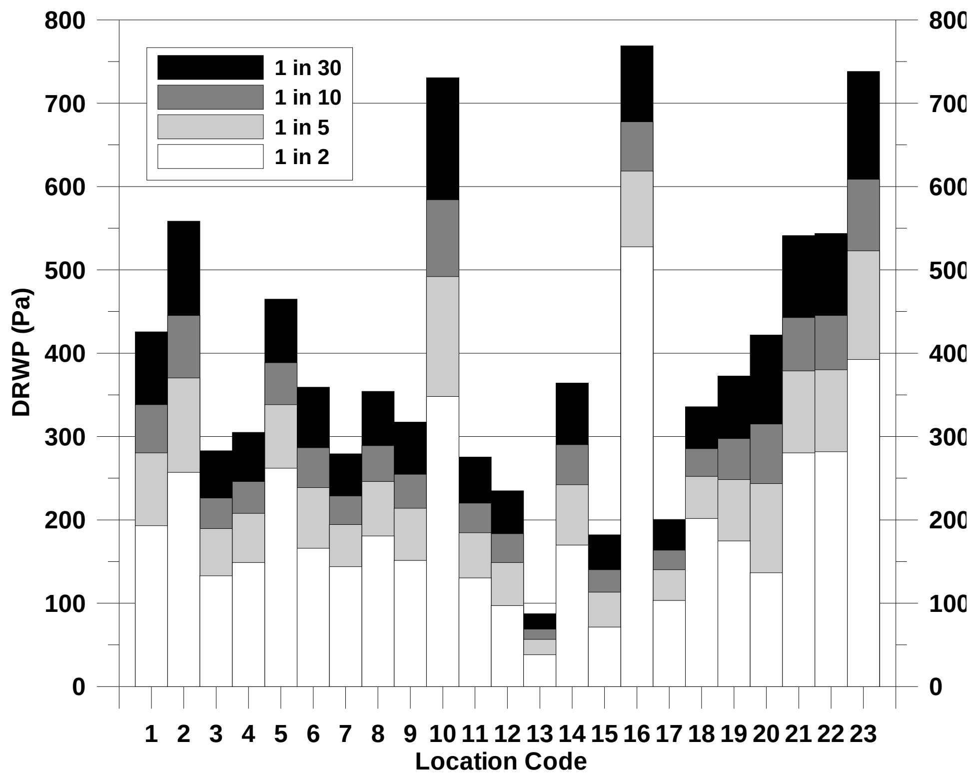

Figure 3-3: A sample of Driving Rain Wind Pressures averaged over 5 minutes for several typical Canadian locations for various return periods at the 1.8-mm/h rain intensity threshold

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

Figure 3-4 shows the 5-minute average wind-driven rain for 9 Canadian locations for different return periods. The effect of using 5-minute averaging times is that a rate of 0.8 L/(min-m^2) is the lowest threshold for normal in-service conditions except relatively exposed coastal regions.

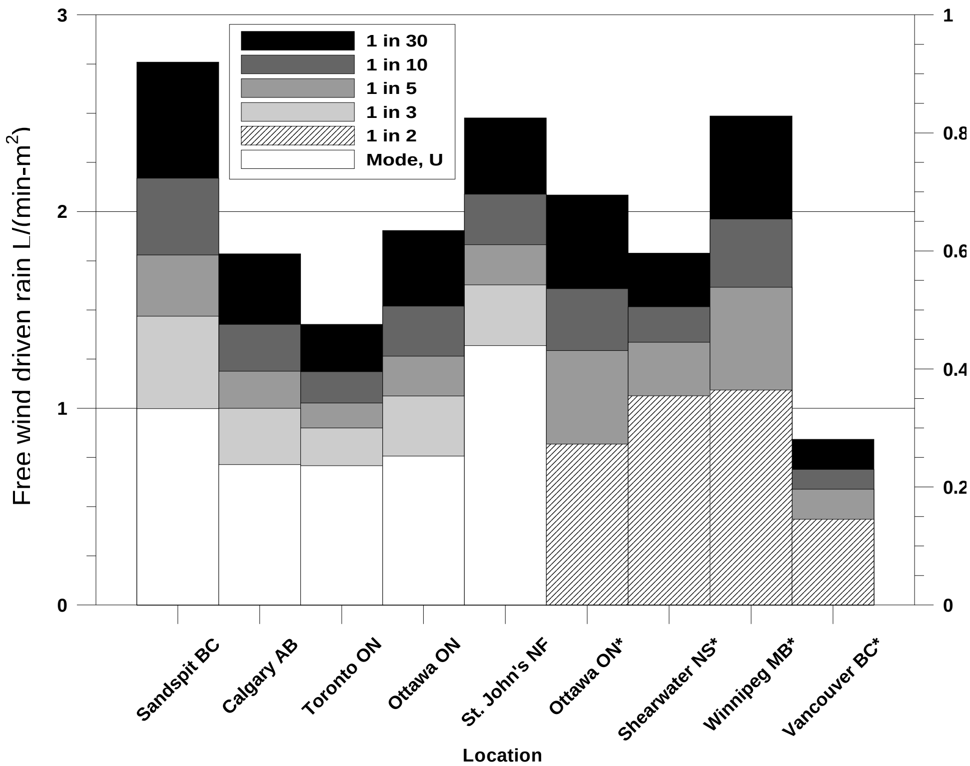

Figure 3-4: A sample of spray rates in L/(min-m^2) based on driving rain with a 5-minute averaging time for several typical Canadian locations for various return periods. Choi's method [10] was used to calculate the free WDR except for locations followed by an asterisk where Straube's [9] method was used.

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

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 was adapted to this study. Both the pressure differences (ΔP) - significant for pristine walls - and the water deposition rate - significant when larger deficiencies are present were varied. Two levels of service were also considered: extreme events and expected or normal conditions. For extreme events a level of 1 in 5 (at least) may be suggested for wall systems. For normal in-service conditions, events having a return period of 1 in 2 years should be considered (i.e. 50 % 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 3-3 as levels. The levels represent the combination of water deposition in the form of wind-driven rain and driving-rain wind pressure.

Level 1 for example represents a very low load on the cladding in terms of low driving rain intensities and low driving-rain wind pressures. Level 5 on the other hand represents the opposite end of the spectrum. North American locations can be thus categorized with respect to these two climate parameters.

Table 3-3: 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						

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 locations except coasts for 1 in 10.
700 Pa	Covers all except windiest (St John's, Port Aux Basques, Sandspit) 1 in 30.
1000 Pa	Covers the most extreme locations.

While the suggested spray rates could be:

0.4 L/(min-m^2) – Normal in-service conditions for hourly averages

0.8 L/(min-m^2) – Normal in-service conditions for 5 min events and most extreme in service conditions for hourly averages except 1 in 30.

1.6 L/(min-m^2) – Covers all hourly average extreme events; covers some locations to 1 in 10 except windiest and Winnipeg for 5 min events

3.4 L/(min-m^2) – Covers all hourly and 5 min events.

Summary of Test Protocol

The test protocol used in this study was adapted from the MEWS protocol, described in Lacasse et al. [2], and a review of wind-driven rain loads as might be experienced across Canada as described in the previous sections and in greater detail in [13].

Hence, following the guidance provided in the previous section in respect to the range of pressure differentials and water spray rates to which test specimens should be subjected, the test protocol was completed in three stages as described below:

Stage	Description
1.	Characterization of air leakage and pressure equalization potential of the wall assembly
2.	Water penetration without deficiency in static mode at specified spray rates of 0.8, 1.6 and 3.4 L/(min-m^2) with pressure variations from 0 to 700 Pa and nominal air barrier system (ABS) leakage of 0.3 and 0.8 L/(s-m^2) at 75 Pa
3.	Water entry with deficiency in static mode at spray rates varying from 0.8 to 3.4 L/(min-m^2) and pressure variations from 0 to 300 Pa and nominal ABS leakage of 0.3 and 0.8 L/(s-m^2) at 75 Pa

The intent of the initial test sequence (Stage 1) was to determine the air leakage characteristics of the specimen installed in the test apparatus such that subsequent tests on different specimens could nominally be conducted at or near the same air leakage rate. As well, information could be obtained on pressure distributions across the wall at or near water collection points and this was useful to assess the relative risk to water entry based on nominal pressure differences at those key locations.

The designated air barrier system (ABS) was the interior finish (clear acyclic sheathing panel) and the trim or joinery with the window frame at the interior finish. The degree of leakage at this plane was regulated by introducing a series of openings at the interface between the window frame and the designated ABS. The desired nominal leakage through the ABS was achieved by providing openings along the wall-window interface at the specimen's interior surface as was necessary to obtain two nominal leakage levels of 0.3 and 0.8 L/(s-m^2). The nominal values for air leakage are those achieved at 75 Pa and derived from air leakage tests over which pressure differences across the specimens ranged from 50 to 700 Pa. Both halves of the test specimen were tested at the same time and the ABS air leakage was assumed to be distributed uniformly between either half.

The next test stage (Stage 2) permitted testing the proposed wall-window interface details to various extreme conditions of wind-driven rain where specimens were assumed to be in unflawed condition and to function as intended (i.e. tested as built in the laboratory and assumed without deficiencies). Water penetration through small unintentional openings, consistent with specimens built of unflawed conditions, tends to be more sensitive to variations in pressure. Consequently the focus in this stage was on the variation of pressure (0 to 700 Pa) with high rates of water spray (0.8, 1.6 and 3.4 L/(min-m^2)).

The ability of the wall-window interface details to manage water given a deficiency along one of the interfaces was assessed in Stage 3. Deficiencies, purposely introduced in the specimens consisted, for example, of openings such as missing lengths of caulking (sealant). Details in respect to the incorporation of these deficiencies in the cladding are provided in Chapter 2[§]. Such deficiencies might, for example, simulate the loss in bond or rupture of the seal brought about by the effects of aging, or indeed be representative of inadequate installation practice. In this situation, the sensitivity of water penetration through relatively large deficiencies to the rate of water impinging on the façade can be evaluated. It is supposed that water entry through larger openings is more sensitive to variations in spray rate than pressure differential. Hence, pressure differentials across the assembly were in this stage restricted to 300 Pa. Deficiencies introduced in the first line of defence against water entry (i.e. cladding) necessarily provided a path for water entry behind the cladding (in this case hardboard siding) that permitted evaluating the ability of the wall-window interface detail, and adjoining elements of the wall, to collect and evacuate water to the exterior of the assembly. Such an approach also permitted replicating inadequate construction installation and helped determine the fault tolerance of the detail in respect to water management.

Water was applied in a cascade over the specimen from its uppermost extremity in an attempt to ensure a uniform water deposition load over the exterior face of the specimen (referred to as cascade rate). The range of values used for both spray rate and air pressure difference exceeded the average values that might be expected on a low-rise building in Canada [13]. However, windows may be subjected to 500 Pa pressure difference in extreme cases (e.g. St. John's, NF) and testing at these level permitted assessing the threshold at which components no longer function adequately. As well, testing at different levels of simulated wind-driven rain may provide a basis from which performance expectations at lower levels can be extrapolated.

Air barrier system (ABS) leakage was regulated by introducing a series of openings at the interface between the window frame and the ABS. The desired nominal leakage through the designated ABS was achieved by applying and lengthening the openings along the interface as was necessary to obtain two nominal leakage levels of 0.3 and 0.8 L/(s-m^2). The nominal values for air leakage were those achieved at 75 Pa and derived from air leakage tests over which pressure differences across the specimens ranged from 50 to 700 Pa.

The water management ability of the specimens and wall-window detailing was investigated in two sets of conditions, as described above in Stages 2 and 3 of the test protocol. The specimens in Stage 2 were evaluated in what were assumed to be unflawed condition, as built in the laboratory. These specimens necessarily include unintentional deficiencies. Thereafter in Stage 3, deficiencies were introduced in the first line of defence against water entry; e.g., a length of sealant and backer rod at the wall-window interface or in the cladding assembly above the window was removed to simulate, e.g., the effect of aging of the seal or inadequate installation. This provided a path for water entry behind the siding and permitted evaluating the ability of the second line of defence at the wall-window interface detail to collect and evacuate water to the exterior of the assembly. Collection of water that either penetrated windows or behind the cladding, or was collected at the subsill, was achieved with various troughs, a detailed description of which is given in Chapter 2[**].

[§] see: Chapter 2 – Summary Description of Test Specimens: Deficiencies Incorporated in the Cladding
[**] see: Chapter 2 – Summary Description of Test Specimens: Water Collection Troughs

Description of Test Apparatus and Related Instrumentation – Dynamic Wind and Wall Test Facility (DWTF)

Overview

The facility used to conduct the tests was the Dynamic Wind and Wall Test Facility (DWTF) a more detailed description of which can be found in [2]. This facility, depicted in Figure 3-5, is capable of subjecting full-scale test specimens (nominal size 2.44-m by 2.44-m) to static or dynamic pressure fluctuations of over 2 kPa and spray rates of up to 8 L/(min-m^2).

A secondary air blower (not shown) generates a steady-state component of air pressure; this was the method used to subject wall specimens to the specified pressure differentials in this study. The air leakage characteristics of the specimens could be determined from measuring air leakage at set pressure differences using the same blower. Air leakage measurements were made using a laminar flow element (Meriam; model 50MW20).

The apparatus also contains a pressure regulated water spray system that simulates the action of rain deposition on the cladding surface. Different water deposition rates are achieved by regulating the pressure level along specific lines of spray nozzles. Water spray rates can be regulated between 0.8 and 8 L/(min-m^2). Water can be applied to the front face of the specimen in either full-spray format in which water is deposited evenly across the front of the specimen, or by cascading water from the top of the specimen in a continuous sheet of water; the latter method of cascading water was the one primarily used in this study (rate of water deposition is referred to as cascade rate, and is expressed in L/(min-m^2)).

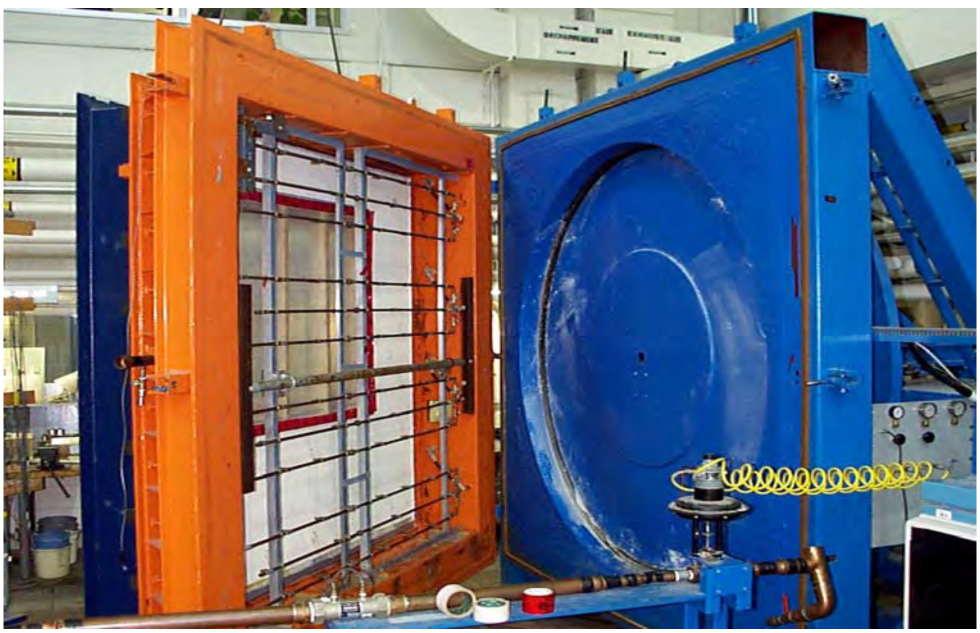

Figure 3-5: Inside view of apparatus showing orange test frame door onto which is affixed test specimen. This same frame contains water spray rack; individual water lines can be seen in photo. When test frame is closed and sealed to test rig, exterior cladding faces inside of apparatus (on right, coloured blue).

A schematic of the test set up (on right) and 2.44 by 2.44-m test specimen (on left) is shown in Figure 3-6. During actual testing, the apparatus is closed so that the specimen faces the water spray rack at (1). Water is sprayed onto the cladding surface (2) and thereafter cascades down onto the specimen and over the components. Water entering inadvertent or purposely made deficiencies is collected in troughs, e.g. beneath the window at the subsill (3) or at the base of the wall (4). This water is then diverted to collection vessels (5) in which are placed water level sensors that permit determining the rate of water collection for any given trough.

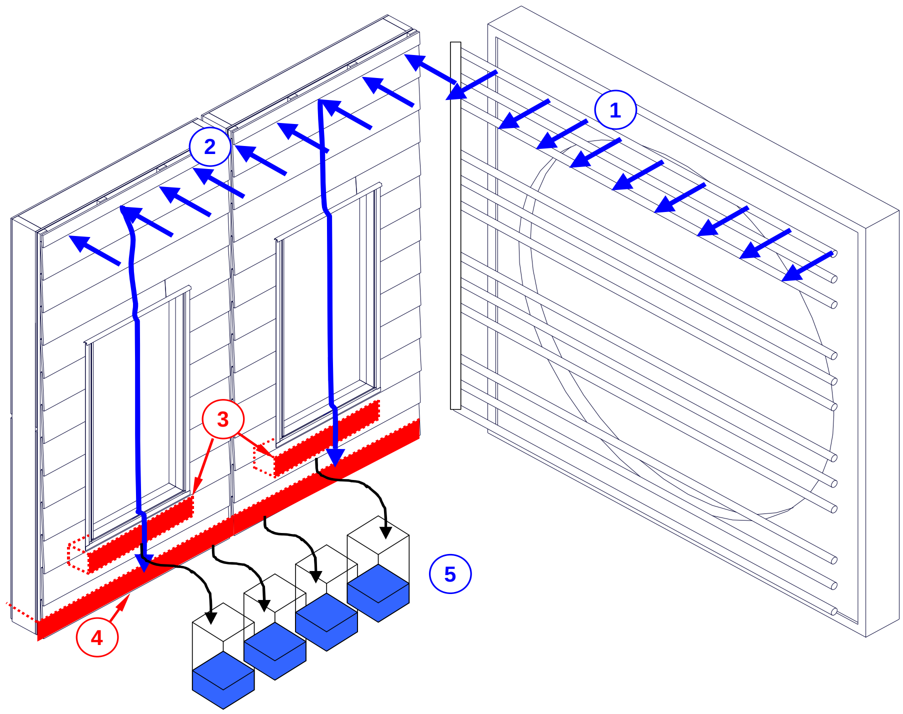

Figure 3-6: Schematic of apparatus (on right) and 2.44 by 2.44-m test specimen (on left). Water at (1) is sprayed onto cladding surface (2) and water cascades down onto specimen. Water entering deficiencies collected in troughs beneath window at subsill (3) or at base of wall (4). Water then diverted to calibrated collection vessels (5).

Calibrated water collection vessels

A description of the location of the different troughs is provided in Chapter 2 (see: § Water Collection Troughs). The water that accumulates in these troughs is diverted by means of plastic tubing, to the respective collection vessels, shown in Figure 3-7. In each vessel, a capacitance level sensor (Intempco; model: LTX20-RP), provided information on the level of water in the vessel, to the nearest 0.1 mm, that was recorded to the DWTF's data acquisition system. For each of these vessels, the change in water level obtained from sensor readings was calibrated, from weight measurements, to a change in volume in the vessel. This volume change was continuously monitored such that the rate of volume change in the vessel was, in turn, attributed to the rate of water collection to the respective trough and was recorded in terms of ml/min.

Pressure sensors and pressure sensor locations in specimen

Several pressure sensors (MKS Instruments; model: 225AD-0001AAB) were used to determine the pressure levels in different parts of the wall assembly such that pressure profiles across sections of the assembly could be determined and the extent of pressure differences across the specimen estimated. The locations of pressure taps, for both halves of the specimen, are provided in Figure 3-8 and pressure tap designations for the respective tap locations are given in Table 3-1.

Pressures, in Pascal (accurate to 1 Pa), were measured continuously over the course of a test and values were recorded to the data acquisition system.

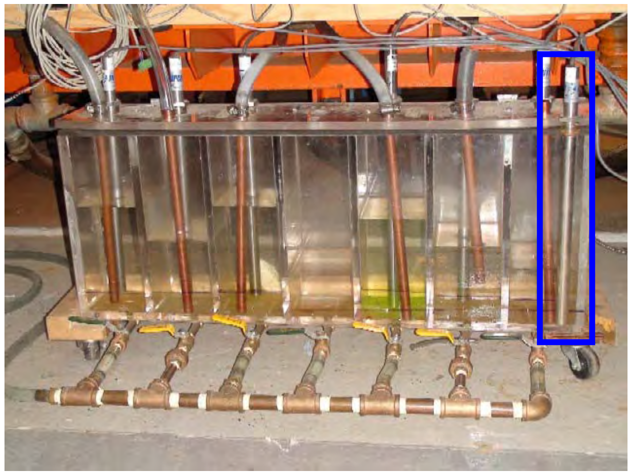

Figure 3-7: Bank of seven (7) calibrated water collection vessels; level sensor is shown on right of photo

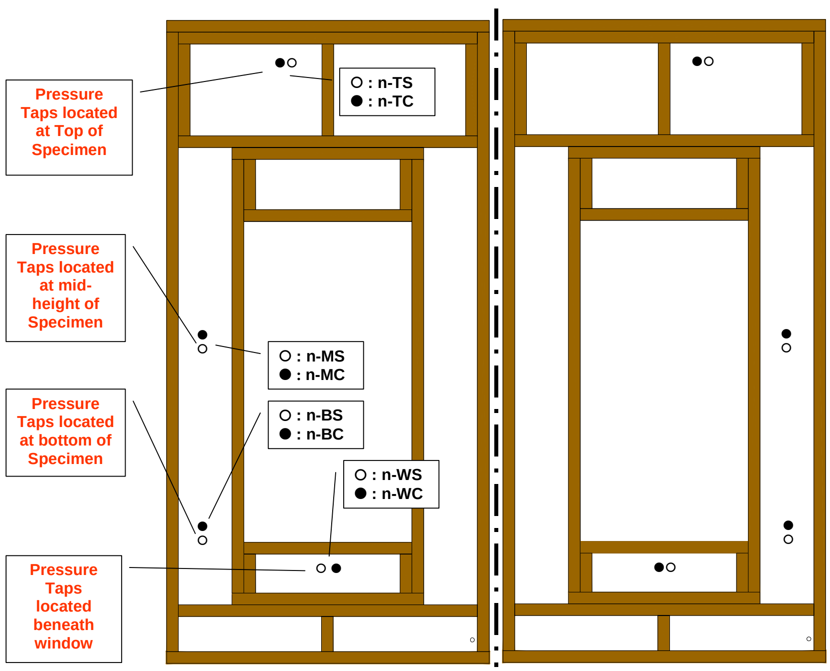

Figure 3-8: Location of pressure taps on both halves of specimen. The pressure tap designation includes the specimen number (n) and respective tap locations provided in Table 3-1.

Table 3-4: Designation of pressure taps located in specimens

Designation	Location in wall assembly
n-TS	At top of wall assembly in stud cavity
n-TC	At top of wall assembly in space behind cladding
n-MS	At mid-height of wall assembly in stud cavity
n-MC	At mid-height of wall assembly in space behind cladding
n-BS	At bottom of wall assembly in stud cavity
n-BC	At bottom of wall assembly in space behind cladding

n: refers to specimen number

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Chapter 4 —
Results from Watertightness Tests on Specimen W1

Introduction and Objective of Test Program

Focus in this Chapter is made on the specifications for and watertightness test results derived from specimen W1. For this specimen, installation details were representative of boxed framed windows and solutions for detailing such windows when incorporated in a rainscreen wall. As previously stated, the overall intent was to determine if, between different approaches, significant differences would be observed in respect to the water management of the respective details. The primary purpose of this evaluation was to determine whether a secondary seal at the junction between the window frame and the sheathing membrane provided benefits as a redundant sealing component when imperfections were present in the primary seal. As well, there was interest in assessing the degree to which the different approaches would permit adequate drainage of the subsill.

A summary of the basic components incorporated in specimen W1 is given in Table 4-1. Configurations details are offered in the subsequent section.

Table 4-1: Summary of all wall-window cladding combinations selected for testing with emphasis on Specimen W1

Speci-men	Window Frame	Window Type*	Wall Type / Siding Installation	Variation (determine effect of)
W1	**Box** **(No flange)**	**Fixed**	**Rainscreen wall – clear cavity behind siding**	**Extra seal at junction of jambs and head of window R.O.****
W2	Flanged	Fixed	Concealed barrier wall – no clear cavity	Changes in protection of R.O.; back dam at subsill
W2		Combination - Operable sliding (upper) / Fixed (lower)	Rainscreen wall – clear cavity behind siding	Two subsill drainage methods for flat sill
W4			Concealed barrier wall – no clear cavity	Sealing sheathing membrane to window flange

*All windows were fabricated of PVC; **R.O. : rough opening

Description of Test Specimen W1

Specimen W1 included non-operable PVC boxed frame windows (CSA A440 rating B7), installed in a rainscreen wall assembly, and a wall assembly having a clear cavity (19-mm) behind the cladding. The hardboard siding was affixed to pressure treated wood strapping and in turn, to 2-in. by 6-in. (38-mm by 152-mm) wood frame studs. A polyolefin-based spun-bonded textile product was used as sheathing membrane.

Both halves of Specimen W1 included a sloped sill (6 % slope) with a flat back (no up stand), the subsill being overlaid with a self-adhered bituminous-based waterproofing membrane that was lapped over the sheathing membrane. The subsill was open to the drainage cavity behind the siding. As well, the same self-adhered waterproofing membrane component was used to cover all exposed faces of the rough opening.

The interface between the cladding and the window jambs and sill (not at head) on both sides of the specimen incorporated a J-trim (40-mm) and a sealant and backer rod. Hence, the sealant and backer rod formed a 12-mm exterior joint between the window frame and J-trim at the jambs and sill. The variation (V-side) of Specimen W1 included an extra sealant and backer rod at the jambs and head of the junction between the window frame and the waterproof membranes, in the plane of the sheathing board and the sheathing membrane (see Figure 4-1and Figure 4-2). The purpose of this extra sealant was to provide continuity of the second line of defence against water entry (i.e. the sheathing membrane) while still allowing full drainage of the subsill. It was also thought of as a form of two-stage joint providing backup to the external bead of sealant in case of failure of the exterior bead. Both sides incorporated a drip cap head flashing (no end dams) made of preformed PVC.

Horizontal sectional views for the B- and V-sides of specimen W1 are provided in Figure 4-1; the differences between approaches adopted for detailing the wall-window interface at the jamb are evident in this figure. A full vertical sectional view of the V-side of the specimen is provided in Figure 4-2 in which the differences in respect to the addition of a caulked joint at the head and jambs are illustrated.

A complete set of configuration details for specimen W1 are provided in Appendix A (Description of the Construction of Specimen W1). Key elements of W1 construction include:

- Horizontal hardboard siding with J-trim at the WWI jambs and subsill
- A 12-mm gap between the J-trim and the jambs and sill of the window frame, filled with backer rod and sealant
- Drip cap head flashing extending 25-mm beyond the window frame
- Clear cavity behind the siding formed by 19-mm wood furring strips
- Fixed PVC window with non-flanged (box) frame
- Sloped and open subsill draining into the air space behind the cladding
- Waterproof membrane protecting the entire frame of the rough opening
- Spun-bonded polyolefin sheathing membrane

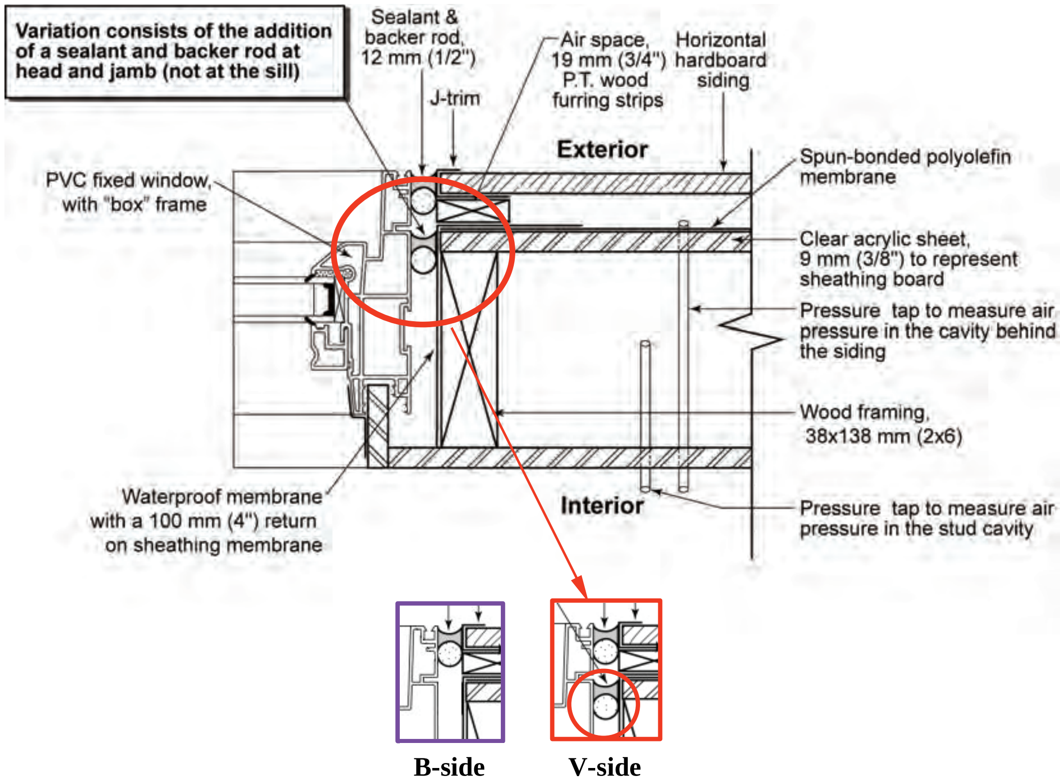


Figure 4-1: Horizontal sectional views of Specimen W1 showing the wall-window interface at the jamb for the Variation (V-side) and selected practice (B-side; base-case) specimen configurations. The difference between the B- and V-sides is that the B-side has a single joint seal whereas the V-side included an additional sealant and backer rod at the interface at the head and jamb (not sill) of the window.

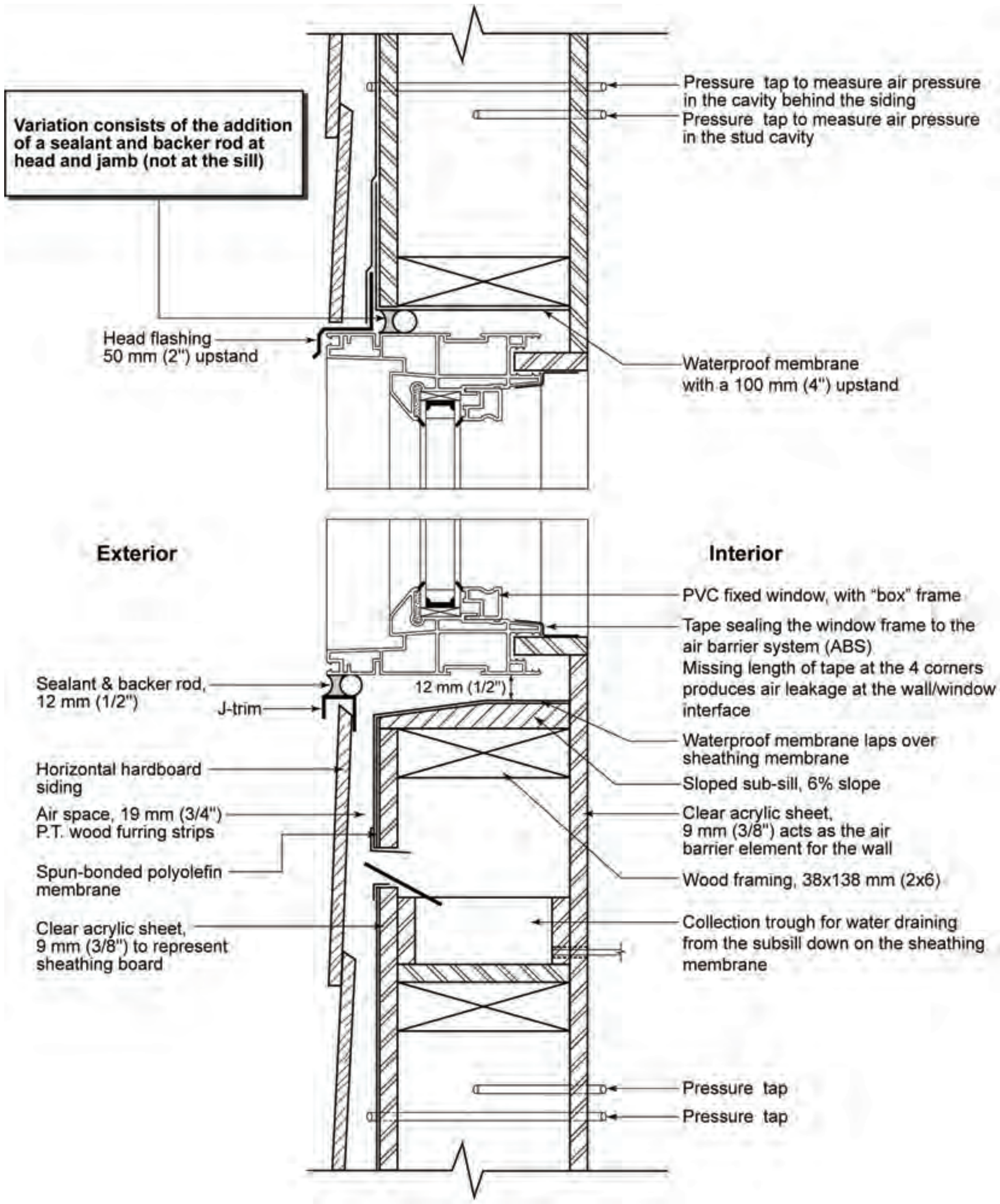


Figure 4-2: Vertical sectional views of specimen W1 at the wall-window interface showing the Variation (V-side) specimen configurations.

Summary of Test Protocol

In total, 16 water penetration or entry tests were performed for specimen W1 a summary of which is provided in Table 4-2. Test trials were performed at a nominal ABS leakage (03 ABS or 08 ABS leakage) and a constant rate of water application (0.8, 1.6, 3.4 L/(min-m^2)), and consisted of up to 7 tests at each of 7 different pressure differentials. During each test, pressure and level sensor data was collected every second over a period of approximately 15 minutes. Instances where tests were not conducted to the expected test levels have been noted as such.

Test trials were either performed in the “as-built” condition (i.e. nominally neither damaged nor altered), or including deficiencies to the wall assembly that attempt to reproduce the effects of changes in the characteristics of an assembly that could occur with aging or improper installation and could have an adverse effect on watertightness of the assembly. In respect to deficiencies, three (3) sets were incorporated at the interface between the exterior cladding and the window frame and included: (1) 90-mm vertical slit (ca. 2-mm width) above window head; (2) 90-mm missing length of sealant and backer rod located at the horizontal joint along the lower and outer corner of the window frame, at the junction of the window frame and the sill flashing, and; (3) a 90-mm long by 6 mm wide missing sealant and backer rod in a vertical joint at mid-height of the outer window jamb. Each of these locations is identified in Figure 4-3.

As well, for each test trial, the type, size and location of the deficiency is given and modifications are noted in Table 4-2 as applicable to the respective test Trial. For example, in Test trial 2, undertaken at 03 ABS (nominal ABS leakage of 0.3 L/(s-m^2)), the deficiency is described as a 6-mm by 90-mm bead of caulking removed from the joint located at the bottom outside corner of the window frame. A small graphic is included to help situate the general location of the deficiency in respect to half of the specimen.

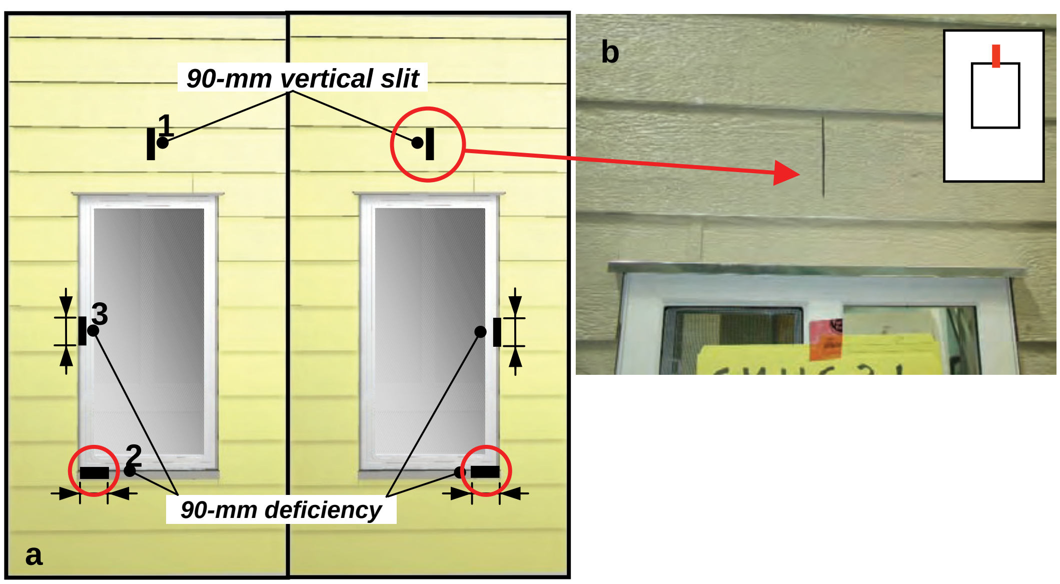
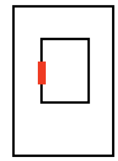
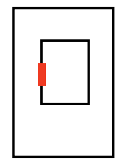
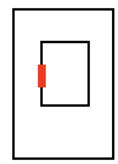
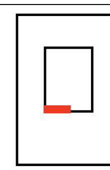
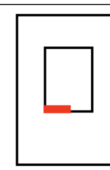
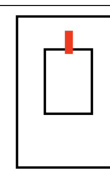


Figure 4-3: (a) Schematic of front elevation of 2.44-m by 2.44-m specimen (cladding exterior) showing nominal location of 90-mm deficiencies (missing sealant, backer rod at specimen face); (b) picture of 90-mm slit located (deficiency 1) above window of Specimen W1 – icon relates to test trial description (Trial 3).

Table 4-2: Summary of Water Penetration or Entry Tests for Test Specimen W1

Condition	ABS	Cascade Rates (L/min-m^2)	Description
As-built (No modifications or deficiencies)	03	0.8 1.6 3.4	Original Configuration, (No modifications or deficiencies)
As-built (No modifications or deficiencies)	08	0.8** 1.6** 3.4**	Original Configuration, (No modifications or deficiencies)
Trial 1a* Deficiencies*	08	3.4	6-mm by 90-mm caulking removed from joint at siding J-trim window jamb and siding – backer rod in place 
Trial 1b* Deficiencies	08	3.4	6-mm by 90 mm caulking removed from joint and backer rod removed along jamb 
Trial 1c* Deficiencies	08	3.4	6-mm by 90 mm caulking removed from joint and backer rod removed along jamb and sealant replaced less a 3-mm strip adjacent to window frame to simulate an adhesive failure of a sealant without backer rod 
Trial 2 Deficiencies	03	0.8 1.6 3.4	6-mm by 90-mm caulking removed from sill joint at bottom outside corner of window frame 
Trial 2** Deficiencies	08	0.8** 1.6** 3.4**	6-mm by 90-mm caulking removed from sill joint at bottom outside corner of window frame 
Trial 3 * Deficiencies and modifications	03	3.4**	All caulking and backer rod re-installed, 2-mm by 60-mm vertical slit cut in cladding panel above window 

***** No water collection measured in trough 3
** Wall only tested up to 300 Pa applied pressure differential

Variation in Data Collection Methods and Techniques

Each half of Specimen W1 was instrumented with 6 pressure taps and 2 collection trays, a summary description of which is provided below.

Pressure Sensors

Pressure taps connected to pressure sensors permitted measuring pressure differentials at different locations in the test specimen as shown in Figure 4-4 and Figure 4-5 respectively. Figure 4-4 provides a schematic of the location of pressure taps in proximity to the window jamb, such as locations at approximately the mid-height of the specimen, given as 1-MS and -MC in Figure 4-5. Such taps measured the pressure differential in either the stud cavity (1-MS) or the cavity behind the siding (1-MC).

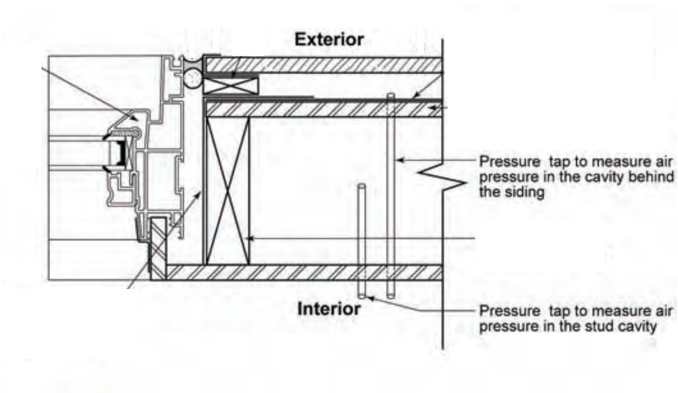


Figure 4-4: Pressure tap locations within wall section

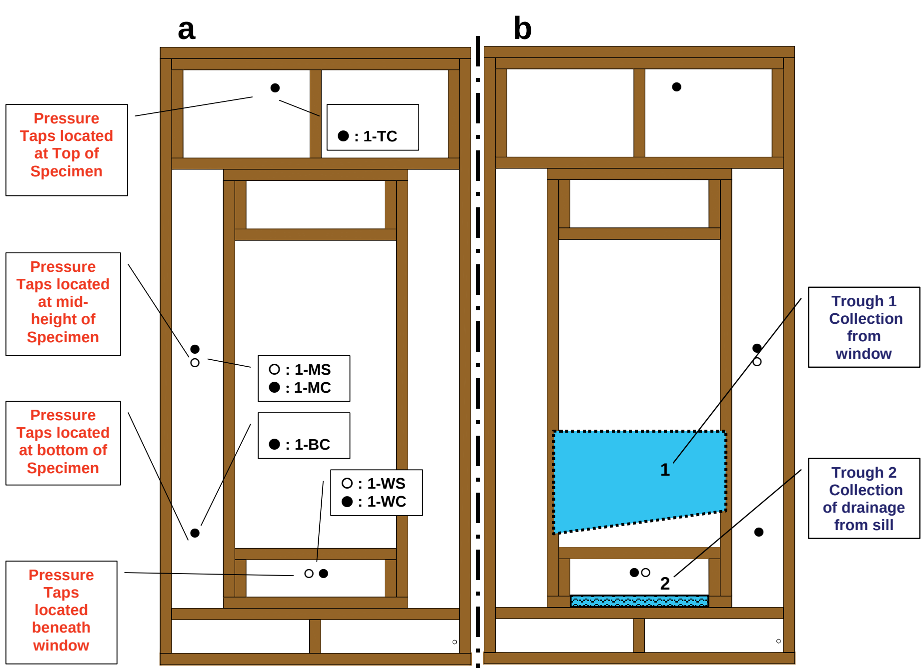


Figure 4-5: (a) Location of pressure taps along height of half-specimen and designated tap labels; (b) location of collection troughs 1 and 2 of half-specimen. Both sides of specimen had troughs located as shown in (b); the blue colour designates the trough and delineates the trough size

Water Collection Troughs

Water penetration at the window proper, entering unintended openings in the cladding and interface, or entering through deficiencies, was collected in troughs located as shown in Figure 4-5 and Figure 4-6. A trough located at (1) in Figure 4-5(b) and Figure 4-6, permitted collecting water that would penetrate the window between the lite and window frame; water accumulating beneath the window at the subsill was intended to be collected in a trough located at (2) which measured water drainage from the subsill to the trough. Figure 4-6 provides a schematic of the expected path for water collection from the collection points to the respective troughs.

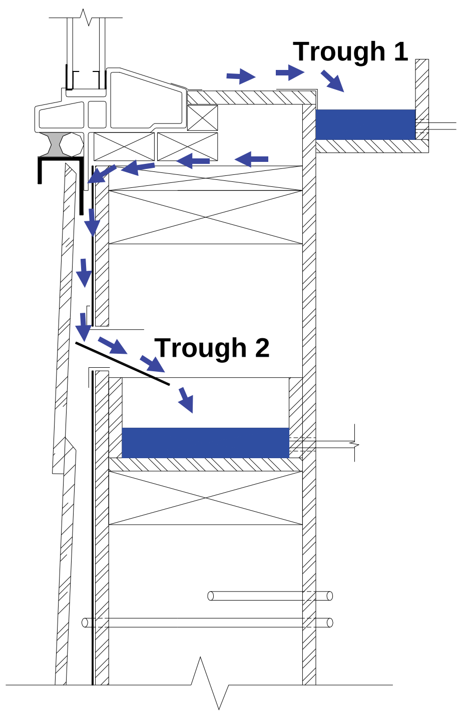


Figure 4-6: Expected direction of water drainage from subsill to collection Trough (2) for both the variation (V-side) and base-case (B side) portions of specimen W1

Results from Watertightness Performance Tests – Specimen W1

Results of watertightness performance tests for specimen W1 are reported in terms of (1) air leakage of the assembly; (2) pressure drops across different components of the assembly and; (3) water penetration of and water entry to and through the assembly.

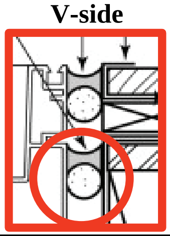
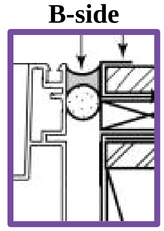
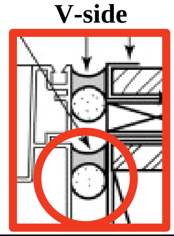
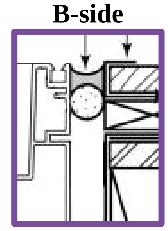
ABS Leakage

For Specimen W1, the air leakage of the wall as built (nominally 03 ABS) was approximately 0.5 L/(s-m^2) at 75 Pa pressure differential. The air leakage at 08 ABS was also slightly higher than nominal, at approximately 1.0 L/(s-m^2). The intent of such tests was to ensure that specimens were tested in nominally the same conditions in respect to air leakage across the assembly; results suggest that at the lower ABS leakage (03 ABS), W1 was approximately 66% greater than the target leakage whereas at the higher ABS leakage (08 ABS), it was ca. 25% greater.

Pressure Drops

A large pressure drop across the siding assembly would provide a driving force for water entry to the next layer of the assembly, i.e., the sheathing membrane and its junction with the window frame. Pressure drops in specimen W1 across the cladding as well as to the stud cavity are provided in Table 4-3. The pressure drops were relatively small compared to results obtained from the other wall tests. During tests on the specimen in the as-built condition, the percentage of drop in pressure measured in the clear cavity behind the cladding and stud cavity were consistently below 1.6% at 03 ABS, and 3.0% at 08 ABS. There were no large differences in respect to pressure drop between the V-side and the B-side of the wall. The pressure drop did increase slightly (1-2%) with an increased air barrier system leakage. This indicates that the test specimen was generally well vented, allowing airflow from one layer to the next resulting in most of the pressure drop occurring across the designated air barrier system on the interior side of the specimen. The designated ABS was constructed using an assembly of acrylic sheathing panels and the ABS continuity was maintained with the appropriate application of tape used at key locations of the interface.

Table 4-3: Stud and Cavity Pressure Drops – Test specimen in as-built condition

Pressure tap Location	03 ABS		08 ABS	
	V-side	B-side	V-side	B-side
				
1-MS	<0.3%	<1.5%	<1.4%	~3.0%
1-TC	<0.5%	<0.4%	<2.5%	~1.0%
1-MC	<1.6%	<1.0%	<2.5%	~3.0%
1-BC	<0.8%	<0.3%	<2.5%	~1.5%
1-WS	~2.3%	~1.5%	~10%	~5.5%
1-WC	N/A	<0.2%	~1.5%	~2.0%

Values for pressure drop derived from readings taken at location 1-WC, located in the area beneath the subsill in proximity to trough 2 (see Figure 4-5a) but directly behind the cladding, was also small (< 2%) for both halves of the test specimen, and these values were consistent with the other values obtained at pressure taps labelled 1-xC (Table 4-3), that is, for taps measuring pressure differentials in the cavity behind the cladding. The pressure drop at tap 1-WS (pressure differential at trough 2) was the greatest pressure drop measured in W1, approximately 10% on the V-side of the wall and 5.5% on the B-side at the higher air leakage rate. These values tend to suggest that one could expect a larger driving force for water entry into the wall assembly on the V side of the wall as compared to the B-side of Specimen W1.

Removing a 90-mm length of sealant and backer rod at the joint between the cladding and J-trim at the window frame and creating an opening (narrow slit) in one horizontal course of cladding above the window caused no significant changes in the values of pressure drop for Specimen W1 at either air barrier system leakage rates.

Water Management Without Deficiency

Water Collection to Trough 1 (Window)

Water entered through the windows onto the interior windowsill starting at 300 Pa pressure differential and reached approximately 200 ml/min at the highest pressure differential (Figure 4-7). The windows on both sides of the wall performed similarly. Results from water entry at the window were only obtained for a 03 ABS leakage condition. The tests undertaken at a 08 ABS leakage condition were only conducted up to a pressure differential of 300 Pa and at this pressure difference, only small amounts of water (< 12 ml/min) entered through the window frame.

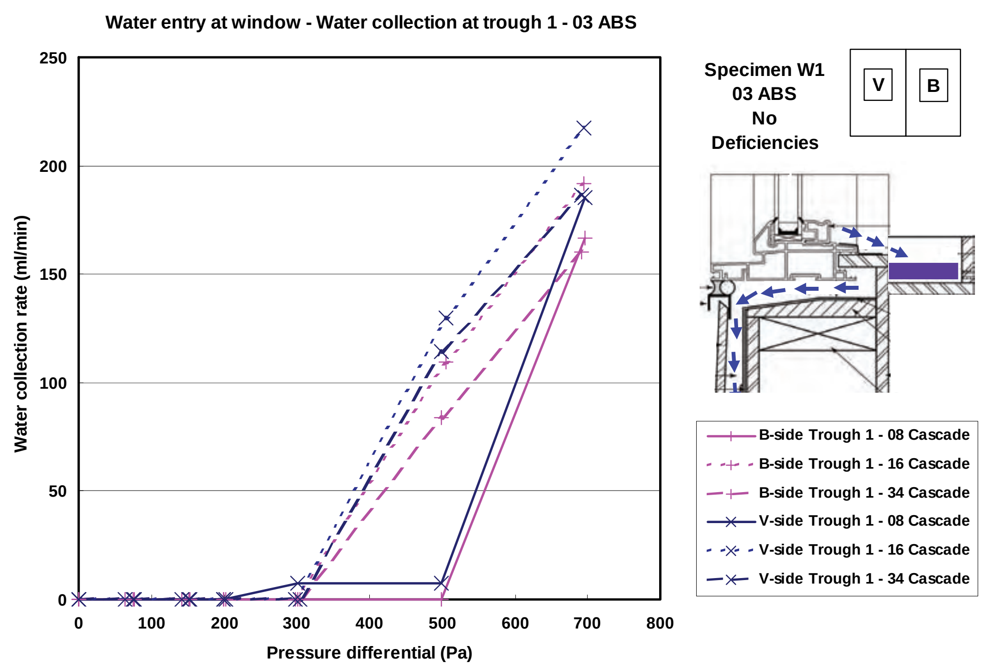


Figure 4-7: Specimen W1 – as built: Collection at Trough 1, 03 ABS

Finally, the results also provided a means of identifying the performance level at which windows may no longer perform in regards to resisting water entry. As shown in Table 4-4, water was collected at the window in trough 1 at the 300 and 500 Pa pressure levels. As well, water was collected in all instances at the 500 Pa level and only in some instances at the 300 Pa level. Hence, the level of performance evidently lies between these two pressures, but likely closer to the 300 Pa level. The CSA rated window performance for this set of windows was B7 (700 Pa), indicating that the windows performed well below their rated performance level.

Table 4-4: Water collection rates in ml/min. at trough 1 (window) for details B- and V-sides at an ABS leakage of 0.3 L/(s-m^2), in relation to nominal cascade rate and pressure difference.

Nominal pressure across specimen (Pa)	**Nominal cascade rate 0.8 L/(min-m^2)**		**Nominal cascade rate 1.6 L/(min-m^2)**		**Nominal cascade rate 3.4 L/(min-m^2)**	
	Window "V" Collection rate ml/min	Window "B" Collection rate ml/min	Window "V" Collection rate ml/min	Window "B" Collection rate ml/min	Window "V" Collection rate ml/min	Window "B" Collection rate ml/min
0	Nil	Nil	Nil	Nil	<1	<1
75	<1	<1	<1	<1	<1	Nil
150	<1	<1	<1	Nil	<1	<1
200	Nil	Nil	n/a	n/a	Nil	<1
300	17	Nil	16	<1	18	<1
500	144	98	179	37	114	103
700	270	168	282	106	216	190

Water collection to Trough 2 (apparent drainage from the sub-sill)

At a 03 ABS leakage condition, as provided in Figure 4-8, water was collected to trough 2 on the B-side only at the two lowest cascade rates (0.8 and 1.6 L/(min-m^2)). By contrast, water was collected to trough 2 on the V-side only at the highest cascade rate (3.4 L/(min-m^2)). When water did enter, rates were small (ca. 10-20 ml/min) and relatively constant across the full range of applied pressure differentials.

At the higher ABS leakage, given in Figure 4-9, water was only collected in trough 2 on the V-side of the wall. Water collection rates were again small, up to a maximum of 11 ml/min, and did not vary with change in pressure differential. It should be noted that water entry rates below 5 ml/min were discarded as these represented the limit to which the apparatus could accurately estimate the rates of water collection from the respective troughs.

In an as built condition, this cladding assembly and its junctions with the window appeared to readily minimize water entry to the next layer of the specimen assembly (i.e. the sheathing membrane).

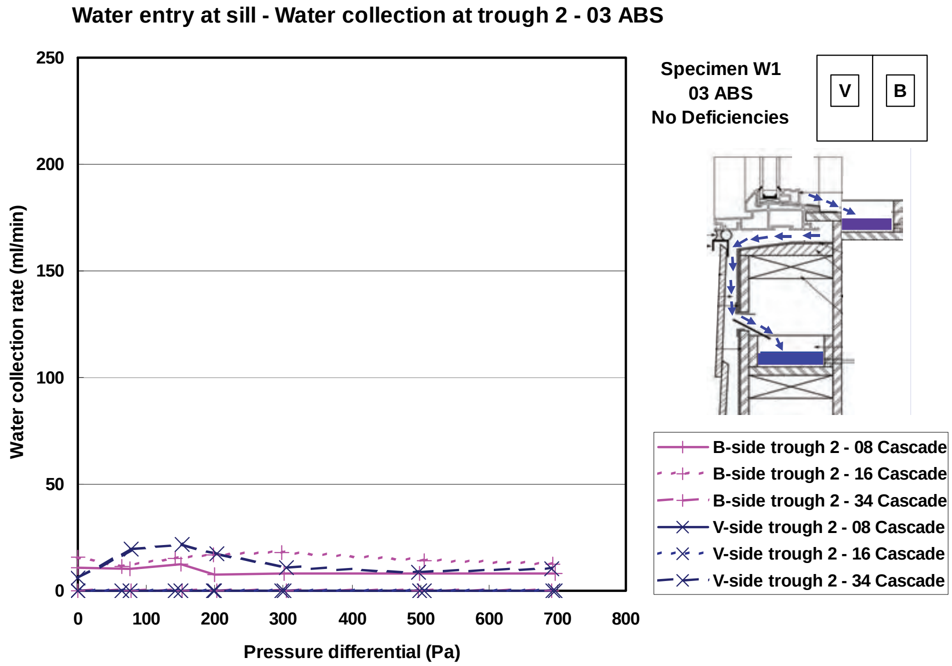


Figure 4-8: Specimen W1 – as built: Collection at trough 2, 03 ABS

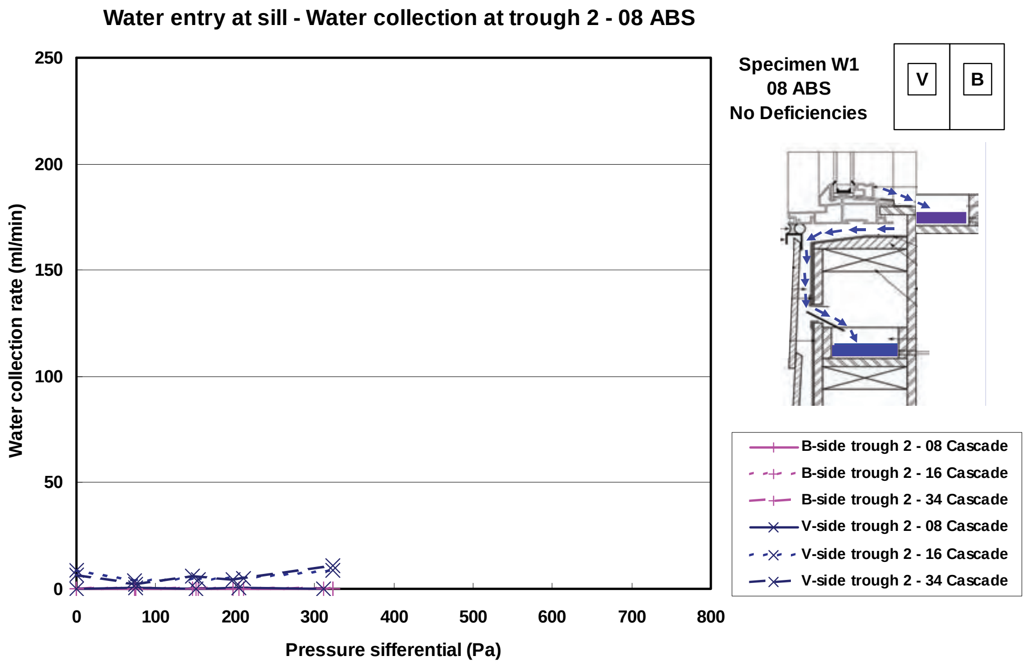


Figure 4-9: Specimen W1 – as built: Collection at trough 2, 08 ABS

Water Management with Deficiency – Trial 2

Several modifications were made to the specimen, as described in Table 4-2, aiming to provide points of water entry into the assembly, that would emulate either the loss of key parts of a component from the aging process, or the lack a sealant due to inadequate installation practices. The evaluation of specimens in which were incorporated different size openings placed in specified locations permitted assessing the vulnerability of the assembly to such deficiencies in relation to the pattern and intensity of water deposition on the face of the specimen and the corresponding pressure differences to which these were subjected.

The deficiency introduced in test Trial 2 (i.e. 90-mm of sealant and backer rod removed at the lower outer corner of the window frame at the interface between the J-trim and cladding) was the only deficiency to result in any increase in water entry to trough 2. It should be noted that this deficiency was also the only one that was aligned horizontally; all other deficiencies were made in a vertical direction.

At a 03 ABS leakage condition (Figure 4-10), the water collection to trough 2 on both sides of Specimen W1 increased significantly when compared to the corresponding results derived from the as-built case; up to 180 ml/min on the B-side of the wall, and up to 100 ml/min on the V-side. This suggests that between ca. 1.5 and 2.7 L of water flowed over a 600-mm wide band of sheathing membrane over a 15 min. period.

Water collection rates showed a dependency on pressure differential and cascade rate; the largest water rates occurring at the highest applied pressure differential, and the highest cascade rates.

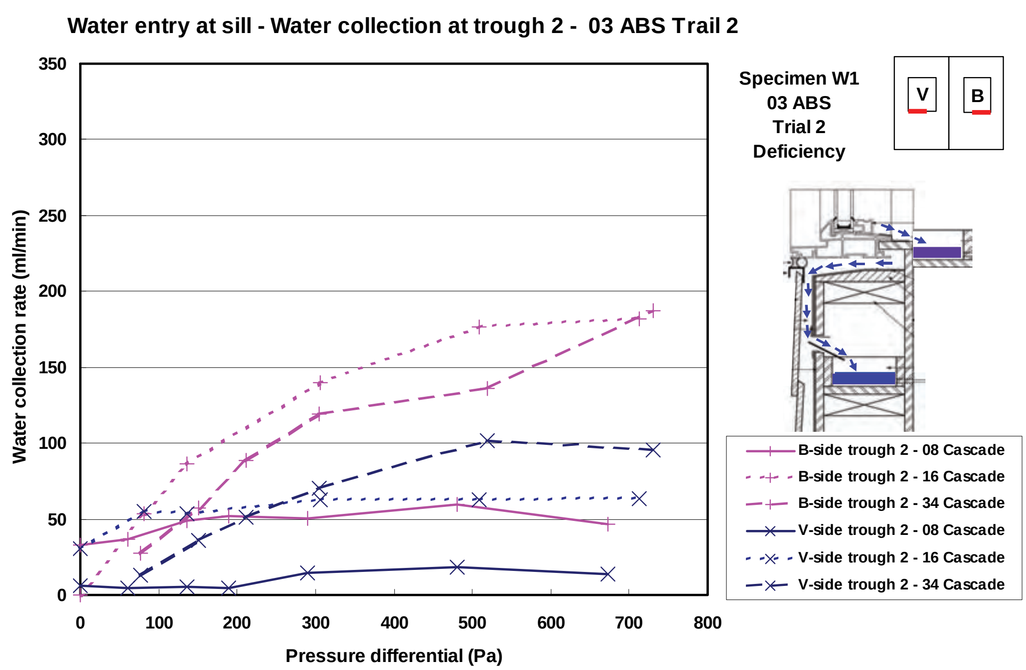


Figure 4-10: Specimen W1 – Trial 2: Collection at trough 2, 03 ABS

Increasing the air barrier system leakage from 03 ABS to 08 ABS (Figure 4-11) resulted in increased water collection for this deficiency. In most instances, water collection rates at the 08 ABS leakage condition were roughly double the measured water collection rates at the lower air barrier system leakage. Water collection rates continued to show the same dependencies on pressure differential and cascade rate that were present at the lower air barrier system leakage rate.

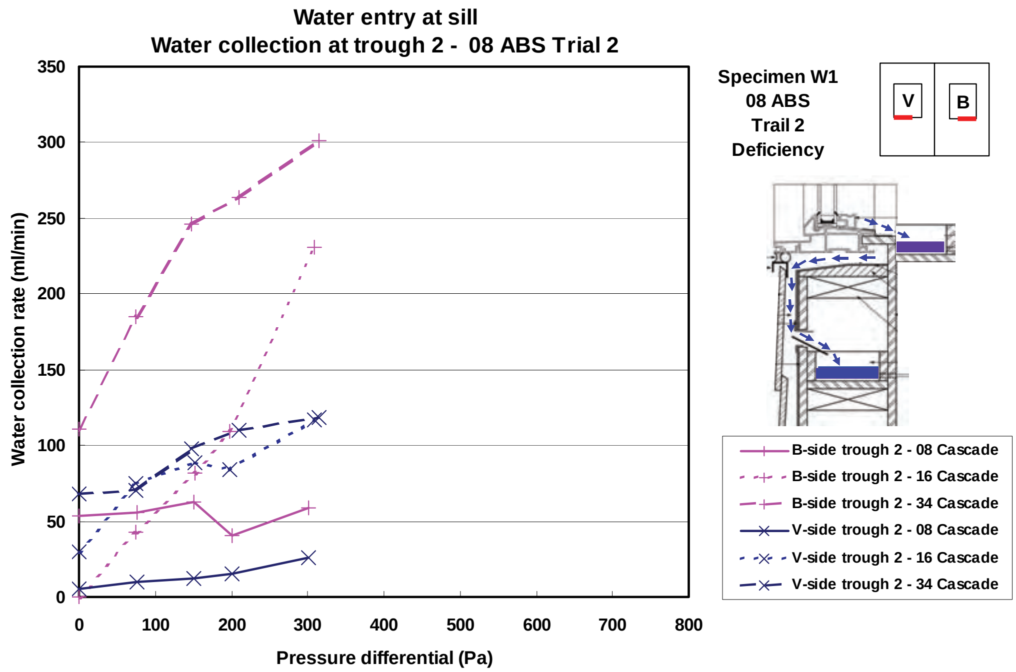


Figure 4-11: Specimen W1 – Trial 2: Collection at trough 2, 08 ABS

Discussion

This was the first specimen exposed to a novel test protocol aiming to simulate the varying intensity in climate loads over a set of several controlled tests. Several observations are made in respect to water collection at the window (troughs 1) and from apparent drainage from the sub-sill (trough 2):

Water collection to Trough 1 (Window)

Although the window was rated for 700 Pa (a B7 window) water began to enter at roughly 300 Pa applied pressure. This is not entirely unexpected; for example, previous work undertaken on testing installed windows by Ricketts[i] has suggested that certain windows may indeed perform at times well below their rated capacity.

[i] Ricketts, D. R. (2002), “Water Penetration Resistance of Windows: Study of Manufacturing, Building Design, Installation and Maintenance Factors”, Study 1, Canada Mortgage and Housing Corporation, Ottawa, December, 86 p.

Water collection to Trough 2 (apparent drainage from sub-sill)

Provided that the two sides of the wall were built with care, and no added-on deficiencies were present at the start of testing, both sides performed similarly in initial test and did not allow water behind the siding. The cladding assembly and related jointing at the wall-window interface were a very effective first line of defense against water entry.

With the introduction of a deficiency at the jambs or head of the wall-window interface, the added protection (sealant and backer rod) on the V-side of the wall would be expected to reduce water ingress at the jambs and consequently reduce water exposure of the subsill. Tests in which deficiencies were introduced in the cladding and sealant had been removed from specified locations, showed such modifications at the jamb did not result in any water entry, even at the highest spray rate and pressure differential; it is supposed that the opening in the jamb along the joint between the J-trim and cladding was not exposed to significant amounts of water. This is based on direct visual observation of the irregular pattern of water distribution on the test specimen as water flows downwards over the specimen, to a great extent, in rivulets as compared to, for example, a uniform film of water evenly bathing the surface of the wall. These rivulets, at times, may aggregate to form larger streams further down their flight of the wall and in other instances disaggregate into much smaller courses, thus meandering their way over the wall. Although efforts were made to ensure that the water deposition system provided an even flow of water over a smooth surface, and considering that the rate of deposition was verified and calibrated, variations in water load from one location to another on the wall were nonetheless evident.

When assessing water loads at a particular location, consideration must also be given to the path of water flow upstream from a point of interest and the flow over different types of surfaces that might affect the load downstream, such as the flow over the changing profile of the cladding or the smooth surface of the window lite. As well, the flow of water over projections that are an integral part of the specimen, such as the drip cap flashing, and other obstructions along the path of downward flow should also be considered in respect to affecting water loads. Hence, estimating the likelihood of a particular load at a specific location is a complex endeavor, and can at best only be determined on the basis of the gross amount of water deposited over the wall in a given period, and the surface area over which it is distributed.

A rough estimate of the load at different types of openings in the cladding would require consideration of the orientation of the opening. For example, water applied at the top of a wall and that subsequently cascades downwards may intercept a narrow vertical opening, such as the deficiencies defined in Trial 1 or 3, and in this instance, only a small amount of water comes into contact with the narrow deficiency, as illustrated in Figure 4-12. By contrast, a deficiency oriented horizontally, such as the one introduced in Trial 2, has a greater likelihood of coming into in contact with a much larger quantity of water and is therefore more conducive to water entry (see Figure 4-12).

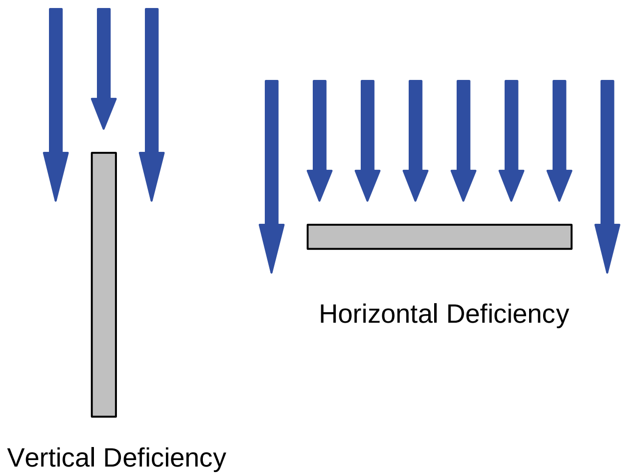


Figure 4-12: Water Entry to Vertical and Horizontal Deficiencies (elevation view)

Hence, given that no water was collected when an unprotected opening at the jamb was present for direct water ingress to the interior it is supposed that the load at this opening was limited. Of course, the secondary seal present on the V-side could have had an effect of controlling the water ingress further into the WWI, however, no water was observed on the B-side. Hence the efficacy of the secondary seal in restraining entry at a deficiency along the jamb was not clearly apparent from the results obtained in these tests.

However, when the external sealant was removed along the lower outer corner of the window at the interface between the cladding and the subsill, water collection was apparent. Clearly this specific location on the specimen was exposed to a significant water load given the rates of water collection in trough 2. Water had cascaded down on the window, and thereafter flowed over the face of the window frame sill and into the opening of the deficiency.

From the results of tests on the as-built specimen, both sides of the wall did perform similarly in that only minimal amounts of water were collected in trough 2. Lack of water entry at some cascade rates during these initial tests can be explained by the behaviour of cascading water over the façade as described previously. This water tends to form streams and at times these streams are directed away from the point of entry for the duration of the test, hence water collection was not evident at all cascade rates because of the intermittent nature of the water load at an opening. The reduced rates of water collection (10-20 ml/min) suggest that the entry points to the subsill were not large. When water entry did occur, it persisted throughout the test – likely due to water continuing to follow along a wetted path and down an already established stream. Hence in the as-built condition, the cladding-window interface and related jointing details performed very effectively as a first line of defense although the complete elimination of water ingress was not achieved. Nonetheless, such approaches to window installation detailing, irrespective of the side, provided for perfectly adequate watertightness performance as the specimens were designed to also provide a secondary line of defense to water entry.

Removing caulking and backer rod from a section on the jambs (Trial 1) or cutting a slit above the window head (Trial 3) had little measured effect on water collection on either side of the wall. In this instance, and contrary to what might have been expected, the B-side did not obtain additional water collection to trough 2 from the lack of a secondary seal.

However it is useful noting that water entry at the vertical opening along the window jamb apparently bridged the 19-mm air space behind the cladding and reached the sheathing membrane where it was intercepted by the lip of the water collection trough. This happened at zero pressure difference across the wall assembly when the cascade rate was in the medium to high range. As the pressure drive increased, so did the water deposition on the sheathing membrane indicating that a large gap can readily be bridged given sufficient water availability. A large cavity behind the cladding can necessarily be an effective capillary break and path for water drainage. As well, and depending on the size off the cavity and the presence and size of openings at either end, it can potentially act as a conduit for the extraction moisture and thereby reduce the time of wetness along the second line of defense. When the first line of defense is subject to gross deficiencies and exposed to high water loads that are thereafter transferred to the second line of defense, the long-term performance of the sheathing membrane may be affected if the moisture is not drained or removed by the transfer of air through the cavity.

Because the V-side only provided a second line of defense around the jambs and head of the window, both sides would be expected to perform similarly when a deficiency was incorporated at the sill in Trial 2. However, results showed that the B-side reservoir collected roughly double the water of the V-side during this Trial. Considering the location of the external opening and the location of the additional features on the V-side, it is difficult to reconcile how the extra intermediary seal could have minimized water entry, except for the possibility that this extra seal reduced the pressure drop across the cladding in its vicinity. However, the measured pressure drops at the location of trough 2 (i.e. pressure tap 1-WS) do not help to explain this phenomenon. Although pressure drops differed, 5.5% on the B-side and 10% on the V-side, a larger driving force for water entry would be expected on the Variation side of the wall, not the B-side. The window on the V-side leaked slightly more water to the interior than the B-side, possibly resulting in slightly less external water available to the opening on the cladding at the sill, but the quantities do help explain the large difference in collection rates between sides.

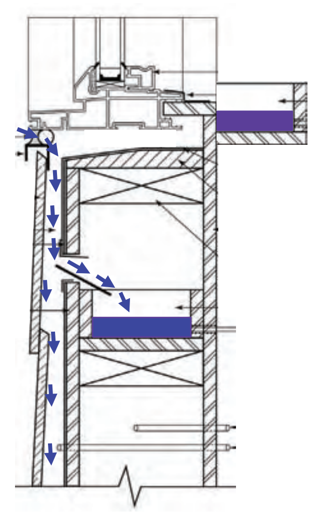


Figure 4-13: Possible path of water entry and collection to trough 2 during Trial

As illustrated in Figure 4-13, because of the nature of collection trough, water collected during trial 2 did not necessarily come from the subsill. Water likely entered directly below the sill, traveled down the backup wall behind the cladding and was directed to trough 2. Water collected in trough 2 on the B-side may have clung to the interior of the siding and avoided collection. As well, the lip of the collection trough extended beyond the width of trough 2, and some water likely bypassed entry to the trough and collected at the bottom of the clear cavity. For later generations of walls that followed these test trials, a barrier was installed to ensure that only water from the subsill was collected in the trough 2.

Summary

This chapter presents watertightness results from the first of four wall specimens, namely W1. The purpose of testing this wall was to determine the effectiveness of an additional sealant at the head and jamb joint between the window frame and the sheathing membrane of the wall. To this purpose, the specimen was divided into two sides – the Base-case side (B-side), with a bead of caulking and backer rod at the window frame/ siding J-trim joint; and the variation side (V- side), featuring an additional seal of caulking and backer rod (at jambs and head only) at the joint between the window frame and the sheathing membrane of the wall.

The wall specimen was tested under a number of different simulated wind and rain conditions. Deficiencies were made in the seal at the window frame/ siding J-trim joint to the wall/window interface to simulate failure. These consisted of the removal of a portion of caulking and backer rod along the jamb, and along the sill of this joint. Another deficiency consisted of a slit in the siding directly above the window.

Results showed that both sides of the wall faired similarly before deficiencies were added, letting in a minimal amount of water behind the siding. When small and large deficiencies were made in a vertical manner (as with the slit in the siding above the window, and the deficiency along the siding J-trim/ window jamb), there was no resulting water entry on either side of the test specimen. The only deficiency to create any increase in water entry was the missing 90-mm of caulking and backer rod at the window sill and siding J-trim resulting in large water entry rates to the trough located below the subsill in both sides of the wall (up to 300 ml/min on the B-side and 120 ml/min on the V-side). In this case, no substantial problem is expected, as water was directed to the cavity behind the cladding.

Chapter 5 —
Results from Watertightness Tests on Specimen W2

Introduction and Objective of Test Program

Focus in this Chapter is made on the specifications for and watertightness test results derived from specimen W2. These installation details were those for windows that included integral mounting flanges and solutions for detailing such windows when incorporated in a non-rainscreen concealed barrier wall. In particular, there was interest in gaining some perspective on two different approaches to the protection of the wood-based components at the rough opening and whether a back dam at the subsill would provide an additional degree of protection against water entry. As well, there was interest in assessing the degree to which the different approaches would permit adequate drainage of the subsill.

A summary of the basic components incorporated in specimen W2 is given in Table 5-1. Configurations details are offered in the subsequent section.

Table 5-1: Summary of all wall-window cladding combinations selected for testing with emphasis on Specimen W2

Speci-men	Window Frame	Window Type*	Wall Type / Siding Installation	Variation (determine effect of)
W1	Box (Non-flanged)	Fixed	Rainscreen wall – clear cavity behind siding	Extra seal at junction of jambs and head of window R.O.**
W2	<u>**Flanged**</u>	**Fixed**	**Concealed barrier wall – no clear cavity**	**Changes in protection of R.O.; back dam at subsill**
W2		Combination – Operable sliding (upper) / Fixed (lower)	Rainscreen wall – clear cavity behind siding	Two subsill drainage methods for flat sill
W4			Concealed barrier wall – no clear cavity	Sealing sheathing membrane to window flange

*All windows were fabricated of PVC; **R.O.: rough opening

Description of Test Specimen W2

Specimen W2 included non-operable (fixed) PVC windows (CSA A440 rating B7), having integral mounting flanges that were installed in concealed barrier wall assembly, hence a wall assembly having no clear cavity behind the cladding. The flanges were used for anchoring the window to the rough opening. Hardboard siding was affixed to 2-in. by 6-in. (38-mm by 138-mm) wood frame studs. A polyolefin-based spun-bonded textile product was used as sheathing membrane.

Of the two different installation methods, the specified practice ("base-case"; "B-side") of Specimen W2 included a back dam at the interior face of the rough flat subsill, the subsill being overlaid with a self-adhered bituminous-based waterproofing membrane, that was lapped over the sheathing membrane, as well as a self-adhered waterproofing membrane to seal the sheathing board to the window flange at the jambs and head (see Figure 5-1 and Figure 5-2).

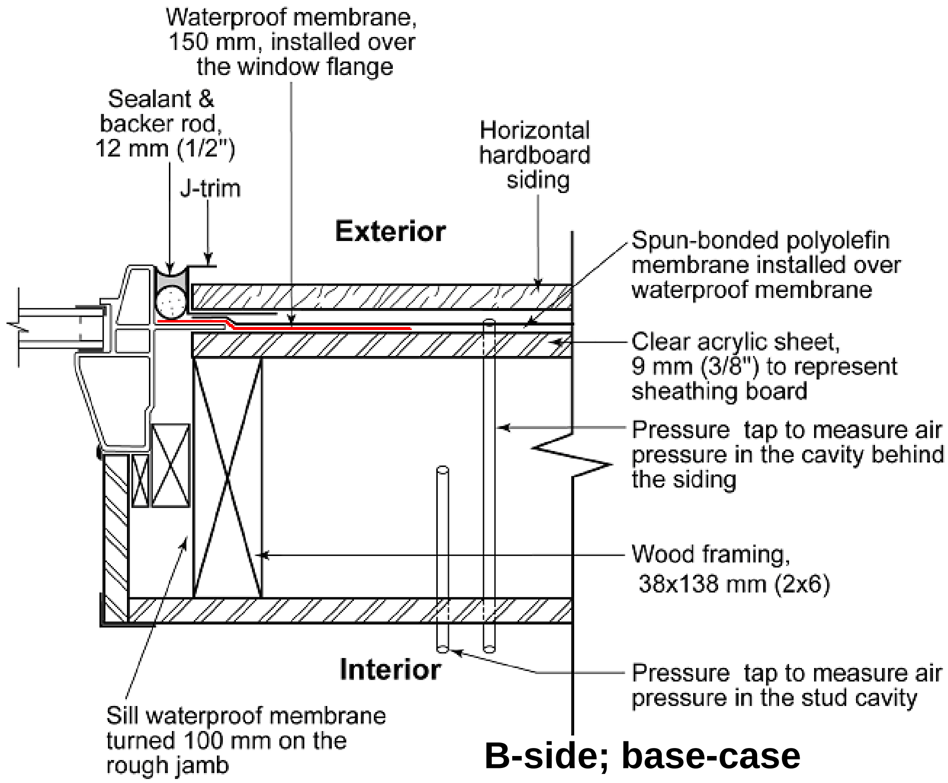
The flat subsill on the V-side was not protected from contact with moisture; the sheathing membrane lapped under the window flange at the rough sill, and lapped over the window flange at the jambs and head. Both sides incorporated a drip cap (no end dams) made of preformed PVC.

The interface between the cladding and the window jambs and sill of the window frame incorporated a J-trim (40-mm) and a sealant and backer rod. The sealant and backer rod formed a 12-mm joint between the window frame and J-trim at the jambs and sill (not at the window head).

Horizontal sectional views for the B- and V-sides showing the wall-window interface at the jamb of specimen W2 are provided in Table 5-1; differences between approaches are highlighted in this figure. As well, a full vertical sectional view of the B-side of the specimen is provided in Figure 5-2 in which the V-side is described by a icon that illustrates the differences at the subsill and emphasizes the absence of back dam or protection of the rough sill.

A complete set of configuration details for specimen W2 is provided in Appendix A (Description of the Construction of W2 Specimen). Key elements of W2 construction include:

- Horizontal hardboard siding
- Concealed barrier wall - No clear cavity behind the siding (no furring strips)
- Sheathing membrane (WRB): polyolefin-based spun-bonded textile product
- Fixed flanged non-operable PVC windows
- Flat subsill protected by self-adhered waterproof membrane and back dam (B-side only)
- Sealant and backer rod in the 12 mm joint between the siding and window frame at jambs
- Drip cap head flashing (no end dams)
- 2-in. by x 6-in. wood-frame construction



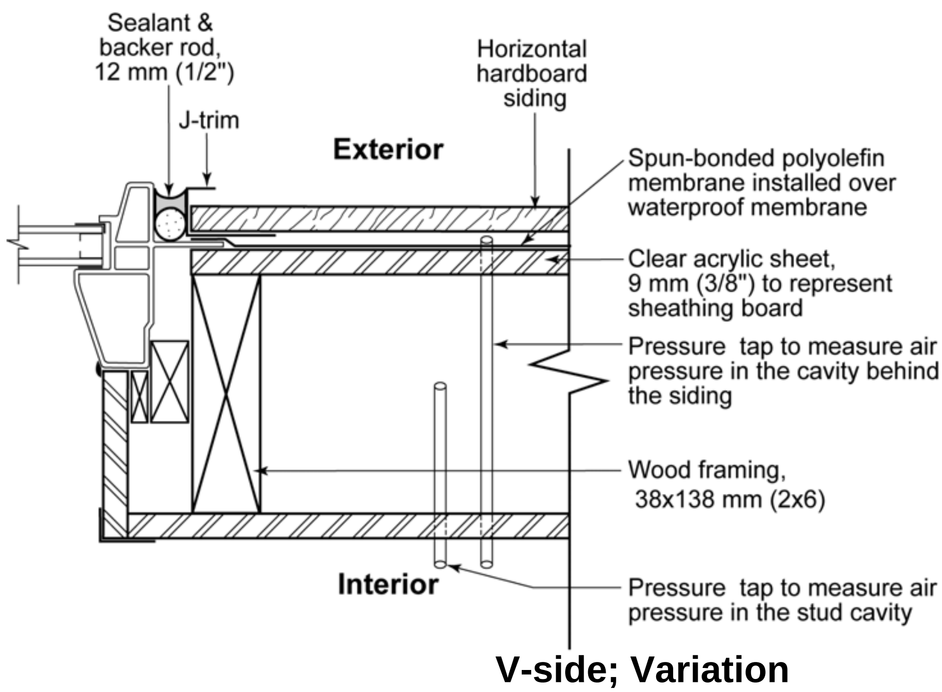


Figure 5-1: Horizontal sectional views of Specimen W2 showing wall-window interface at jamb for selected practice (B-side) and Variation (V-side) specimen configurations respectively. The only difference between B- and V-sides is that the window mounting flange on the B-side has been sealed with a self-adhered waterproof membrane (150-mm) at the jambs and head of the window.

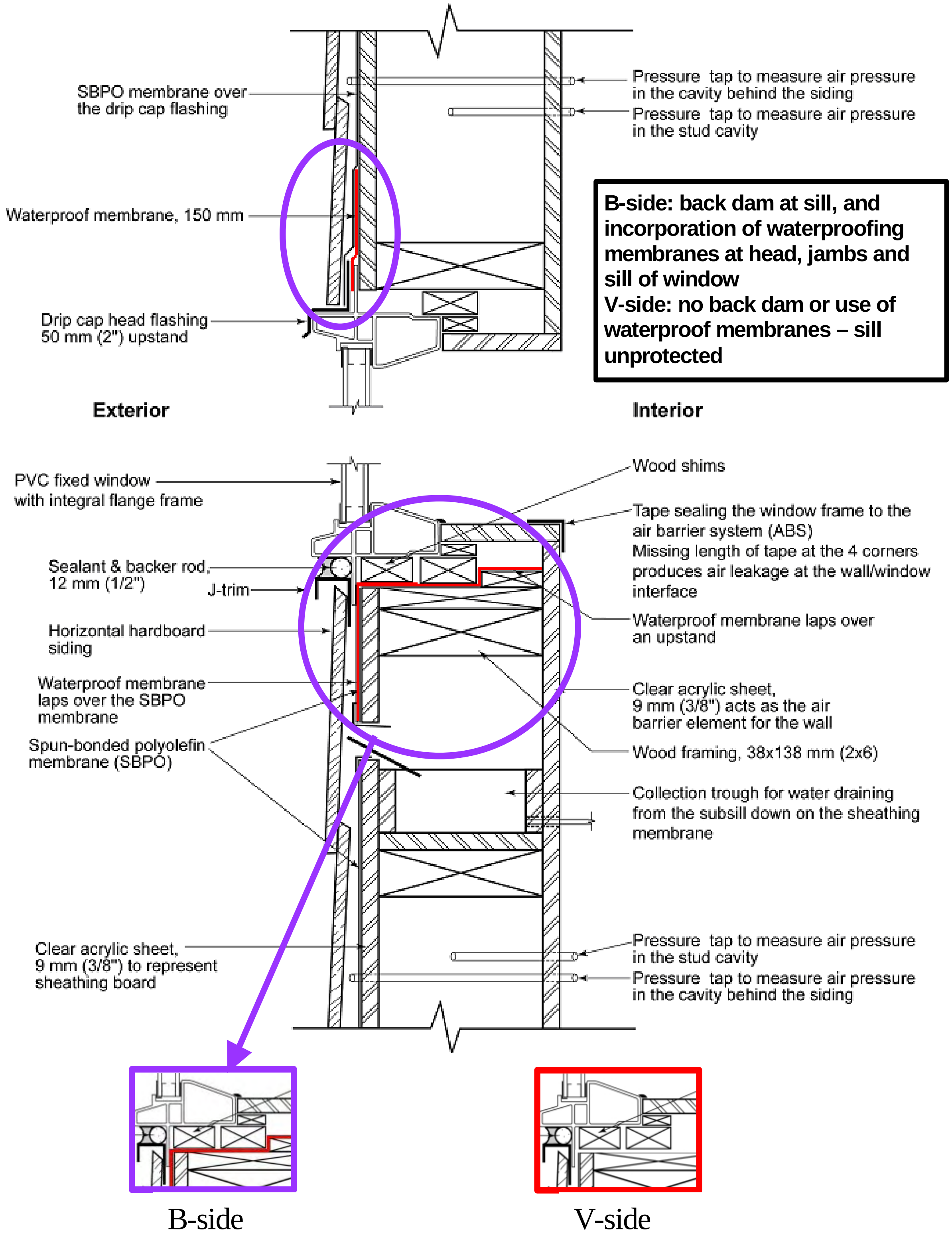


Figure 5-2: Vertical sectional views of specimen W2 at the wall-window interface showing the (a) selected practice side (B-side; base-case) and (b) Variation (V-side) specimen configurations.

Summary of Test Protocol

In total, 20 water penetration or entry tests were performed for specimen W2, a summary of which is provided in Table 5-2. Test trials were performed at a constant ABS leakage (03 ABS or 08 ABS leakage) and a constant rate of water application (0.8, 1.6, 3.4 L/(min-m^2)), and consisted of up to 7 tests at each of 7 different chamber pressures. During each test, pressure and level sensor data was collected every second over a period of approximately 15 minutes. Instances where tests were not conducted to the expected test levels have been noted as such.

Test trials were either performed in the "as-built" condition (i.e. nominally neither damaged nor altered), or including deficiencies to the wall assembly or modifications for collection of water with troughs added at the subsill beneath the window. In respect to deficiencies, three (3) sets were incorporated at the interface between the exterior cladding and the window frame and included: (1) 90-mm vertical slit (ca. 2-mm width) above window heads; (2) 90-mm missing length of sealant and backer rod located at the horizontal joint along the lower and outer corner of the window frame, at the junction of the window frame and the subsill flashing, and; (3) a 90-mm long by 6 mm wide missing sealant and backer rod in a vertical joint at mid-height of the outer window jamb. Each of these locations is identified in Figure 5-3. As well, for each test Trial, the type, size and location of the deficiency is given and modifications are noted in Table 5-2 as applicable to the respective test Trial. For example, in test Trial 2, undertaken at 03 ABS (nominal ABS leakage of 0.3 L/(s-m^2)), the deficiency is described as a 6-mm by 90-mm bead of caulking removed from the joint located at the bottom outside corner of the window frame between the J-trim and the underside of the window frame. A small graphic is included to help situate the general location of the deficiency in respect to half of the specimen. As noted previously, such types of deficiencies were chosen to simulate failure of the component due either to an inadvertent event, such as improper installation, or simply from natural aging. The details regarding the location of the deficiencies are provided in Figure 5-3(b), Figure 5-4 and Figure 5-5.

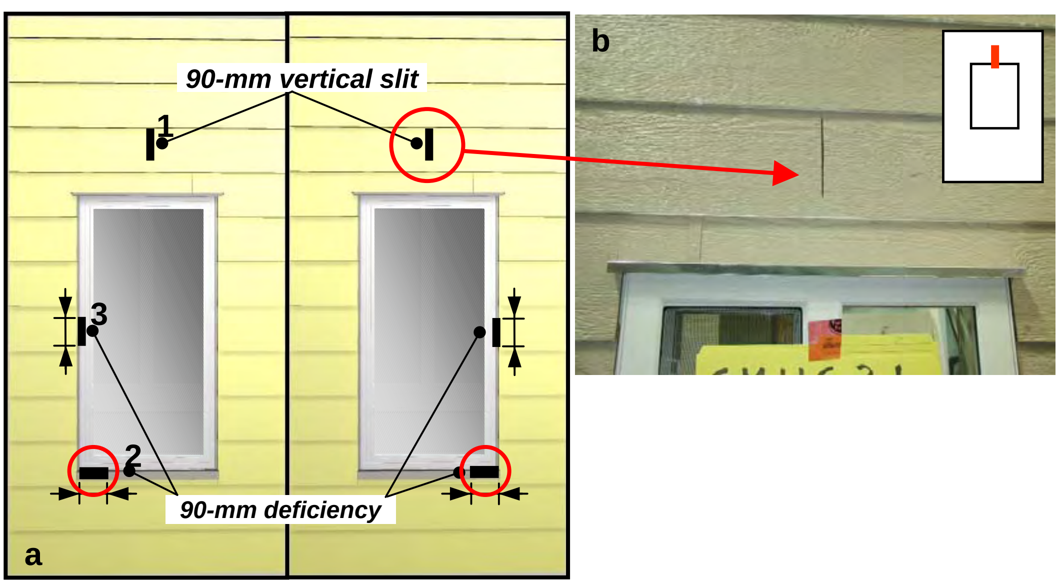
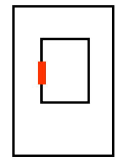
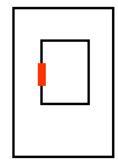
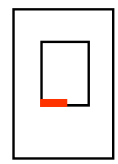
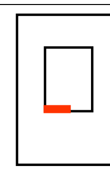
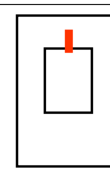
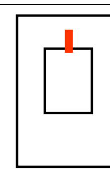


Figure 5-3: (a) Schematic of front elevation of 2.44-m by 2.44-m specimen (cladding exterior) showing nominal location of 90-mm deficiencies (missing sealant, backer rod at specimen face); (b) picture of 90-mm slit located (deficiency 1) above window of Specimen W2 – icon relates to test Trial description (Trial 3).

Table 5-2: Summary of Water Penetration or Entry Tests for Test Specimen W2

Condition	ABS	Cascade Rates (L/min-m^2)	Description
As-built (No modifications or deficiencies)	03	0.8 1.6 3.4	Original Configuration, (No modifications or deficiencies)
As-built (No modifications or deficiencies)	08	0.8 1.6 3.4	Original Configuration, (No modifications or deficiencies)
Trial 1a* Deficiencies*	08	3.4	6-mm by 90-mm caulking removed from joint between window jamb and siding – backer rod in place. 
Trial 1b* Deficiencies	08	3.4	6-mm by 90 mm caulking removed from joint and backer rod removed along jamb. 
Trial 2 Deficiencies	03	0.8 1.6 **3.4	6-mm by 90-mm caulking removed from subsill joint at bottom outside corner of window frame between sill cap flashing and underside of window 
Trial 2** Deficiencies	08	0.8 1.6 3.4	6-mm by 90-mm caulking removed from sill joint at bottom outside corner of window frame. 
Trial 3 Deficiencies* and modifications	03	0.8 1.6 3.4	All caulking and backer rod re-installed, 2-mm by 90-mm vertical slit in cladding panel above window. 
Trial 3 ** Deficiencies* and modifications	08	0.8 1.6 3.4	All caulking and backer rod re-installed, 2-mm by 90-mm vertical slit in cladding panel above window. 

***** No water collection measured in trough 3

** Wall only tested up to 300 Pa applied chamber pressure

Figure 5-4: Location of deficiency (3) in Trial 1 as shown in Figure 5-3

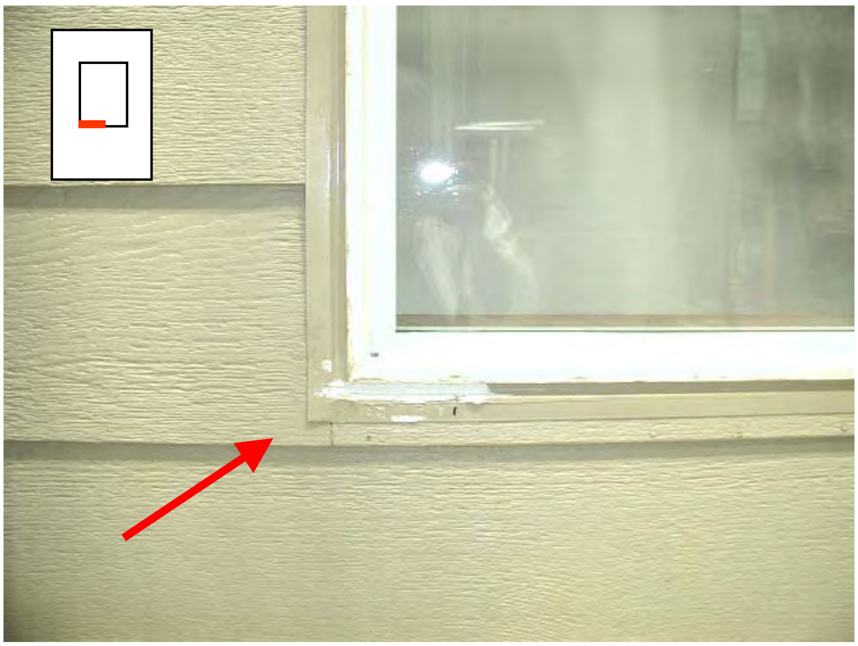


Figure 5-5: Location of deficiency (2) in Trial 2 as shown in Figure 5-3

Variation in Data Collection Methods and Techniques

Each half of Specimen W2 was instrumented with 8 pressure sensors and 2 collection troughs, a summary description of which is provided below.

Pressure Sensors

Pressure taps connected to pressure sensors permitted measuring pressure differentials at different locations in the wall as shown in Figure 5-6 and Figure 5-7a. Figure 5-6 provides a schematic of the location of pressure taps in proximity to the window jamb, such as locations at approximately the mid-height of the specimen given as 2-MS and -MC in Figure 5-7a. Such taps measured the pressure differential in either the stud cavity (2-MS) or the cavity behind the siding (2-MC).

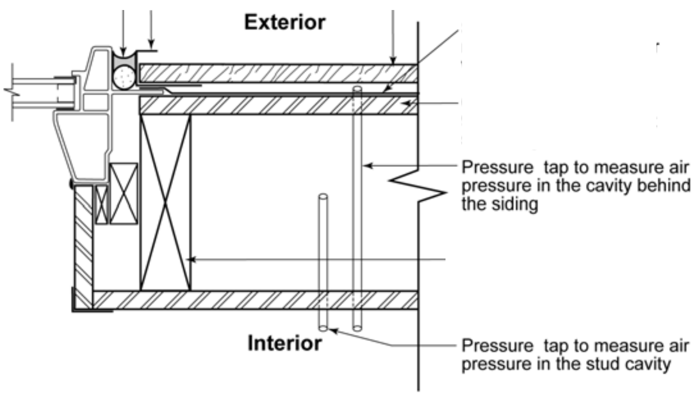


Figure 5-6: Pressure tap locations within wall assembly

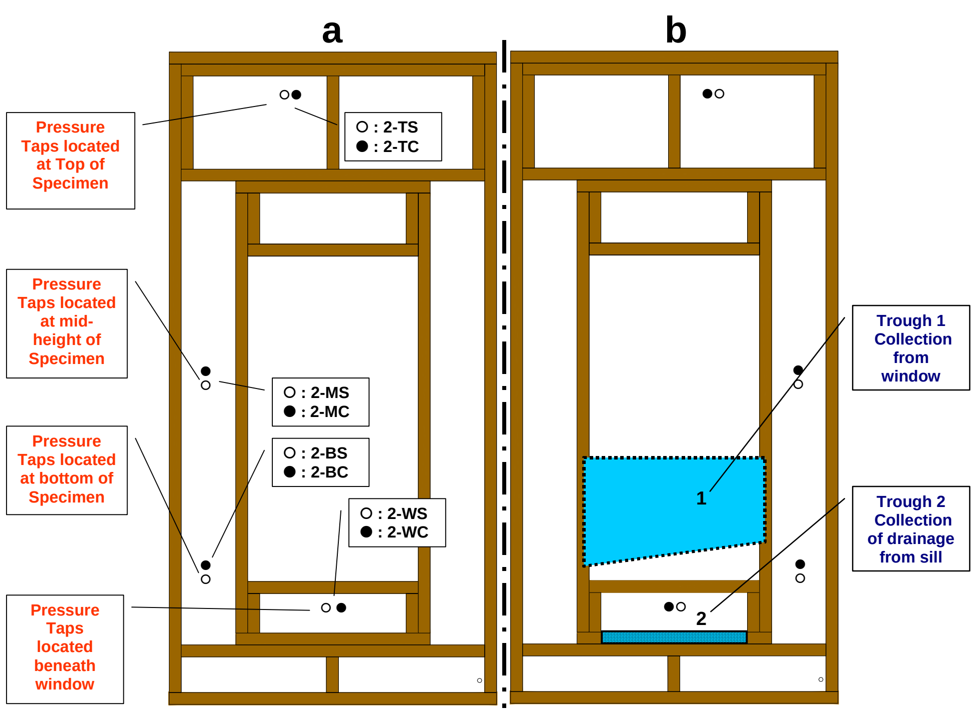


Figure 5-7: (a) Location of pressure taps along height of half-specimen and designated tap labels; (b) location of collection troughs 1 to 2 of half-specimen. Both sides of specimen had troughs located as shown in (b).

Water Collection troughs

Water penetration at the window proper, entering unintended openings in the cladding and interface, or entering through deficiencies, was collected in troughs located as shown in Figure 5-7b and Figure 5-8. A trough located at (1) in Figure 5-7(b) and Figure 5-8, permitted collecting water that would penetrate the window between the lite and window frame; water accumulating at the subsill could be collected in a trough located beneath the subsill at (2) which was intended to measure water drainage from the subsill to the trough. Figure 5-8 provides a schematic of the expected path for water collection from the collection points to the respective troughs.

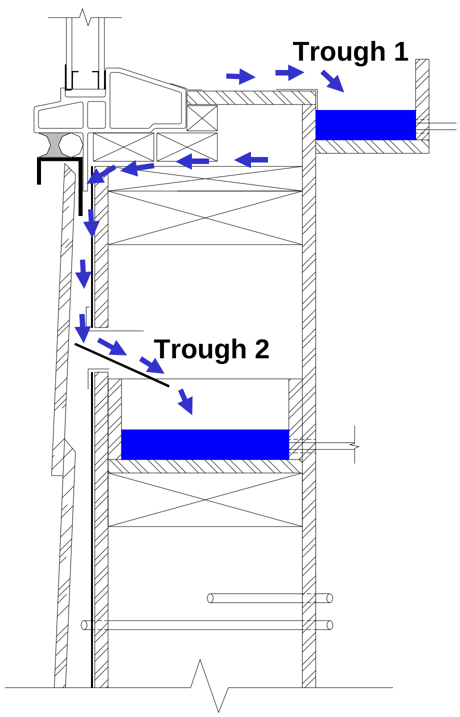


Figure 5-8: Expected path of water drainage from subsill to collection trough 2 for both the variation (V-side) and (B side) portions of specimen W2; Note that although the cladding system is considered a concealed barrier for which cladding is typically in contact with the sheathing membrane, for clarity, the schematic is not drawn as such. This permits showing the drainage path of water from the subsill to collection trough 2.

Results from Watertightness Performance Tests - Specimen W2

Results of watertightness performance tests for specimen W2 are reported in terms of (1) air leakage of the assembly; (2) pressure drops across different components of the assembly and; (3) water penetration of and water entry to, and through, the assembly.

ABS Leakage

The air leakage of Specimen W2 as built (nominally 03 ABS) was approximately 0.03 L/(s-m^2) at 75 Pa chamber pressure, one-tenth the nominal 0.30 L/(s-m^2). The air leakage at 08 ABS leakage condition was slightly lower than the nominal, at approximately 0.66 L/(s-m^2). The intent of such tests was to ensure that specimens were tested in nominally the same conditions in respect to air leakage across the assembly; results suggest that at the lower ABS leakage condition (03 ABS), W2 is approximately 90% less that the target leakage whereas at the higher ABS leakage condition (08 ABS), it is ca. 18% less. In comparison to Specimen W1, specimen W2 was considerably more airtight; this is perhaps due to the concealed barrier mode of assembly that may offer a comparatively tighter seal at the wall cladding to window frame interface in relation to specimen W1. However, the design approach used for Specimen W2 may also result in higher pressures drops at these locations. It may also suggest that the degree of airtightness afforded the cladding to the back up wall in specimen W2 is greater than that of the designated ABS.

Pressure Drops Across Wall Assembly

A large pressure drop across the cladding would provide a driving force for water entry at openings present in the plane of the cladding. As provided in Table 5-3, at the lower air barrier system leakage (03 ABS), pressure drops in the stud cavity, and cavity behind the siding, were small; up to 4% of the applied chamber pressure. Whereas at the nominal 08 ABS leakage, pressure drops in stud cavity within the wall assembly (i.e. taps 2-TS, 2-MS, 2-BS) increased almost tenfold with an increase in the designated ABS leakage, up to 37%. In the cavity behind the cladding pressure drops also increased but to a lesser extent, as is evident particularly at the middle and bottom locations of the stud cavity, for which pressure drops of up to 30% on the V-side and 13% on the B-side were evident. Pressures drops at the top of the stud cavity remained small at both ABS leakage rates.

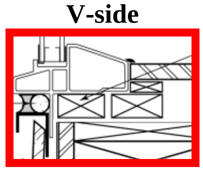
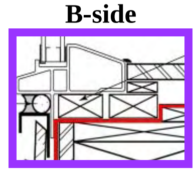
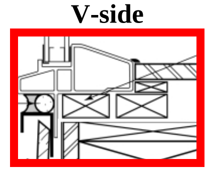
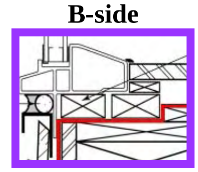
The significant increase in the degree of pressure drop across the cladding when testing at the higher as compared to the lower ABS leakage rate (ca. 10 times) would be expected to provide a larger driving force for water entry into the wall-window interface on the V-side as compared to the B-side of the wall, and likewise, for water entry to increase at the higher ABS leakage rate.

At 08ABS leakage, the V-side behaved quite differently as compared to the B-side if considering the pressure drop across the cladding at the bottom and middle height of the specimen (i.e. pressure taps 2-MC, 2-BC): The lower pressure drop on the B- as compared to the V-side was likely the result of the incorporation of a self-adhered flashing membrane that sealed the window flange to the sheathing board at the jambs and head. It appears that in this instance, this secondary plane of protection from water ingress offered a greater resistance to airflow. The value of pressure drop at tap 2-TC suggests that this cavity was not greatly affected by this addition. Additionally, the results may be due to the fact that the V-side had a greater ABS leakage than the B-side and hence, experienced a larger pressure drop.

Pressure tap 2-WS was located behind the siding in the space located at trough 2, as shown in Figure 5-7a. This represents the pressure drop that closely corresponded to the pressure drops measured at 2-BS, located at the bottom of the specimen in the stud cavity (see above). This is expected since there is an opening between trough 2 and the bottom behind the siding cavity to permit water collection.

Interestingly, the incorporation of deficiencies (e.g. openings in the cladding) caused no significant changes in the pressure drops measured in the wall or in proximity to the wall-window interface at either air barrier system leakage rates. A pressure tap in close proximity to a deficiency would necessarily be affected by openings. However, given that nature of the cladding and degree to which horizontal courses of cladding components are isolated and hence compartmentalised, the extent to which an opening could affect pressure differentials further away from deficiencies would necessarily depend of the location of the opening in relation to the pressure tap. In this instance, it appears that the taps were located in the cladding course just above the location of the opening for deficiencies located along the jamb at mid-height of the specimen.

Table 5-3: Pressure drops in the stud space and cavity behind the cladding without deficiency

Pressure Tap Location	**03 ABS**		**08 ABS**	
	V-side 	**B-side** 	**V-side** 	**B-side** 
2-TS	~3%	~4%	27-37%	~33%
2-MS	~2%	~4%	27-37%	~33%
2-BS	~2%	~4%	27-37%	~33%
2-TC	<0.6%	<0.5%	~2%	<0.1%
2-MC	~2%	<0.5%	20-30%	1-3%
2-BC	~2%	<1%	20-30%	7-13%
2-WS	~2%	~1%	20 - 30%	7 - 14%
2-WC	~2%	~1%	20 - 30%	7 - 14%

Results from Water Penetration and Water Entry Tests

A summary of results obtained from watertightness performance tests of specimen W2 are provided in Table 5-4. Information is presented in terms of the indication of water collection to troughs 1 (at window) and 2 (apparent drainage from subsill) for the different test conditions including test Trials undertaken with no deficiencies incorporated in the cladding or when different types of deficiencies are present as denoted in Trials 1 to 3 inclusively. When water was collected, information on the rate of collection (ml/min), pressure level and water cascade rate at which the collection occurred is provided. As well, information is organised to provide ready comparison between results obtained from the V-side as compared to the B-side and in terms of the different nominal air barrier leakage configurations be they 03 or 08 ABS leakage.

Table 5-4: Summary of Results from Watertightness Performance Tests of Specimen W2

Collection Troughs	03 ABS		08 ABS	
1 and 2	**V-side**	**B-side**	**V-side**	**B-side**
No deficiencies				
1 – Window	No water entry	No water entry	No water entry	No water entry
2 – Drainage from subsill	No water entry	No water entry	No water entry	No water entry
Deficiencies				
Trial 1a* (at jamb backer rod in place)				
1 – Window	N/A	N/A	No water entry	No water entry except at 700 Pa (6 ml/min), and highest CR
2 – Drainage from subsill	N/A	N/A	No water entry except at 700 Pa (35 ml/min) and highest CR	No water entry
Trial 1b** (at jamb no sealant or backer rod)				
1 – Window	N/A	N/A	No water entry	No water entry
2 – Drainage from subsill	N/A	N/A	No water entry	No water entry
Trial 2 (lower ext. corner of window)				
1 – Window	No water entry	No water entry	No water entry	No water entry
2 – Drainage from subsill				
0.8	No water entry	~10 ml/min	No water entry	~10 ml/min
1.6	No water entry	~12 ml/min	0 ml/min < 700 Pa and 8 ml/min at 700 Pa	~50 ml/min
3.4	No water entry	~60 ml/min > 100 Pa	0 <300 Pa to 45 ml/min at 700 Pa	Increasing with dP from 0 to 45 ml/min
Trial 3				
1 – Window	No water entry	No water entry	No water entry	No water entry
2 – Drainage from subsill				
0.8	No water entry	No water entry	No water entry	~8 ml/min
1.6	No water entry	No water entry	No water entry	~20 ml/min
3.4	No water entry	Fluctuates from 5 to 15 ml/min at 300 Pa; 5 ml/min at 700 Pa	No water entry	0 <150 Pa 30 ml/min > 150 Pa

* Missing sealant but **backer rod in place** along mid-height of window jamb
** Missing sealant and backer rod along mid-height of window jamb
*** Missing sealant and backer rod at lower exterior extremity of wall-window interface.

Results for specimen tested as-built (unaltered condition - without deficiencies)

Water collection at trough 1 and trough 2 — As provided in Table 5-4, no water was collected in trough 1 (collection of water penetrating window proper) on either half of the test specimen. Likewise, no water was observed penetrating the window assembly to collect at the interior windowsill.

Similarly, for the specimen in the as-built condition, throughout the entire set of tests no water was collected in trough 2 of either the B- or V-side of specimen W2. It appears that even though there existed a driving force, the path for water to reach the sheathing membrane and trough 2 was not evident or was perhaps convoluted. That is, entry may have occurred but was not witnessed at the windowsill nor was any collection made to the trough. This suggests that the first line of defence for this assembly was effective in retarding water entry. It may also be that water did enter the behind the cladding but could not drain to the lower courses given that there was no clear drainage path behind the cladding.

Results for specimen tested with deficiencies

Water entry test Trial 1 — Test Trial 1 consisted of incorporating deficiencies along the window jamb at mid-height of the interface between the window and the cladding; Trial 1a included missing sealant (backer rod remained in place) whereas, Trial 1b had both sealant and backer rod removed. These tests were conducted only at the 08 ABS test conditions and results, as given in Table 5-4, indicate that water entry was only observed over one test condition this being the most severe, at a pressure differential of 700 Pa and water cascade rate of 3.4 L/(min.-m^2). At these test conditions, small rates of water were observed to collect at trough 1 (6 ml/min collection at window) on the B-side of specimen W2 and 35 ml/min. to trough 2 on the V-side. Such types of deficiencies did not apparently lead to significant amounts of water collection.

Water entry test Trials 2 and 3 — Water entry to trough 1 (collection at window), as given in Table 5-4, was not observed in either of these two test Trials hence focus is made on results from collection in trough 2 (apparent drainage from window subsill).

Test Trial 2 included assessing the effects of incorporating a deficiency at the interface between the cladding and window frame, for which a 90-mm sealant and backer rod were removed from the bottom outside corner of the window. Whereas in test Trial 3, the deficiency consisted of a 150-mm long opening cut in cladding board (2 boards above the window) to simulate a deficiency above the window head. Generally, these two deficiencies resulted in water collection to trough 2 primarily on the B-side of the wall; the trough on the V-side remained relatively dry except at the highest pressures and cascade rates.

Water entry test Trial 2 – Results from test Trial 2 showed that water entry mainly occurred on the B-side of specimen W2. For tests undertaken at 03 ABS leakage, as provided in Figure 5-9, water entered trough 2 on the B-side at a constant rate of 10 ml/min at both the 0.8 and 1.6 L/(min-m^2) cascade rates. At the highest cascade rate, water collection to trough 2 was in the range of 65 ml/min. No water collection was recorded on the V-side at this air barrier system leakage rate.

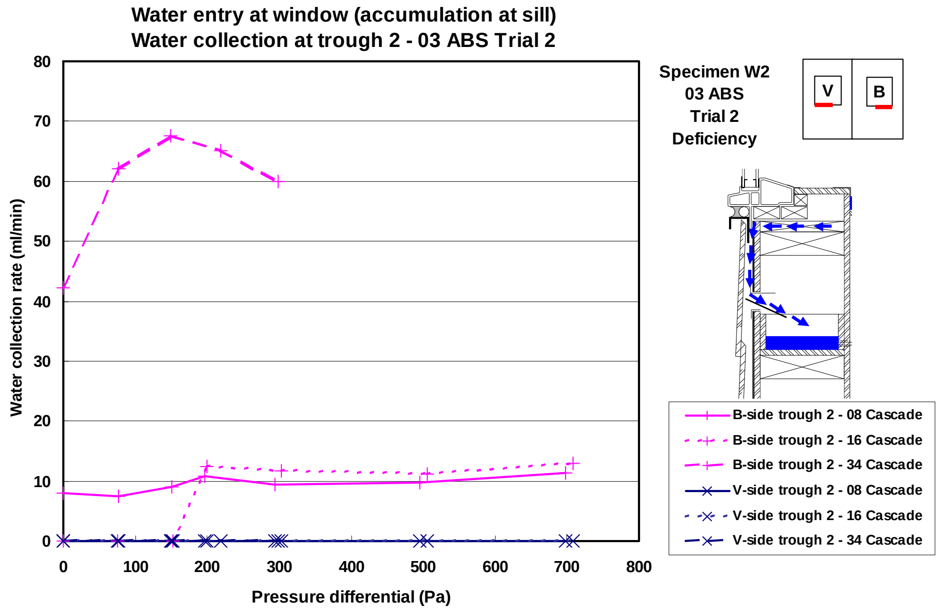


Figure 5-9: Water entry test Trial 2 of Specimen W2 at 03 ABS leakage, showing water collection in trough 2 as a function of pressure differential (Pa), for the B- and V-sides at different water cascade rates.

As provided in Figure 5-10, increasing the air barrier system leakage (08 ABS) resulted in water collecting to trough 2 on the V-side at higher pressure differentials and cascade rates, up to a maximum of 45 ml/min. Water collection to trough 2 on the B-side remained the same at the 0.8 L/(min-m^2) cascade rate (i.e. 10 ml/min), increased to 50 ml/min at the 1.6 L/(min-m^2) cascade rate, and showed dependence on pressure differentials applied across the specimen at the 3.4 cascade rate. At the highest cascade rate, water collection on the B-side showed some similarity to water entry on the V-side of W2.

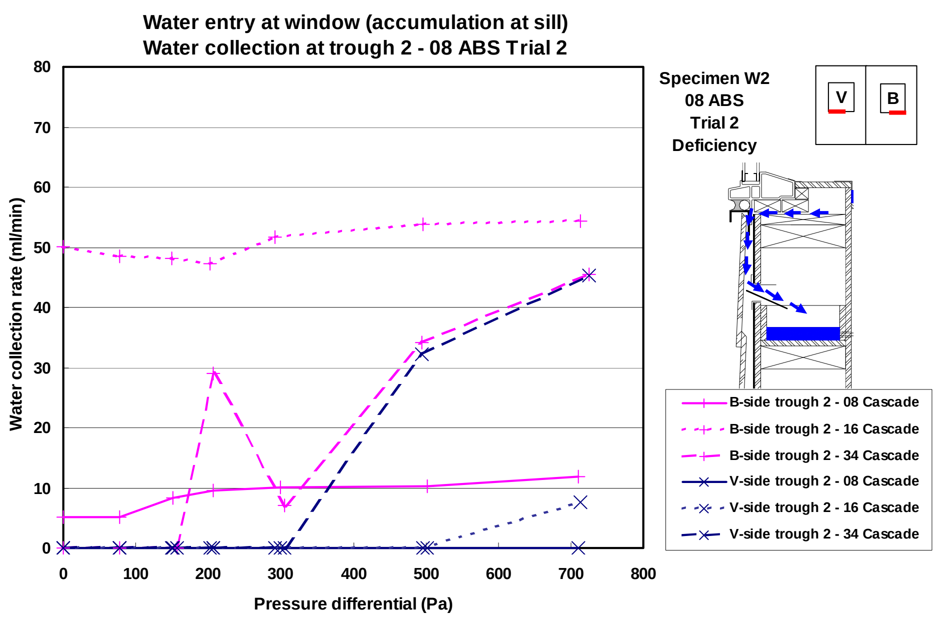


Figure 5-10: Water entry test Trial 2 of Specimen W2 at 08 ABS leakage, showing water collection in trough 2 as a function of pressure differential (Pa), for the B- and V-sides at different water cascade rates.

Water entry test Trial 3 – In test Trial 3, results of which are provided in Figure 5-11 and Figure 5-12, water collection to trough 2 was recorded only on the B-side (deficiency - 150-mm long opening cut in cladding board above window head). For the tests undertaken at the 08 ABS leakage condition (Figure 5-12), water entered only at the highest cascade rate (3.4 L/(min-m^2)) at a fairly constant 10 ml/min. Water collection did not show any dependence in pressure differential applied across the assembly at the higher air barrier system leakage rate. At 08 ABS, water entry was highly dependent on the water deposition rate, entering at approximately 10, 20 and 30 ml/min respectively for the three cascade rates in increasing order.

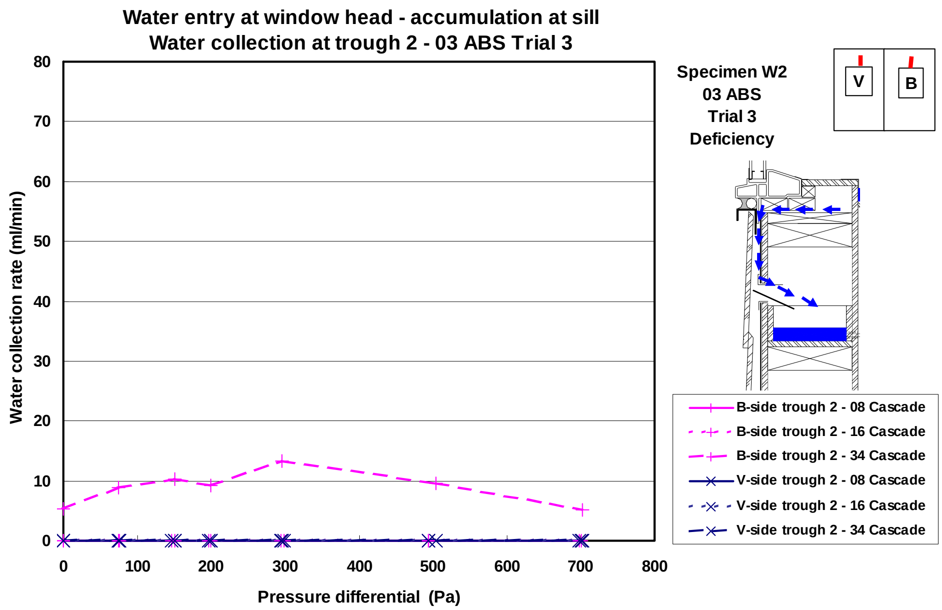


Figure 5-11: Water entry test Trial 3 of Specimen W2 at 03 ABS leakage, showing water collection in trough 2 as a function of pressure differential (Pa), for the B- and V-sides at different water cascade rates.

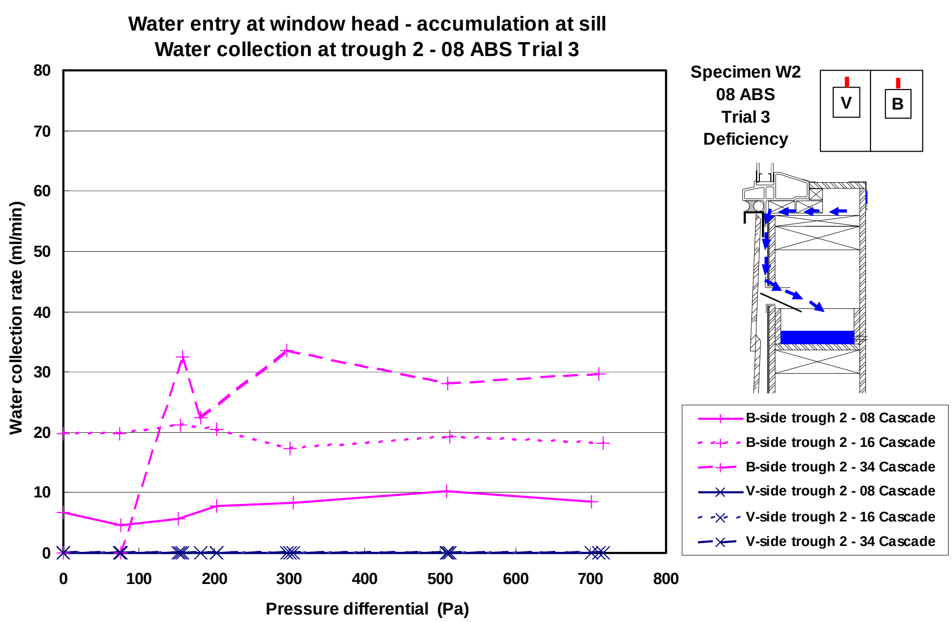


Figure 5-12: Water entry test Trial 3 of Specimen W2 at 08 ABS leakage, showing water collection in trough 2 as a function of pressure differential (Pa), for the B- and V-sides at different water cascade rates.

Discussion on Water Entry test Trials

Water Entry at Window

The fixed flange PVC window tested in specimen W2 exhibited the best performance of the 3 different types of windows tested over the course of Phase 1. This set of windows, rated as B7 (700 Pa), was the only window set for which little or no water penetration was observed throughout the full range of test conditions, the exception being a reduced rate of collection (6-ml/min) observed in test Trial 1 at 700 Pa pressure differential across the assembly at the highest water deposition rate. That this was observed in this set but not in the initial set of windows is indicative of the variability of the watertightness performance of windows in general. It will be seen in subsequent chapters in which results from Specimens W3 and W4 are discussed this was not the case. The windows sets used in Specimens W3 and W4 were combination windows, the upper portion being a sliding window that in any case are somewhat more prone to water penetration under the tests conditions used in the study.

Water Entry to trough 2 – apparent drainage from window subsill

Initial tests on specimens in the as-built condition (without deficiency) revealed that the wall-window interface details on both sides of the wall were equally successful in preventing water entry throughout the full range of test conditions.

When deficiencies were introduced, such as an unprotected opening in the cladding, water was collected in trough 2, under several test conditions. Water collection in trough 2 was indicative of different collection scenarios. For example: (1) in instances where no water is expected to reach the subsill, it can indicate a failure of the wall-window interface detail to prevent water from attaining the subsill area; (2) Where the design details incorporate protection due to the expected entry of some incidental water, drainage from the subsill collection may indicate adequate water management, directing water away from the subsill area to drain down the wall in the cavity behind the siding: (3) Collection in trough 2 can also be water that ran down the face of the sheathing membrane on the back-up wall assembly and was intercepted by the lip intended to divert water to the trough.

Because of the nature of W2, all the above conditions were expected to manifest. The waterproofing layers that lap over the window flange at the head and jambs of the B-side of the wall add a layer of protection to water penetration along their lengths. In the event of a deficiency, less water would be expected to penetrate through the wall-window interface on the B-side than on the V-side, the V-side lacking this protection. Also, the back dam at the subsill of the B-side would direct any water that reached the subsill to the reservoir collection tray, whereas water in the V-side of the wall would be expected to build up in the subsill area and not necessarily be collected by trough 2.

Given the lack of visual evidence of collection at the subsill over the course of these test Trials, water collected in trough 2 likely came directly from the cavity behind the cladding, and not from the subsill, as described below. As shown in Figure 5-13, it is supposed that the J-trim became a shelf for water to collect and some of the water thereafter percolated down on the face of the sheathing membrane whereas some water might have clung to the back of the siding.

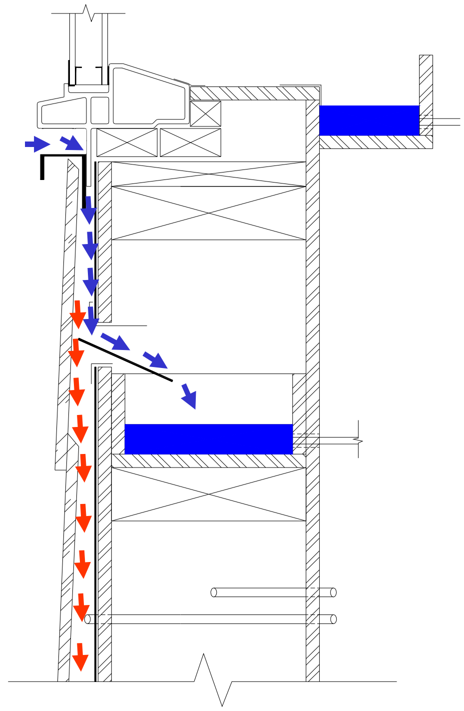


Figure 5-13: Test Trial 2 – Potential Paths of Water collection to trough 2

The removal of sealant and backer rod from a segment along the jamb (Test Trial 1) resulted in no water collection to trough 2 on either side of the wall. The most likely explanation is that little water came into contact with the vertical deficiency (as was evident, e.g. in specimen W1). Additionally, any water entering at this location was likely prevented from reaching the back side of the flange by the wall-window interface details of the B- and V-side of the wall, diverting water down the wall in the cavity behind the siding, and likely bypassing the collection trough.

The removal of sealant and backer rod from a segment along the joint between the siding J-trim and the windowsill (Test Trial 2) resulted in water collection mainly on the B-side, up to ~65 ml/min. The absence of sealant and backer rod created a horizontal pocket for water running down the face of the windowsill to accumulate and seep behind the J-trim and the siding. A deficiency in this region would allow water to enter between the J-trim and flange. During the test run with this deficiency in place in the specimen, water that collected in trough 2 did not necessarily come from the subsill area. A more likely scenario as seen with the use of blue arrows in Figure 5-13, is that water passed directly from the flange down the surface of the wall to the collection trough. This would help to explain why water only started entering the V-side at high pressures. Water on the V-side may have been clinging onto the back of the siding, or passing on the side of the trough. At higher chamber pressure and air barrier system leakage, the greater prevalent driving force to the trough may have helped direct the water to it.

The results from test Trial 3 (opening - narrow slit - in the siding above window head) can be related to the results from test Trial 2. Water was collected only in the B-side reservoir throughout this test Trial. In order for water to collect in the trough, it would have to either follow a path along the exterior of the window flange at the head, down the jambs and to the reservoir (blue path in Figure 5-14), or pass through the waterproofing layer and over the flange at the head of the window, down the jambs to the subsill, and to the collection trough. The first scenario is the most likely, as no water leakage was visually observed at the head of the window on the interior of the wall, or on the subsill. As in the previous test Trial, it is possible that no water entry was observed on the V-side of the wall because water followed a path along the inside of the cladding, or passed on either side of the reservoir opening.

Figure 5-14: Potential path of water to reservoir collection tray during test Trial 3

Although the results indicate that both the V-side and B-side wall-window interface details prevented water from attaining the subsill area for the deficiencies tested, it should be noted that it was not possible to differentiate water collection at the subsill from any other water collected at trough 2. For the subsequent set of specimens, improvements were made to the water collection method to help ensure that trough 2 only collected water from the subsill, and that water in the cavity behind the cladding was diverted to another collection trough.

Water Entry Dependencies

Water entry to the reservoir during the deficiencies did exhibit some of the same trends and dependences that were evident from results obtained on W1:

- **Was there evidence of an increase in water collection rates with increases in applied pressure differential across the specimen?**

Pressure drops, in percentage, were fairly constant for the range of applied chamber pressures. This implies that pressure drops increased as chamber pressure increased thereby creating a larger driving force for water entry. However, on the B-side, water entry was relatively constant across all applied pressure differentials indicative of little dependency in these instances. Hence there is no direct relationship between the magnitude of the pressure drive and water collection in trough 1 or 2. This may be due to a number of uncertainties, including the size of the openings, the magnitude of the water available at openings, the actual pressure difference at openings, or indeed, the convoluted path for water entry. The only instance in which this trend was evident was for test Trial 2 undertaken at 08 ABS leakage to water collection in trough 2 on the V-side.

- **Is there evidence of an increase in water collection with an increase in air barrier system leakage?**

In principle, a higher air barrier system leakage would create larger pressure drops in the wall, and therefore create a larger driving force for water entry. From the 03 to 08 ABS leakage, the pressure drops in the wall-window interface, as measured in percentage, increased roughly tenfold on both sides of the wall. In test Trial 3, water entry to the B-side reservoir increased with increase in air barrier system leakage, from 10 ml/min to 30 ml/min at the highest cascade rate. This increased ABS leakage resulted in water entry at the lower two cascade rates as well, where none had existed at the 03 ABS condition.

- **Is there evidence of increase in water entry with an increase in cascade rate?**

In principle it is expected that an increase in water deposition rate on the cladding (water load) will necessarily result in greater water entry and in turn, increases in water collection to the respective troughs. In reality the degree of entry, irrespective of the average amount of water available for entry, is accommodated, in large part, by the size of openings and if openings are sufficiently large, then is dependent on the water load at that opening. The sizes are a function of construction details, and in the test Trials, specified openings at defined locations were used, these openings being generally large (i.e. 2 to 12-mm wide by 90 to 150-mm long) in comparison to the size of deficiencies one would inherently expect following the fabrication of wall assembly (say ca. < 1-mm). The load at the opening may or may not be directly related to the average water deposition rate and there are a number of factors that affect the manner in which water may otherwise flow down the surface of a wall. In particular, consideration should be given to whether a wall has a number of vertical projections, or horizontal obstructions that would in the former case, channel the flow of water or, in the latter instance, divert the path of water flow either towards or away from openings (either small or large). Hence in some instances the load at the opening may be intermittent and for others more constant, depending on the nature of the details at the opening and the likelihood such details provide for the stooling or pooling of water.

Although the deficiency incorporated in test Trial 1,and consisting of a long narrow opening at the window jamb interface, did not result in any water collection, results from collection at trough 2 on the B-side in test Trial 3 for the 08 ABS leakage test condition indicated that each increase in cascade rate resulted in a 10 ml/min increase in water collection rate. Such instances were the exception and not the rule in this series of test Trials. For example, on the B-side for test Trial 2 for the 08 ABS leakage test condition, the 1.6 cascade rate resulted in higher rates of water collection than those obtained at the 3.4 cascade rate. This variation can in part be attributed due to water bypassing the collection trough as previously discussed.

Summary of Results and Observations

- The wall specimen was tested under a number of different simulated wind and rain conditions. Deficiencies were made to the wall-window interface to simulate failure. These deficiencies included a slit in the siding directly above the window, removal of a portion of caulking and backer rod along the jamb, and removal of a segment of caulking and backer rod along the corner of the subsill.

- Without added deficiencies, the wall-window interface details on both sides of the wall prevented water entry for the entire range of test conditions, up to 3.4 L/(min-m^2) cascade rate and 700 Pa applied chamber pressure. With deficiencies, both sides of the test specimen again prevented water from reaching the subsill. Water that was collected during the deficiency tests was attributed to water passing down the wall in the cavity behind the cladding. Additionally, no water entry was detected through the fixed flanged windows tested during these trials.

- Some trials during the Wall 2 tests exhibited water entry dependence on chamber pressure, air barrier leakage rate and water cascade rate – trends that were first exhibited during tests on W1.

- Water entry patterns in this wall assembly were quite complex and did not show a direct straightforward relationship with any single causal factor for water entry, be it water load, pressure load and opening for several reasons.

Chapter 6 —
Results from Watertightness Tests on Specimen W3

Introduction and Objective of Test Program

Focus in this Chapter is made on the specifications for and watertightness test results derived from specimen W3. These installation details were those for windows that included integral mounting flanges and solutions for detailing such windows when incorporated in a rainscreen wall. The use of PVC windows having integral mounting flanges is typically used in new construction but is increasingly being used when reconstruction of damaged facades is required. Given that for reconstruction there is also interest in applying a rainscreen wall solution, focus was placed on evaluating different variations of such installation details. In particular, there was interest in knowing the degree to which the different approaches would permit adequate drainage of the subsill area, and as well, whether the mounting flanges would restrict the rate of drainage from the subsill. A summary of the basic components incorporated in specimen W3 is given in Table 6-1. Configurations details are offered in the subsequent section.

Table 6-1: Summary of all window-wall cladding combinations selected for testing with emphasis on Specimen W3

Speci-men	Window Frame	Window Type*	Wall Type / Siding Installation	Variation (determine effect of)
W1	Box (Non-flanged)	Fixed	Rainscreen wall – clear cavity behind siding	Extra seal at junction of jambs and head of window R.O.**
W2	Flanged	Fixed	Concealed barrier wall – no clear cavity	Changes in protection of R.O.; back dam at subsill
W3		**Combination – Operable sliding (upper) / Fixed (lower)**	**Rainscreen wall – clear cavity behind siding**	**Two subsill drainage methods for flat subsill**
W4			Concealed barrier wall – no clear cavity	Sealing sheathing membrane to window flange

*All windows were fabricated of PVC**R.O.: rough opening

Description of Test Specimen W3

Specimen W3 included PVC combination windows (horizontal sliding upper portion of 800-mm height, CSA rating B3; fixed lower portion of 400-mm height, CSA rating B4; total assembly not rated), having integral mounting flanges that were installed in a rainscreen wall incorporating a 19-mm clear cavity behind the cladding. The hardboard siding was affixed to 19-mm pressure-treated furring strips, the strips fastened to 2-in. by 6-in. (38-mm by 138-mm) wood frame studs. The rough opening at the subsill (rough sill) was protected with strips of bituminous-based self-adhered membrane: one membrane covered the rough sill, the bottom of the rough jambs, and extended 150-mm over the sheathing membrane below the subsill. A second strip of self-adhered membrane covered the bottom 150-mm of the rough jambs and a 150 mm wide band of sheathing board. A paper-based asphalt impregnated product used for the sheathing membrane, was also used to protect the remaining portions of the rough opening extending along the height of the jambs and across the head of the window.

Of the two different installation methods, the specified practice (“base-case”; “B-side”) included installation of the window directly on the furring strips, as shown in Figure 6-1(a) and Figure 6-2 (a). The variation of this detail (“V-side”), shown in Figure 6-1 (b) and Figure 6-2 (b), had the window flange mounted to the protected sheathing board on the backside of which were placed shims (Fig. 6-2 (b); photograph) that provided a small space (2-3-mm) between the mounting flange and the board. The shims were made of small portions of bituminous-based self-adhered membrane that had been folded over and applied to the flange at fastener locations. The lower portion of the sheathing membrane just below the rough opening at the subsill was first installed followed by water proofing membrane applied to the subsill and lower portions of the jamb. Sheathing membrane when then placed along the rough opening at the jambs and head after which furring strips were installed adjacent to the window. The window was then installed, and drip cap flashing (rigid PVC), not incorporating end-dams, was installed at window heads. Thereafter, sheathing membrane was lapped over (no seal) the window flange at the head and jambs. Rigid metal flashing, served as windowsill drip cap, and was placed at the junction of the window and cladding. The 6-mm joint between the cladding and window frame was sealed with a backer rod and sealant.

Full vertical sectional views of both specimen halves are provided in Figure 6-3. A complete set of configuration details for specimen W3 are provided in Appendix A (Description of the Construction of CMHC Wall 3 Specimen). Key elements of W3 construction include:

- Horizontal hardboard siding
- 19-mm clear cavity behind the siding (furring strips)
- Sheathing membrane (WRB): paper-based asphalt impregnated
- Combination PVC flanged window – top horizontal slider, bottom fixed
- Flat subsill protected by self-adhered waterproof membrane and back dam
- Sealant and backer rod in 6 mm joint between the siding edge and window frame at jambs (no J-trim used)
- Drip cap head flashing (no end dams)
- Cap flashing at windowsill with sealant bead at joint between windowsill and flashing
- 2-in. by x 6-in. wood-frame construction

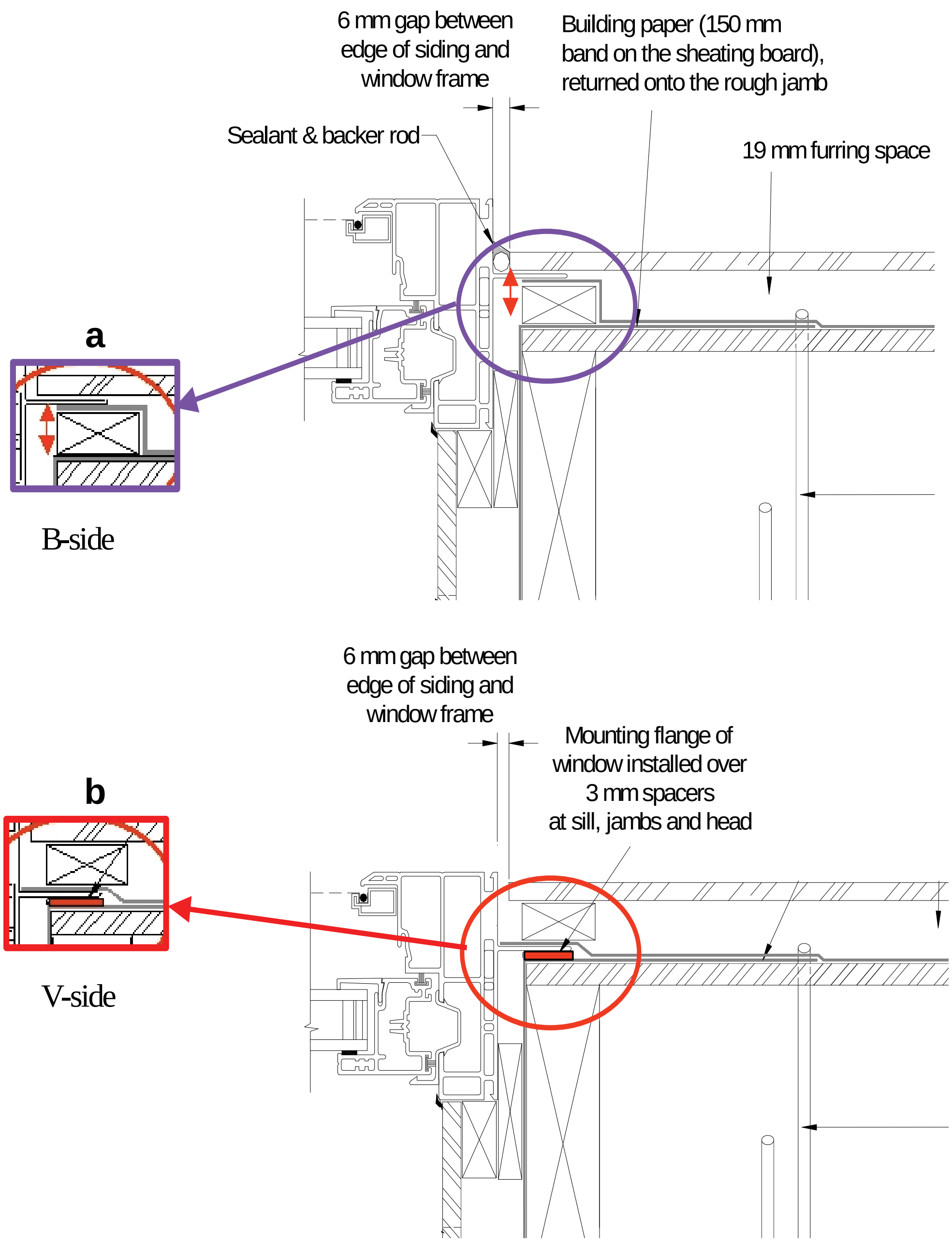
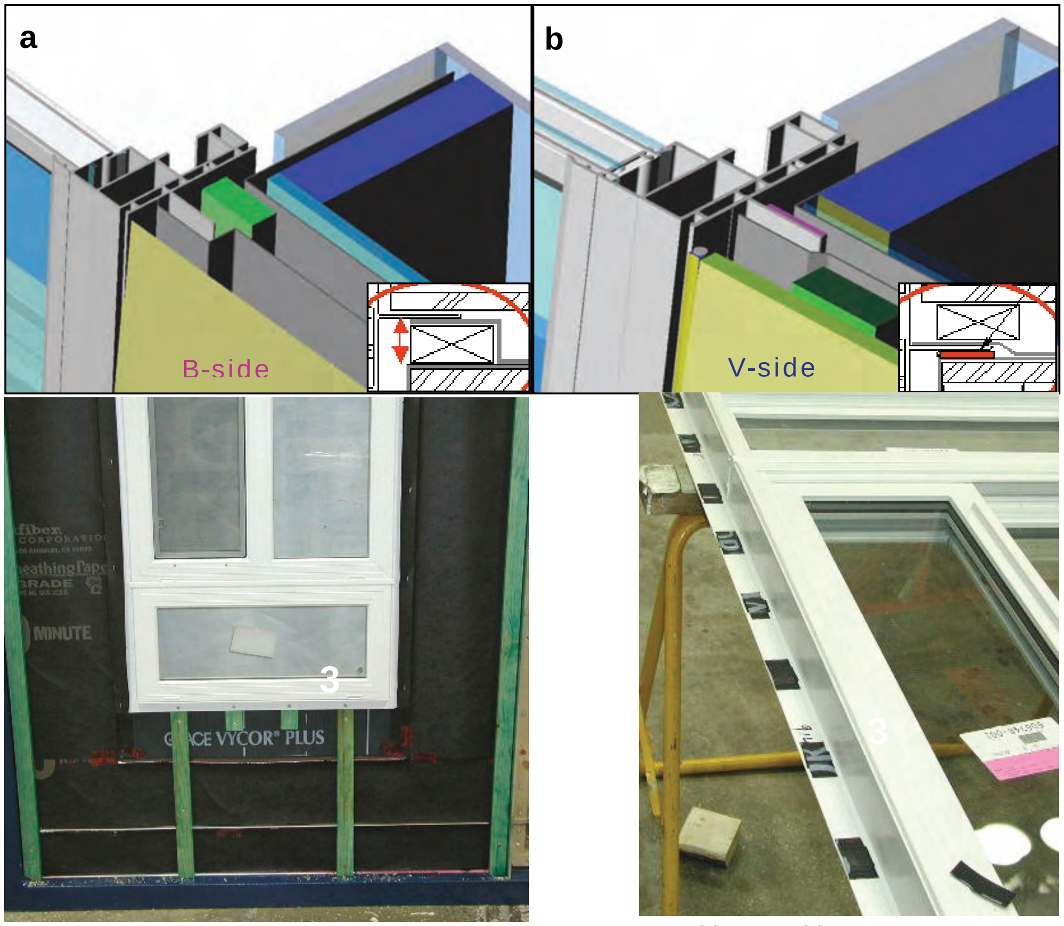


Figure 6-1: Horizontal Sectional views of Specimen W3 showing wall-window interface at jamb for (a) Selected practice (B-side; base-case) and (b) Variation (V-side) specimen configurations



Window installed over 19-mm furring strips

Shims provide a 2 to 3-mm gap

Figure 6-2: Schematic of horizontal section of (a) base-case ("B-side") window and photograph (below) showing window installed on 19-mm furring strips; (b) variation ("V-side") window and accompanying photograph (below) showing location of shims, fabricated from self-adhered flashing membrane, on backside of mounting flange; shims provide a 2 to 3-mm gap between flange and backup wall.

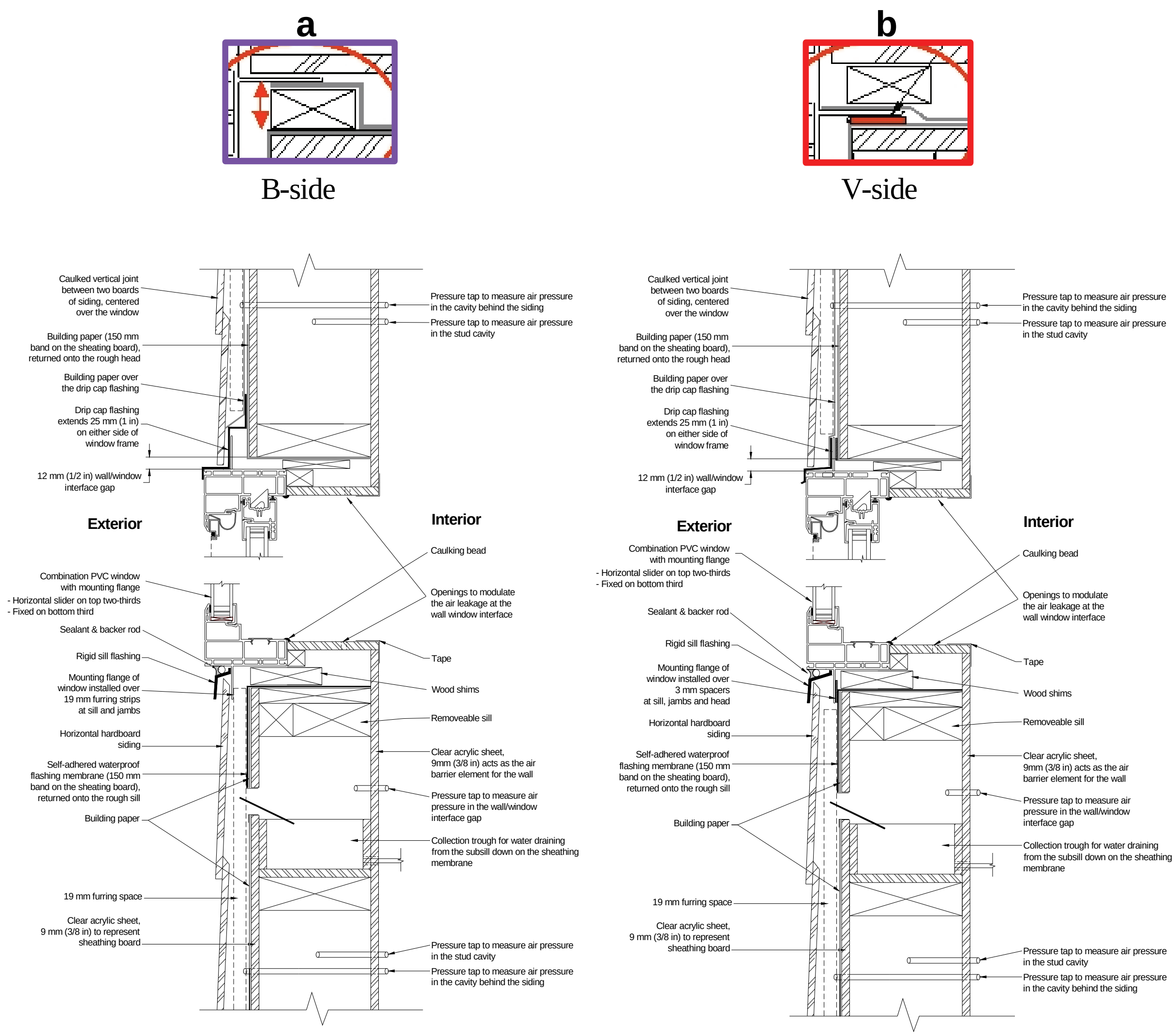


Figure 6-3: Vertical Sectional views of specimen W3 at the wall-window interface showing the (a) selected practice side (B-side; base-case) and (b) Variation (V-side) specimen configurations.

Summary of Test Protocol

In total, 18 water penetration or entry tests were performed for specimen W3 a summary of which is provided in Table 6-2. Test Trials were performed at a constant ABS leakage (03 ABS or 08 ABS leakage) and a constant rate of water application (0.8, 1.6, 3.4 L/(min-m^2)), and consisted of up to 7 tests at each of 7 different chamber pressures. During each test, pressure and level sensor data was collected every second over a period of approximately 15-minutes. Instances where tests were not conducted to the expected test levels have been noted as such. Test Trials were either performed in the "as-built" condition (i.e. nominally neither damaged nor altered), or including deficiencies to the wall assembly or modifications for collection of water with troughs added at the sill beneath the window.

In respect to deficiencies, three (3) sets were incorporated at the interface between the exterior cladding and the window frame and included: (1) 90-mm vertical slit (ca. 2-mm width) above window heads; (2) 90-mm missing length of sealant and backer rod located at the horizontal joint along the lower and outer corner of the window frame, at the junction of the window frame and the sill flashing, and; (3) a 90-mm long by 6 mm wide missing sealant and backer rod in a vertical joint at mid-height of the outer window jamb. Each of these locations is identified in Figure 6-4. As well, for each test Trial, the type, size and location of the deficiency is given and modifications are noted in Table 6-2 as applicable to the respective test Trial. For example, in Test Trial 2, undertaken at 03 ABS (nominal ABS leakage of 0.3 L/(s-m^2), the deficiency is described as a 1 to 3-mm by 90-mm bead of caulking removed from the sill joint located at the bottom outside corner of the window frame between the sill cap flashing and the underside of the window frame. A small graphic is included to help situate the general location of the deficiency in respect to half of the specimen. As noted previously, such type of deficiencies were chosen to simulate failure of the component due either to an inadvertent event, such as improper installation, or simply from natural aging. Additional details regarding deficiencies are provided in Appendix A.

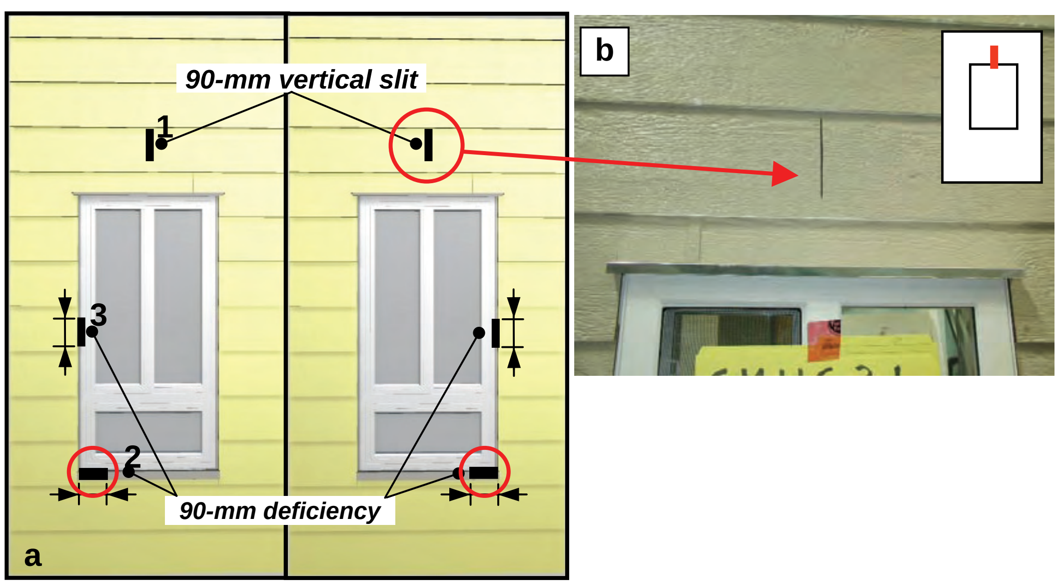
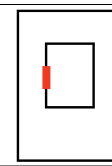
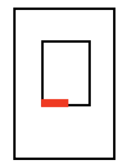
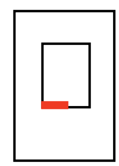
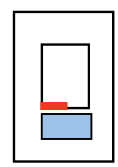
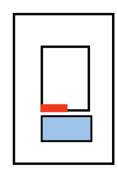
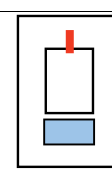


Figure 6-4: (a) Schematic of front elevation of 2.44-m by 2.44-m specimen (cladding exterior) showing nominal location of 90-mm deficiencies (missing sealant, backer rod at specimen face); (b) picture of 90-mm slit located above window of Specimen W3 – icon relates to test Trial description.

Table 6-2: Summary of Water Penetration or Entry Tests for Test Specimen W3

Condition	ABS	Cascade Rates (L/(min-m^2))	Description
As-built (No modifications or deficiencies)	03	0.8 1.6 3.4	Original Configuration, (No modifications or deficiencies)
As-built (No modifications or deficiencies)	08	0.8 1.6 3.4	Original Configuration, (No modifications or deficiencies)
Trial 1 Deficiencies*	08	3.4	6-mm by 90-mm caulking and backer rod removed from joint between window jamb and siding 
Trial 2 Deficiencies	03	0.8 1.6 3.4	1-3 mm by 90-mm caulking removed from sill joint at bottom outside corner of window frame between sill cap flashing and underside of window 
Trial 2 Deficiencies	08**	0.8 1.6 3.4	1-3 mm by 90-mm caulking removed from sill joint at bottom outside corner of window frame between sill cap flashing and underside of window 
Trial 2b Deficiencies and modifications	03	3.4	1-3 mm by 90-mm caulking removed from sill joint at bottom outside corner of window frame between sill cap flashing and underside of window  **Trough 2 – water collection at subsills**
Trial 2b Deficiencies and modifications	08	0.8 1.6 3.4	1-3 mm by 90-mm caulking removed from sill joint at bottom outside corner of window frame between sill cap flashing and underside of window  **Trough 2 – water collection at subsills**
Trial 3 Deficiencies* and modifications	08**	3.4	2-mm by 90-mm vertical slit in siding panel above window and includes **Trough 2 – water collection at subsills** 

***** No water collection measured in trough 3
** Wall only tested up to 500 Pa applied chamber pressure

Variation in Data Collection Methods and Techniques

Each half of Specimen W3 was instrumented with 8 pressure sensors and up to 4 collection trays, a summary description of which in provided below.

Pressure Sensors

Pressure sensors at different locations in the wall measured either the pressure differential in the stud cavity or the pressure differential in the cavity behind the siding (see Figure 6-5).

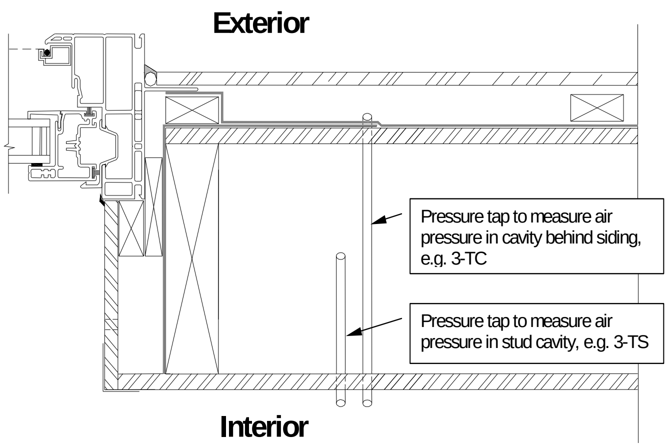


Figure 6-5: Pressure tap locations within wall section

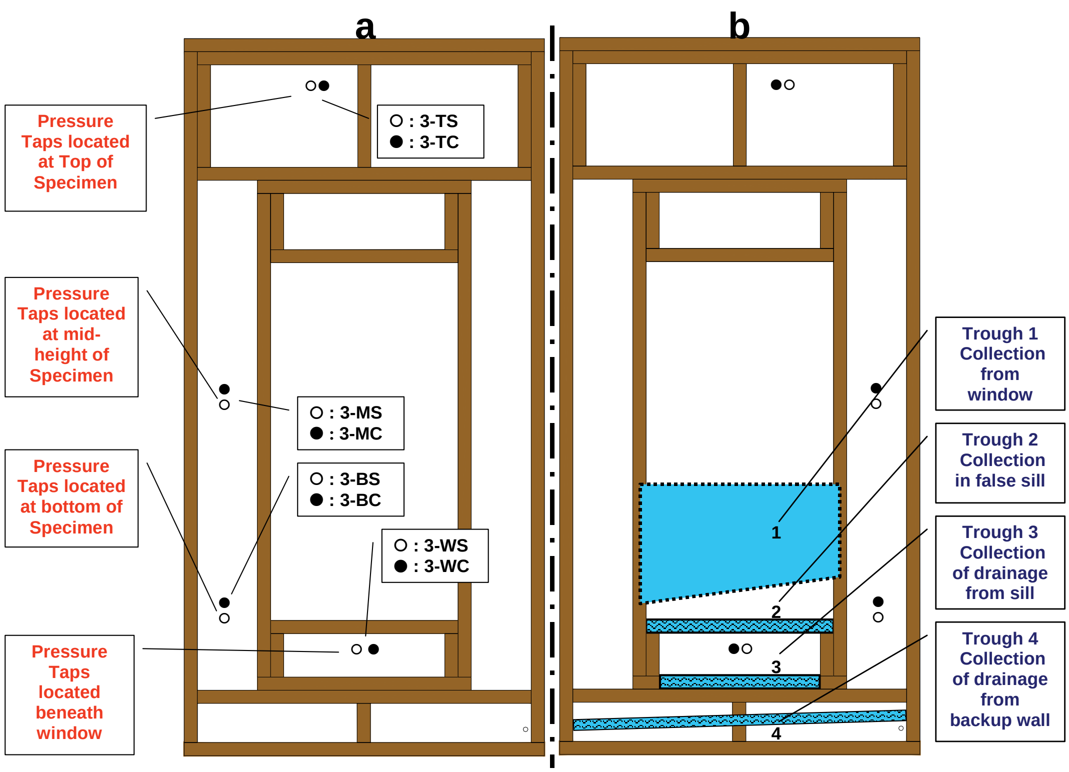


Figure 6-6: (a) Location of pressure taps along height of half-specimen and designated tap labels; (b) location of collection troughs 1 to 4 of half-specimen. Both sides of specimen had troughs located as shown in (b).

Water Collection Troughs

Water penetration at the window proper, entering unintended openings in the cladding and interface, or entering through deficiencies, was collected in troughs located as shown in Figure 6-6(b) and Figure 6-7(b). A trough located at (1) in Figure 6-6 (b) permitted collecting water that would penetrate the window between the lite and window frame; water accumulating at the subsill could be collected in a removable sill trough at (2), or in a trough located beneath the subsill at (3) which measured water drainage from the subsill to the trough; water finding its way behind the cladding and onto the backup wall would be collected near the base of the wall in the trough at (4). The trough at location (4) was a new addition as compared to the previous set of collection troughs used for water collection in Specimens W1 and W2. Nominally, this permitted quantifying the amount and rate of water entry along different paths and differentiating the significance of these paths given different test conditions.

For example, water entering the subsill area, as shown in Figure 6-8, would be expected to drain from the subsill down the front of the waterproof membrane and thereafter, into collection trough (3) beneath the subsill. As shown in the Figure 6-8, water was redirected to this trough using a protruding metal plate that was placed in a horizontal opening, a narrow slit, located ca. 180-mm below the edge of the subsill. The plate did not extend to the backside of the cladding hence it only collected water that drained along the backup wall.

As shown in Figure 6-7, when all four (4) collection troughs were in use, water collected in trough 1 (collection at window) and trough 4 (at base of wall in cavity behind cladding) were combined in a single container due to limitations on the number of available level sensors.

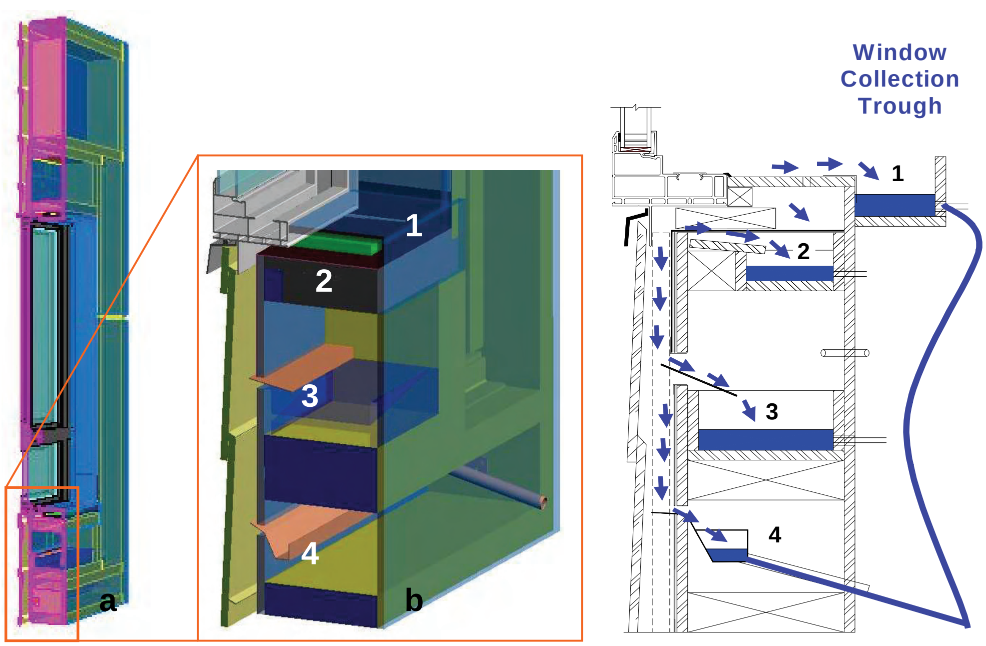


Figure 6-7: (a) Vertical wall section showing location (b) of water collection troughs at (1) window on interior side of test specimen, (2) beneath window in removable subsill; (3) beneath subsill for collection of water drained from subsill and, (4) lower most trough for collection behind siding.

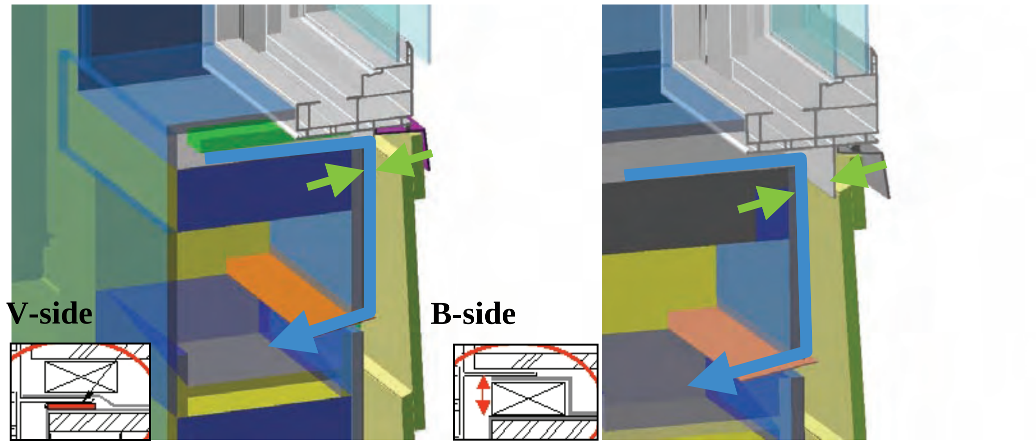


Figure 6-8: Expected direction of water drainage from subsill to collection trough (3) for variation (V-side) and base-case (B side) portions of specimen W3

Results from Watertightness Performance Tests – Specimen W3

Results of watertightness performance tests for specimen W3 are reported in terms of (1) air leakage of the assembly; (2) pressure drops across different components of the assembly and; (3) water penetration of and water entry to and through the assembly.

ABS Leakage

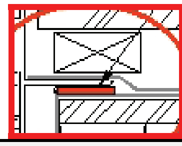
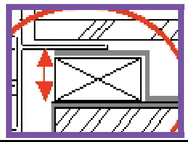
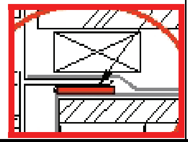
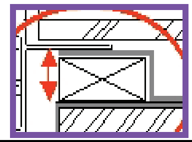
The air leakage of Specimen W3 as built (nominally 03 ABS) was approximately 0.29 L/(s-m^2) at 75 Pa chamber pressure, very close to the nominal 0.3 L/(s-m^2). The air leakage at the 08 ABS leakage condition was slightly higher than nominal, at approximately 0.96 L/(s-m^2). The intent of such tests was to ensure that specimens were tested in nominally the same conditions in respect to air leakage across the assembly; results suggest that W3 was within a 20% range of the target leakage for the ABS.

Pressure Drops Across Wall Assembly

A large pressure drop across a barrier provides a driving force for water entry through openings present in the plane of the barrier. As provided in Table 6-3, the lower air barrier system leakage (03 ABS), pressure drops in the cavity behind the cladding and stud cavity were small, most below 1% of the applied chamber pressure. Pressure drops in the wall assembly (i.e. taps 3-Tx, 3-Mx, 3-Bx; Figure 6-6a) did not significantly increase with increased ABS leakage and were similar for the B and V-side of specimen W3. Pressure drops at both wall-window interface locations (taps 3-WS and 3 –WC) were low, similar to drops in the wall assembly (cavity behind cladding and stud cavity). No significant changes in pressure drop were evident when deficiencies were incorporated in the test specimen at any of the pressure taps located in the wall or at the wall-window interface at either air barrier system leakage rate.

The pressure drops across the cladding and the exterior sheathing board were minimal on both the V-side and B-side of W3. This is a result of air to passing freely through the gap between the backup wall and window flange, thereby equalizing the pressure in the interstitial space between the window rough opening and the window frame with the chamber pressure. There was no large

Table 6-3: Stud and Cavity Pressure Drops Without Deficiency

Pressure Tap Location	03 ABS		08 ABS	
	V-side 	B-side 	V-side 	B-side 
3-TS	<1%	<1%	<1%	<1%
3-MS	1-2%	<1%	1-2.5%	<1%
3-BS	<1%	<1%	<1%	<1%
3-TC	<1.3%	N/A	<1.3%	N/A
3-MC	<1.3%	<1%	<0.4%	<0.5%
3-BC	<1.3%	<1%	<1.3%	<0.5%
3-WS	<1%	<0.5%	<1.3%	<0.7%
3-WC	<1%	<0.5%	<0.5%	<0.7%

difference in pressure drop when a comparison is made between the B- and the V-side of the specimen; the small 3-mm gap created by spacers on the V-side did not create any additional measurable restriction compared with the larger 19 mm gap present on the B-side. Such low pressure drops would be expected to create only a small driving force for water to penetrate through the wall-window interface

The designated air barrier system for the specimen was the interior finish, made of an assembly of transparent acrylic sheet sealed to each other and to the interior part of the window frame. The information in Table 6-3 shows that the pressure drop at several locations within the specimen assembly is low; this in turn indicates that the designated ABS was indeed the main plane of resistance to air flow and that the internal layers of the test specimen were well vented to the outside thereby allowing transfer of the external pressure to the designated ABS. The presence of a free cavity behind the siding and the absence of any sealing product applied to the interface between the window mounting flange and the sheathing membrane would help ensure both venting and pressure distribution. Increasing the air leakage from 03 to 08 did not affect the distribution of pressure within the assembly; the system being well vented, the ABS remained the primary plane of resistance to air leakage.

Results from Water Penetration and Water Entry Tests

The water penetration tests subjected the specimens to the simultaneous application of a water cascade on and pressure difference across the wall assembly. Specimens in a pristine condition were first tested and thereafter, deficiencies were introduced in the wall, as previously described, and the series of tests repeated for each deficiency and at two different levels of nominal air barrier system (ABS) leakage (“tight” – 0.3 L/(s-m^2); “leaky” 0.8 L/(s-m^2) at 75 Pa). Over the course of the test, rates of water entry (ml/min) to the respective collection troughs were recorded as were the pressure differential across the test assembly and water cascade rate.

Results for specimen tested as-built (without deficiencies)

Results from tests on the specimen in the as-built condition are summarised in Table 6-4. The information in the Table indicates very little or no collection of drainage from the subsill area (Trough 3) or behind the cladding (Trough 4) for either the B- or V-side of the specimen. The maximum rate of water collection in trough 4 was 15 ml/min on the B-side and 5 ml/min on the V-side. However, above a differential test pressure of 200 Pa, water entry at the windows increased substantially (Trough 1). This might have been expected given the sliding window used in the upper part of the combination window; the sliding window is rated as CSA B3 (i.e. 300 Pa). As shown in Figure 6-9, at the highest pressure differential, water cascade rate and degree of ABS leakage (i.e. 700 Pa and 3.4 L/(min-m^2) and 08 ABS, respectively) water entry at the window of the B-side was roughly double that of the V-side up to a maximum of 484 ml/min on the B-side, and 237 ml/min on the V-side. As well, above these pressure levels, the rate of water entry for either side was dependent on both, increases in water cascade rate and increases in pressure differential.

The difference in penetration rates across both the windows, that nominally have the same expected performance rating, was perhaps due to the difference in respective water “loads”, (i.e. quantity of water per unit area and time) at the face of the window proper. It is understood that these “loads” may be affected by protrusions from the cladding plane be they the window profile or drip cap flashing placed at the head of the window.

Both windows had head flashing however, the window on the B-side projected out from the cladding plane to a greater extent (~ 16-mm) than the window on the V-side; hence, the B-side window may have been exposed to more a more substantial water “load” accounting for the increased entry rates on the B-side as compared to the V-side of the window.

Table 6-4: Water collection at troughs for tests on As-built specimen W3 (no deficiencies)

Collection Trough	**V-side**		**B-side**	
	03 ABS	08 ABS	03 ABS	08 ABS
1 - window	No water entry for ΔP* < 200 Pa; increasing with increase in ΔP	No water entry for ΔP* < 200 Pa; increasing with increase in ΔP	No water entry for ΔP* < 200 Pa; increasing with increase in ΔP	No water entry for ΔP* < 200 Pa; increasing with increase in ΔP
**0.8 CR	100 ml/min (4.4%)	75 ml/min (3.3%)	80 ml/min (3.6%)	90 ml/min (4.1%)
1.6 CR	65 ml/min (1.3%)	100 ml/min (1.7%)	260 ml/min (5.3%)	190 ml/min (3.9%)
3.4 CR	150 ml/min (1.5%)	240 ml/min (2.3%)	350 ml/min (3.5%)	485 ml/min (4.6%)
3- drainage from subsill	No water entry	No water entry	Minimal water entry	Minimal water entry at 0.8 and 1.6 CR and 30 ml/min water entry at 3.4 CR, decreasing to nil at 500 and 700 Pa ΔP
4- drainage from behind cladding	No water entry	Minimal water collection (5 ml/min recorded in only a single trial)	Minimal water entry	Minimal water entry

* ΔP: nominal pressure differential condition between test chamber and laboratory;
** CR: Rate of water cascade: L/(min-m^2)

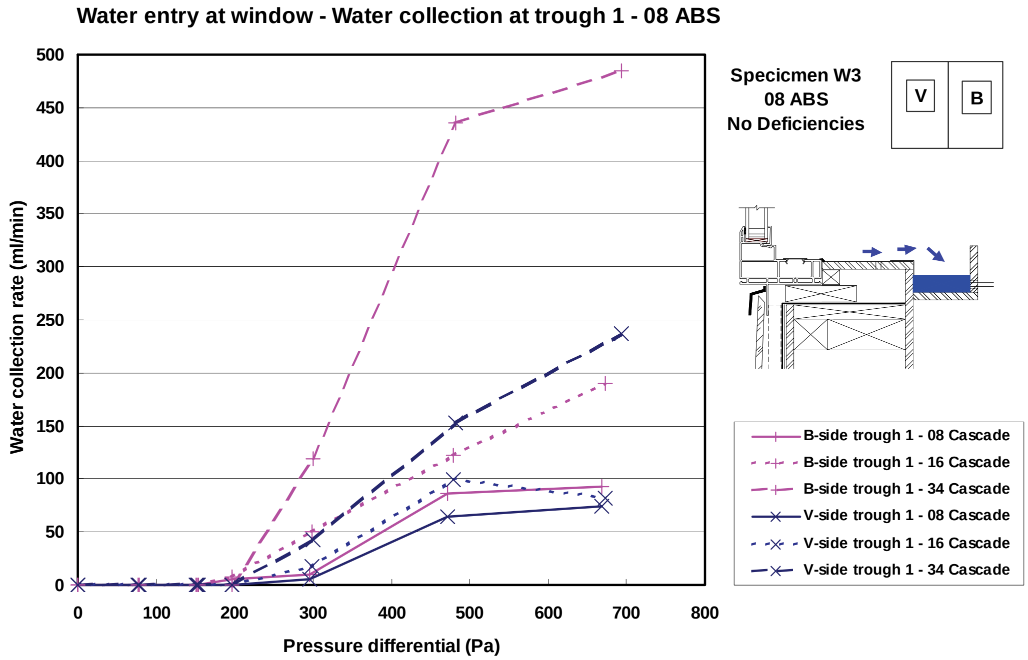


Figure 6-9: Water collection rates to Trough 1 located at window of specimen W3 (Figure 3 (c) – trough (1)); collection rates (ml/min) are shown in relation to pressure differential ("chamber pressure") across test specimen (Pa) for both B- and V-side of specimen at different water cascade rates for which, for example, "08 Cascade" refers to nominal cascade rate of 0.8 L/(min-m^2). The test was conducted for a specimen having an ABS leakage of 0.8 L/(s-m^2) at 75 Pa.

Water collection to trough 3 (Apparent drainage from sill) — As shown in Figure 6-10, no water was collected in trough 3 on the V-side throughout the trials; small amounts of water entered trough 3 on the B-side at low chamber pressures: up to 30 ml/min at 08 ABS leakage and a lower rate of 15 ml/min at a reduced ABS leakage (03 ABS). This water collection was not evident at chamber pressures above 300 Pa. Given that no water was collected in the corresponding trough on the V-side throughout the Trial do the results suggest that the B-side was any more vulnerable to water entry in respect to the design choice? The results are inconclusive in this respect and the variation in collection is difficult to attribute to any one source. Variations in finish of the jointing components or related details along the wall-window interface may have contributed to an increase in water entry to the subsill on the B- as compared to the V-side and this in turn may have resulted in the differences observed in the rates of collection. It could also be that the window on the B-side was defective and thus more prone to leakage to the interior as compared to that used on the V-side.

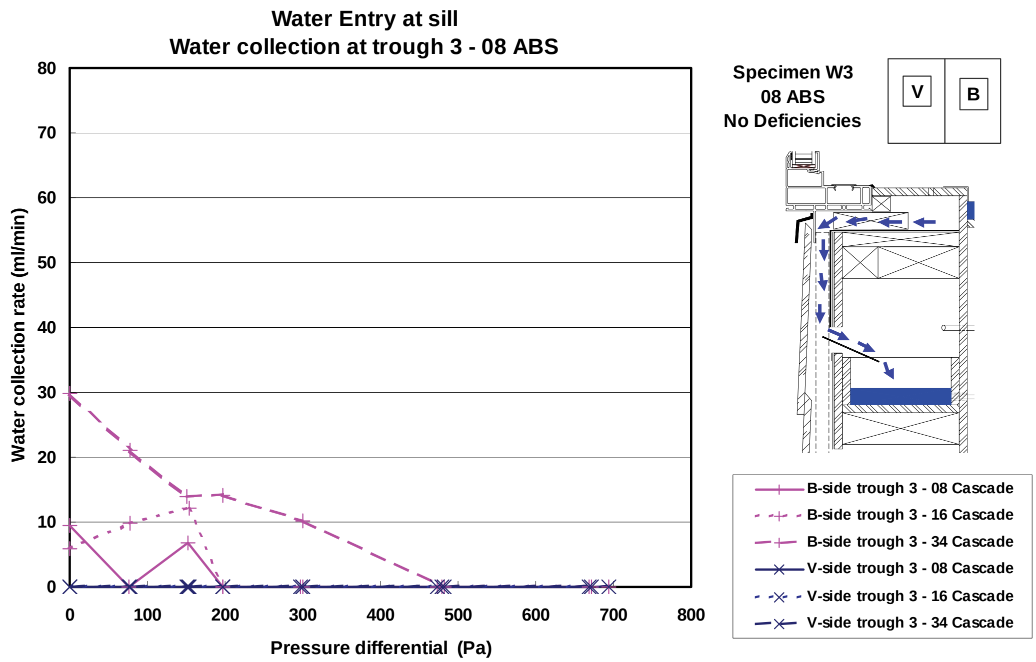


Figure 6-10: Water collection rates to trough 3 located beneath subsill of specimen W3; As built – 08 ABS

Results for specimen tested with deficiencies

Of the three deficiencies incorporated in the test specimen and subjected to tests conditions, the only deficiency that resulted in any substantial increase in water entry to any of the respective troughs as compared to results from tests with no deficiencies, was a 90-mm missing length of sealant and backer rod located along the horizontal joint at the lower and outer corner of the window frame (Trial 2; vz. circle, Figure 6-4 (a)). These results are first presented followed by those obtained from tests on Specimen W3 in which vertical openings were incorporated as deficiencies in the cladding (Trials 1 and 3).

Results from watertightness test Trial 2 (with deficiencies) — Results from Trial 2, that included a specified deficiency of a missing sealant and backer rod at the lower exterior corner interface of the window and cladding, are summarised in Table 6-5. The results are provided in terms of collection rates and related information at the different numbered troughs for the V- as compared to the B-side of specimen W3 for both sets of ABS leakage conditions. Trial 2b refers to the test Trial in which a removable subsill was used to collect water at the subsill location.

<u>Overview of collection in different troughs</u> – Both halves experienced water entry behind the first line of protection with the introduction of an unprotected opening at the lower exterior corner of the window frame (90-mm of caulking and backer rod removed at base corner of window frame). This resulted in substantial water collection to trough 4 (base of wall behind cladding) on the respective sides of specimen W3. In general, the V-side experienced a higher rate of water ingress at the cladding than the B-side when evaluated at either air leakage condition (Figure 6-11 and Figure 6-12). The interface configuration on the V-side allowed water entry through the

Table 6-5: Summary of Results from Watertightness Performance Tests of Specimen W3 - Trial 2

Collection Troughs 1 to 4	03 ABS V-side	03 ABS B-side	08 ABS V-side	08 ABS B-side
1 – Window				
	No water entry for ΔP* < 200 Pa; increases with increase in ΔP	No water entry for ΔP* < 200 Pa; increases with increase in ΔP	No water entry for ΔP* < 200 Pa; increases with increase in ΔP	No water entry for ΔP* < 200 Pa; increases with increase in ΔP
*0.8 cascade rate	90 ml/min	115 ml/min	170 ml/min	90 ml/min
1.6 cascade rate	130 ml/min at 500 Pa	180 ml/min at 500 Pa	140 ml/min	180 ml/min
3.4 cascade rate	260 ml/min	450 ml/min	225 ml/min	390 ml/min
2 – Subsill (Trial 2b)				
3.4 cascade rate	No water entry	~15 ml/min at low ΔP, nil at or above 200 Pa	No water entry	~20 ml/min at low ΔP
3 – Drainage from subsill				
*0.8 cascade rate	12 ml/min drop to 4 ml/min at ΔP 150 Pa then constant at higher ΔP	No water entry	No water ΔP < 200 Pa increase to ~25 ml/min at higher ΔP	~20 ml/min at low ΔP
1.6 cascade rate	Increase from 70 to 110 ml/min	~20 ml/min at low ΔP	Increase from 13 to 80 ml/min	~20 ml/min at low ΔP
3.4 cascade rate	Range of 0 to 100 ml/min	~20 ml/min at low ΔP no water entry for ΔP > 300 Pa	Range of 0 to 100 ml/min with no water entry at lowest two ΔP then drop to 0 ml/min at ΔP 500 Pa	~20 ml/min at low ΔP no water entry for ΔP > 300 Pa
Trial 2b				
0.8 cascade rate	N/A	N/A	~15 ml/min	No water entry
1.6 cascade rate	N/A	N/A	~130 ml/min	No water entry
3.4 cascade rate	Increase from 90 to 155 ml/min at ΔP 150 Pa, constant above ΔP 150 Pa	~8 ml/ min at low ΔP, no entry at or above ΔP 200 Pa	60 to 190 ml/min at 150 Pa then slow drop to 140 ml/min	Declining from 100 to 6 ml/min with increasing ΔP
4 – Drainage from behind cladding				
	Water entry - not dependant on ΔP	Water entry constant at all ΔP, increasing with cascade rate		
0.8 cascade rate	~25 ml/min	No water entry	~20 ml/min peak of 30 ml/min at 200 Pa	No water entry
1.6 cascade rate	~150 ml/min	~30 ml/min	Increase from ~40 to ~150 ml/min, then constant above 150 ΔP	~60 ml/min
3.4 cascade rate	Range of 50 to 150 ml/min	~80 ml/min	Increase from ~25 to ~50 ml/min with increase in ΔP	Increase from 8 to ~80 ml/min at 150 Pa, then constant
Trial - 2b at 3.4 cascade rate + trough 1 (window)	150 ml/min below 200 Pa, 130 ml/min above ΔP 200 Pa	~100 ml/min	Linear rise from 50 to 400 ml/min with increase in ΔP	From 45 to 600 ml/min

* missing sealant components and backer rod at lower exterior extremity of wall-window interface.

unprotected opening directly behind the cladding into the drained cavity where it could be intercepted, in part by collection in trough 3 (directly beneath the sill), or collected at the base of the wall in trough 4. The external unprotected opening on the V-side had a greater degree of exposure to water cascading down from the window to the sill as compared to the B-side. As well, the degree of water penetration at the window on the B-side (Trough 1) was greater than that for the same type of window on the V-side and this may have contributed to the reduced water load further downstream at the unprotected external opening.

Collection in Trough 3 - V-side – Water collection to Trough 3, indicating apparent drainage from subsill (Figure 6-11 and Figure 6-12), was consistently highest on the V-side of the wall, reaching approximately 110 ml/min before Trough 2 (collection at subsill) was installed, and up to 190 ml/min after the trough was in place. Water collection to Trough 3 on the V-side did not exhibit any consistent dependence on the applied pressure differential across the test specimen, fluctuating across the range of test pressures. There was some apparent dependence on cascade rate, the 0.8 cascade rate resulting in water collection below 25 ml/min. However, in all this set of test Trials, the water entry rate at the 1.6 cascade rate surpassed the water entry rate at the 3.4 cascade rate for one or more applied chamber pressures. The change in air barrier system leakage from 03 to 08 ABS resulted in no consistent increase or decrease in water collection to Trough 3 on the V-side of W3.

Collection in Trough 3 - B-side – Without Trough 2 in place (collection at subsill), water entry to Trough 3 (Figure 6-11 and Figure 6-12) on the B-side of the wall was similar to previous tests with no deficiency – small amounts of water entry (up to 20 ml/min) at applied pressure differentials below 300 Pa. With Trough 2 in place (see Figure 6-12), larger amounts of water entered Trough 3 on the B-side at the highest cascade rate, up to 100 ml/min at 0 Pa pressure, and decreasing to 10 ml/min at the highest pressure differentials. No significant water entry was detected at the 0.8 and 1.6 L/(min-m^2) cascade rates.

Trough 2 - Collection at subsill: B and V-side – As depicted in Figure 6-14, a small amount of water was collected in Trough 2 (collection at subsill) on the B-side of specimen W3 at the highest cascade rate - up to 20 ml/min at pressure differentials below 200 Pa, whereas no water was collected at the two lower cascade rates. Trough 2 on the V-side remained dry throughout the test Trials. As well, subsill water collection results (Trough 2) were similar for either ABS leakage conditions (03 and 08 ABS).

Trough 4 (behind cladding at base of wall) – Results of water collection to Trough 4, provided in Figure 6-15 and Figure 6-16, are in contrast to that obtained in the previous tests of the as-built specimen W3 (without deficiency) for which no collection was recorded. Water collection to Trough 4 was higher on the V-side of the wall than the B-side for both the 0.8 and 1.6 cascade rates. Water collection to Trough 4 on the V-side of W3 was highest at the 1.6 cascade rate, reaching a maximum of 167 ml/min. The maximum collection rate in Trough 4 on the B-side was 85 ml/min, recorded at a cascade rate of 3.4 L/(min-m^2) and 03 ABS leakage condition.

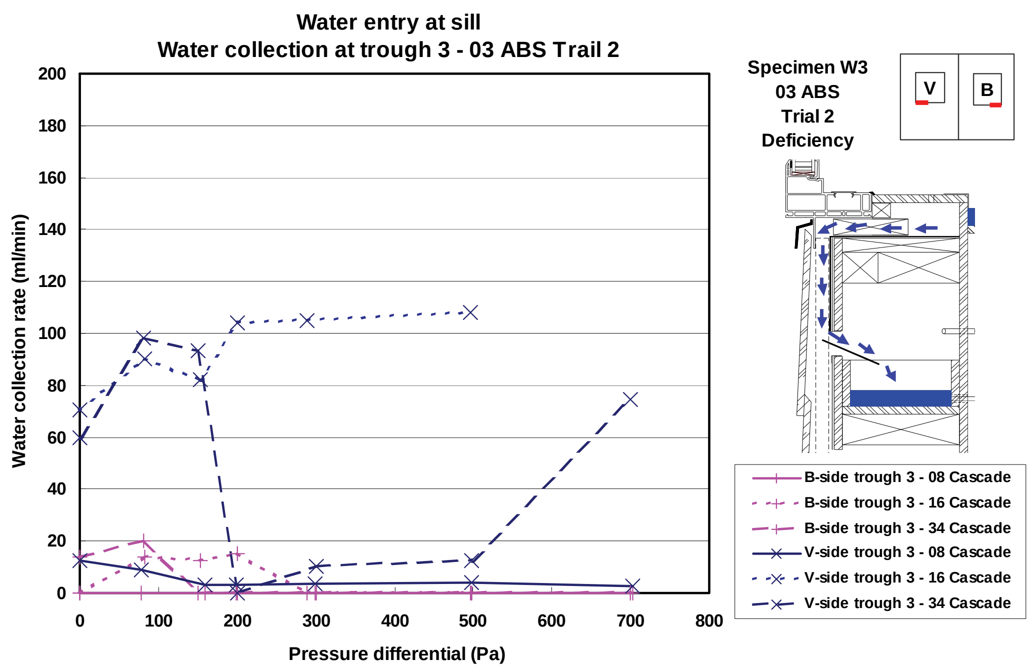


Figure 6-11: Specimen W3, Water collection to Trough 3, test Trial 2, Deficiency, 03 ABS

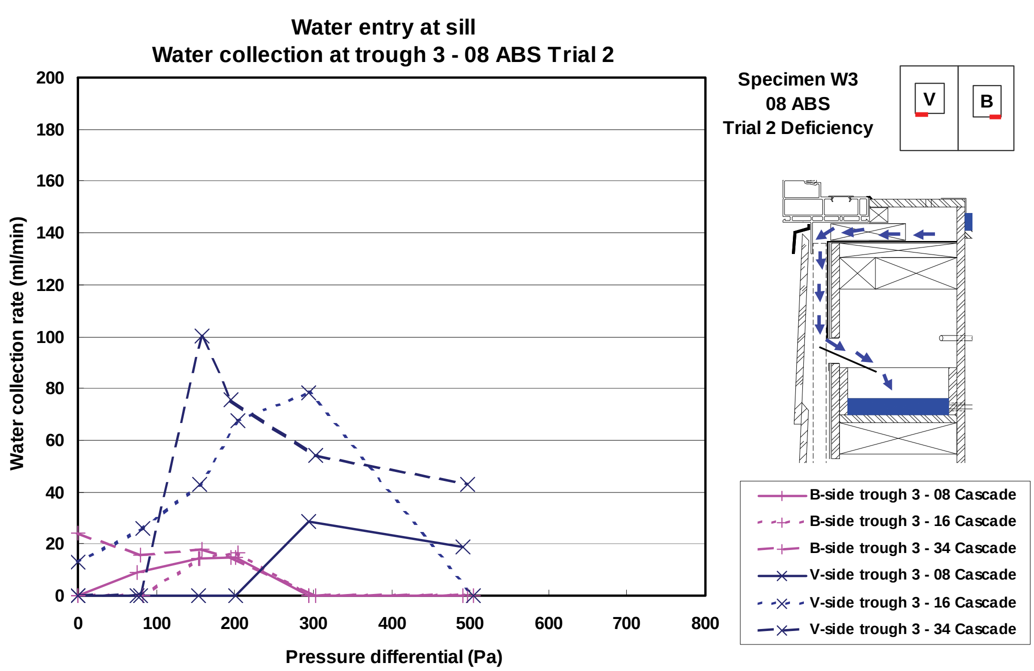


Figure 6-12: Specimen W3, Water collection to Trough 3, test Trial 2, Deficiency, 08 ABS

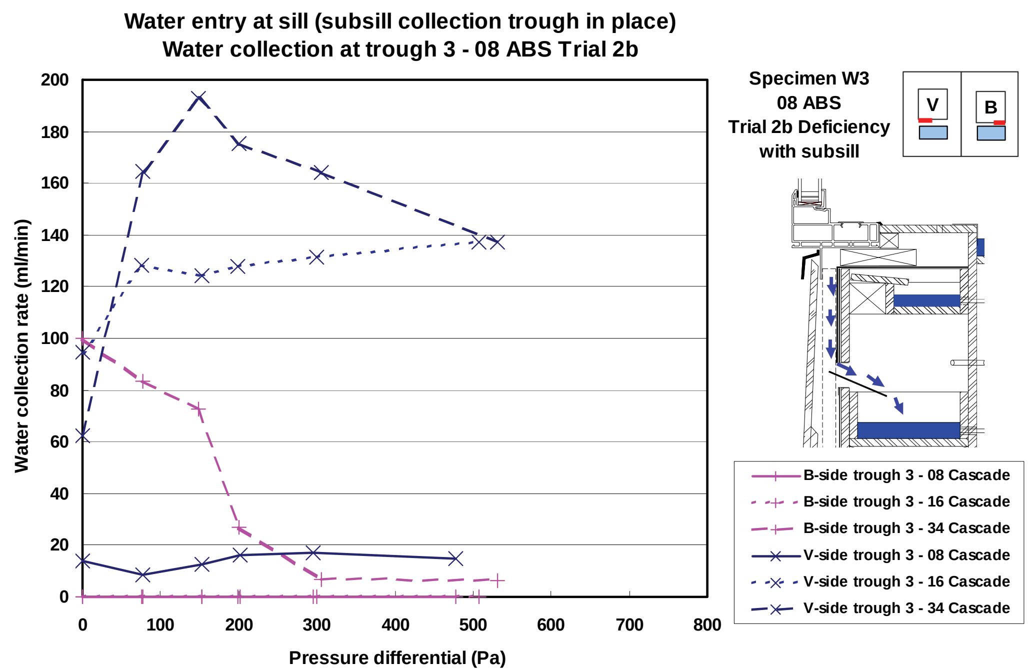


Figure 6-13: Specimen W3, Water collection to Trough 3, test Trial 2b (with removable subsill trough) and Deficiency, 08 ABS

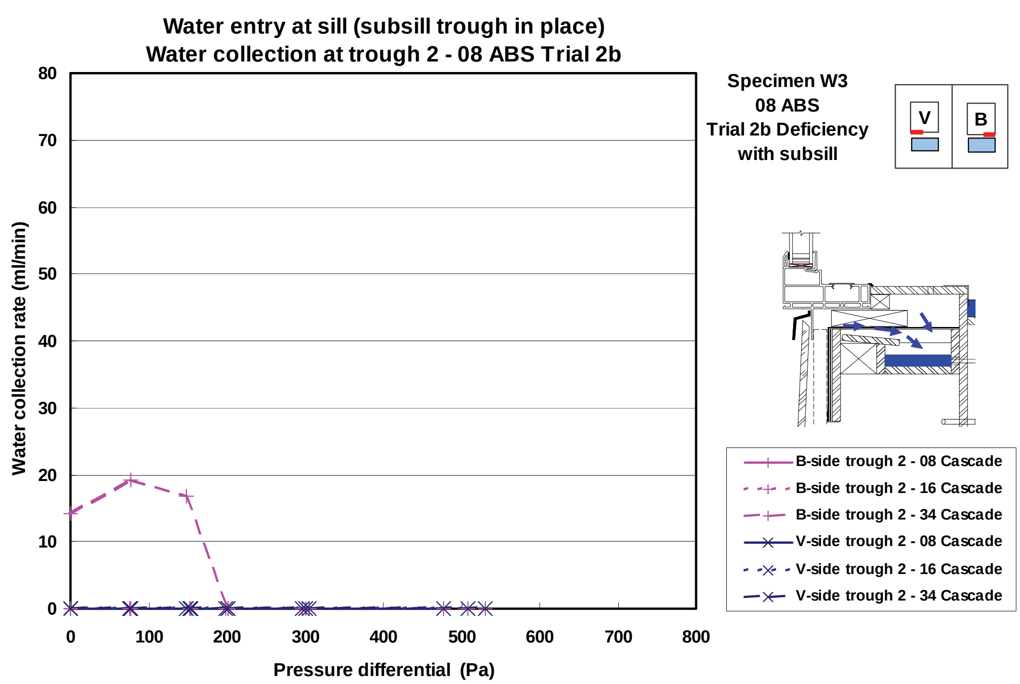


Figure 6-14: Specimen W3, Water collection to Trough 2 (removable subsill trough), test Trial 2b, and Deficiency, 08 ABS

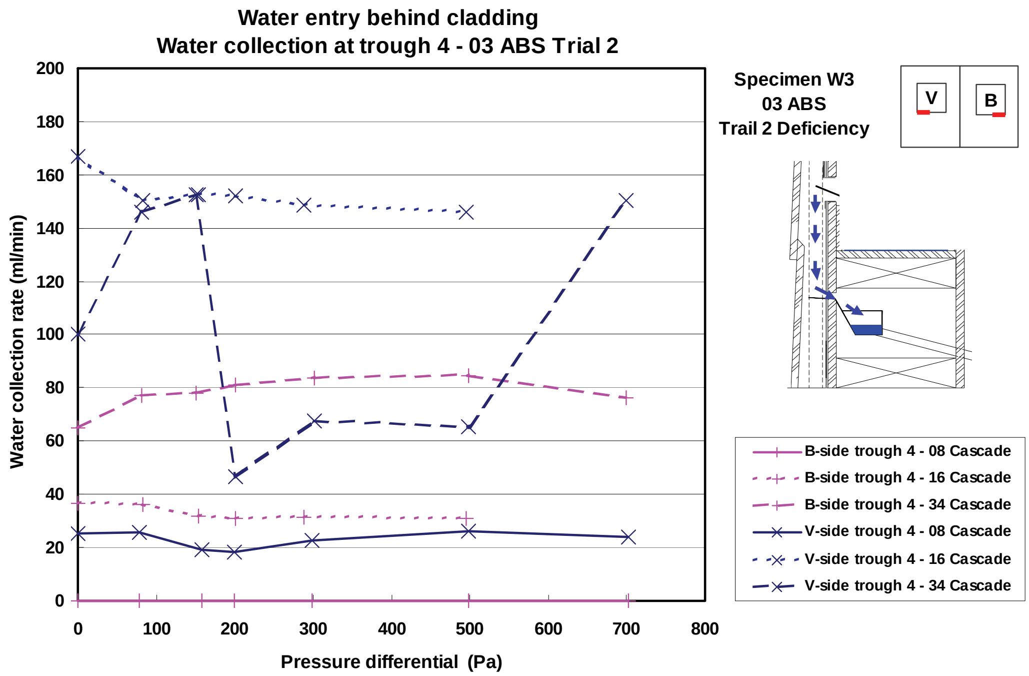


Figure 6-15: Specimen W3, Water collection to Trough 4 (base of wall behind cladding), test Trial 2, and Deficiency, 03 ABS

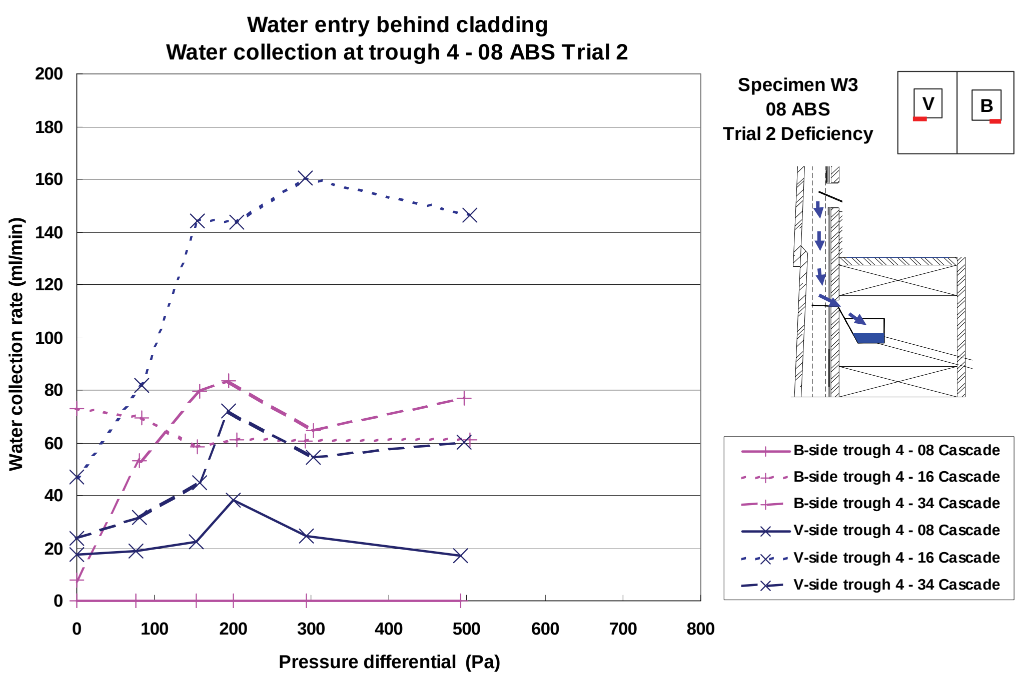


Figure 6-16: Specimen W3, Water collection to Trough 4 (base of wall behind cladding), test Trial 2, and Deficiency, 08 ABS

Discussion of results from trial 2 — Two collection trays were added to Specimen W3, in addition to the Trough 3, in order to develop a full picture of the methods of water entry through the wall-window interface. The three collection troughs – 2, 3 and 4 (collection at subsill with removable trough, drainage from subsill, behind cladding at base of wall, respectively) – all serve different complementary purposes. Trough 4 was intended for collection of water that might enter behind the cladding and drain down the backup wall. In a real installation, this water would drain safely down the wall to the outside. Water entry to Trough 3 (drainage from subsill) had two possible origins. Water could be directed to this trough from the subsill or, as seen in previous evaluations, water could be diverted directly to the trough from the cavity behind the siding. Trough 2 (collection at subsill with removable trough) was added to help distinguish between these two origins. With Trough 2 installed, water that reaches the subsill was collected at that location, and Trough 3 was reserved for water entry from other sources.

The objective in testing Specimen W3 was to determine the relative effectiveness of drainage from the subsill of two assemblies having different size of opening at the lip of the subsill; the size of opening through which water could drain being determined by the overall length and depth of the gap between the window flange and backup assembly at the lip of the subsill. The expectation was for the larger opening on the B-side of the wall to allow better drainage from the subsill. In terms of water collection, water collected in Trough 3 on the B-side of the wall before the installation of Trough 2 (subsill collection) would be expected to be larger or equal to the amount collected in Trough 2 following its installation. This would indicate that the entire amount of water that reached the subsill was successfully diverted to the exterior of the backup wall. By contrast, if the smaller opening on the V-side of the wall prevented proper water drainage from the subsill, the water collected in Trough 3 on the V-side of the wall before the installation of the subsill collection trough (Trough 2) would be smaller than the amount collected by Trough 2 when in place. This would indicate that some water was trapped in the subsill area.

Initial tests without deficiency and without subsill collection trough (Trough 2) revealed small amounts of water entry to Trough 3 on the B-side of the wall (~20 ml/min) at low chamber pressures. No water entry was detected in Trough 3 on the V-side of the wall. This could indicate that water was trapped in the subsill area of the V-side of the wall; however, subsequent tests with Trough 2 (collection at subsill) revealed that no water was reaching the V-side subsill area. On the B-side, water collection at the subsill (Trough 2) was consistent with water collection in Trough 3, indicating that all water reaching the B-side subsill was successfully drained to the outside of the wall. This water collection in Trough 2 on the B-side was no longer evident at chamber pressures above 300 Pa. However, this is coincident with the appearance of water collection in Trough 1 at the window. Apparently, at high chamber pressures, water that was originally collected in Trough 2 at the subsill no longer provided a load further down the wall, given that it had been diverted to a different path through the window itself.

The removal of caulking and backer rod from a segment at the corner of the windowsill (Trial 2) resulted in substantial water collection to Trough 3 on the V-side of the wall. This water came from the backup wall and not from the subsill, as was subsequently determined from trials with the subsill collection tray (Trial 2b). On the B-side, water collection to Trough 3 was consistent with the trials without deficiency, whereas water collection to Trough 4 increased. The small amount of water that reached the B-side subsill in the trials without deficiency was still present. Water entering the deficiency at the windowsill did not reach the subsill on either side of the wall and cascaded down the backup wall behind the cladding.

The fact that less water reached Trough 3 or Trough 4 on the B-side as compared to the V-side of the wall can be related directly to the differences in the construction of the two halves. Two items are considered that affected water loads at the unprotected openings in the cladding: (i) the effect of the projection of the window above the cladding, as shown in Figure 6-17; (ii) the detail at the interface between the window frame and windowsill flashing. Each will be considered in turn.

Projection of the window above the cladding – On the B-side, the window projected beyond the cladding because the window flange was installed over furring strips._This projection reduced the likelihood that water would accumulate on the windowsill flashing; essentially, it reduced the load in proximity to the unprotected opening. Water that did reach the cavity behind the cladding was directed away from the backup wall and the edge of trough 3 by the location of the flange, 19-mm away from the backup wall (See Figure 6-17).

On the V-side of the wall, the exterior surface of the window was almost flush with the cladding. There was a greater likelihood of water accumulating on this side as compared to the other. Water was more easily channeled towards the cavity behind the siding, and could easily overcome the 3-mm gap to the backup wall, and thereby to Trough 3. In this manner, more water entered the V-side of the wall than the B-side, and more of this water was channeled to Trough 3. This complex path of water entry also helps to explain the fluctuations in water collection results. Because water had a tendency to form streams on vertical surfaces, it would at intervals bypass the unprotected opening.

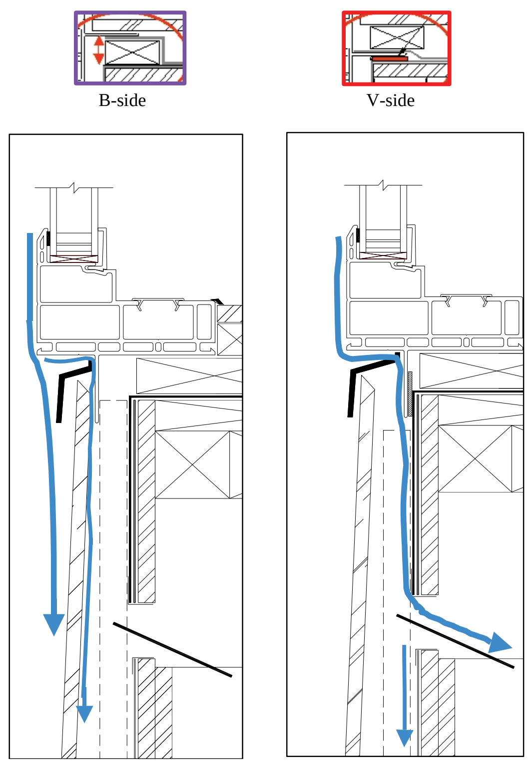


Figure 6-17: Sectional views of W3 showing projection of window above cladding at lower exterior corner of wall-window interface

Water entry at the windowsill flashing
In respect to water entry at the windowsill flashing, it is useful to first consider the likelihood of water penetrating the up-leg of the rigid metal flashing used beneath the window of both specimens. The intent of this flashing was to help drain water that had migrated from the window above the flashing, away from the cladding surface directly below the flashing. Additionally, it should also minimize water entry at its juncture with the windowsill.

Figure 6-18 (a) shows the lower corner details at the cladding-window interface and (b), the 4-mm cap flashing up-leg. It is supposed that water ran down the window face and, given the shallow slope of the cap flashing, pooled on the protruding flashing. Access to the back of the cap flashing was possible since the sealant and backer rod were removed at this location. Hence, the "pooled" water accumulated at this location and readily surmounted the ~ 4-mm cap flashing up-leg.

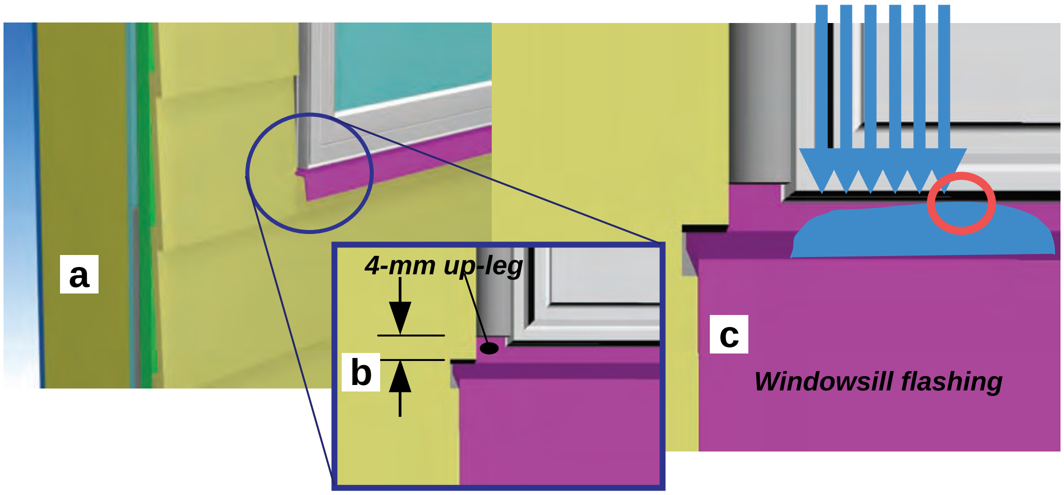


Figure 6-18: Variation-side of W3 and details of deficiency at (a) lower corner of window-cladding interface; (b) details of windowsill flashing showing 4-mm up-leg and; (c) water accumulation at windowsill flashing.

Figure 6-19 shows a vertical section at the wall-window interface for both the V- and B-sides of specimen W3. On the V-side (Figure 6-19 (a)), water surmounted the up-leg of the cap flashing and passed behind it, running down along the window mounting flange. However, the proximity of the mounting flange to the backup wall allowed water to bridge the 3-mm gap created by the shims at the back of the window flange. As shown in Figure 6-19 (b) for the B-side, water followed a similar path as on the V-side although the 19-mm gap created by the furring proved difficult to bridge. In both cases, a portion of water reached the backup wall and was collected at trough 3, with the remainder running down the interior of cladding and was collected at the base of the wall in trough 4. However, given the smaller gap of the V-side as compared to the B-side (3-mm / 19-mm) and the relative ease for water to bridge the smaller gap, implies that a greater amount of water collected on the V-side of the specimen.

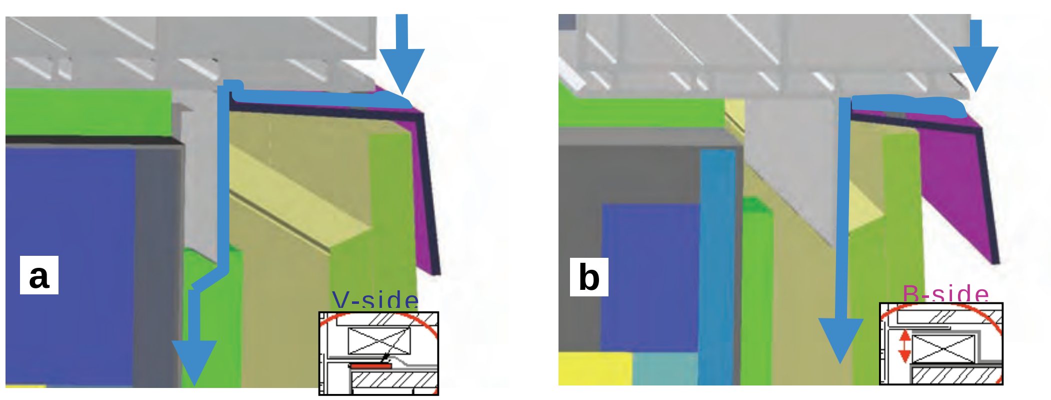


Figure 6-19: Vertical section at wall-window interface of (a) Variation, V-side and; (b) selected practice B-side of W3 showing path of water entry from outside to the interior behind cladding.

In respect to determining which interface detailing practice is preferable, both sides were shown to provide adequate protection when no deficiencies were present as in either case, little or no water entry was observed at the subsill. When deficiencies were introduced in the cladding-window interface, water entry was clearly more prevalent. However, given the rainscreen wall system, most of this water would not find its way to the subsill and would be drained to the base of the wall. The consequence of a deficiency such as the missing length of sealant and backer rod along the horizontal joint between the cap flashing and the junction between the cladding and the window frame would be additional water entry behind the cladding that would drain to the base of the wall, provided adequate details were provided to drain water at this location. The V-side detail, for which the mounting flange is but 3-mm from the backup wall, would necessarily have a greater proportion of this entry collect and flow down the backup wall. This might be considered as an increased risk to water entry for elements below the entry location in the event that these have been improperly installed.

One important aspect of this detailed review of water migration over the window, the pooling on the flashing and the subsequent entry through unintentional openings behind the cap flashing, is that such details can dictate whether water will or will not enter. Consider for example the sill cap flashing details as shown in Figures 6-17, -18. -19. The sill cap flashing is shown to have a downward slope, to promote, as expected, drainage from this surface; in reality, the flashing was installed with little or no slope thus providing for the possibility of pooling along its edge to the point where the 4-mm up-leg could readily be breached. Had the flashing been sloped, pooling would most likely not have occurred, or occurred to a lesser extent, although water may have momentarily been pressed to the opening of a sloped flashing when gusts of high wind occurred. This nonetheless clearly demonstrates the vulnerability of selected points in the assembly.

Results from watertightness test Trials 1 and 3 (with deficiencies) —
The vertical openings introduced in this specimen at two locations: one at the cladding-window frame interface, mid-height along the jamb (Trial 1), the other, a narrow slit located above the window head in the cladding (Trial 3). A summary of results is provided in Table 6-6; these are deficiencies that characteristically appear not to have provided substantial opportunity for water entry. For example, in Trial 3 (90-mm vertical slit in cladding above window) no water was collected in either troughs 3 or 4, whereas only small amounts of up to 12 ml/min were collected on the B-side in trough 2 (removable subsill trough) at low chamber pressures, as shown in Figure 6-20.

Table 6-6: Water collection at different troughs in relation to V- or B-side of specimen W3 for test Trial 1 (vertical opening along window jamb) and Trial 3 (vertical slit above window head)

Collection Trough	V-side		B-side	
	Trial 1 - 08 ABS	Trial 3 - 08 ABS	Trial 1 - 08 ABS	Trial 3 - 08 ABS
1 – window at 3.4 CR	No water entry for $\Delta P^* < 200$ Pa; increase with increase in ΔP to 175 ml/min (1.7%)	No water entry	No water entry for $\Delta P^* < 200$ Pa; increase with increase in ΔP to 430ml/min (4.3%)	No water entry
2-subsill	N/A	No water entry	N/A	Small amounts of water entry (~11 ml/min) at 0 and 75 Pa ΔP for CR 3.4
3- drainage from subsill	Minimal water entry	No water entry	Minimal water entry	No water entry
4- drainage from behind cladding	No water entry	No water entry	No water entry	No water entry

CR: Cascade rate: 3.4 L/(min-m^2); maximum ΔP of 500 Pa

One of the reasons for the lack of evidence of water entry may be related to the quantity of water available for entry through narrow vertical openings over which water may flow. In principle, for a given rate of water flow over the cladding, a uniform film of water forms thus providing a water "load" in proportion to the width over which it is applied. Hence, narrow vertical openings, such as those that may appear at the juncture of two cladding panels, necessarily have smaller potential for water entry as compared to wider horizontal openings, assuming the width of the horizontal openings are comparatively greater than that of a narrow slit. In practice, one must also consider protrusions up-stream of the flow of water that potentially affects the load downstream. Certainly, head flashing can affect water flow and flow over surfaces is not always uniform which may also lead to variations in the water "load" at openings, vertical or otherwise.

Hence given these different factors that may affect the rate of downward migration of water on a vertical surface, the degree of local wetting of surfaces may necessarily vary considerably from the average projected flow.

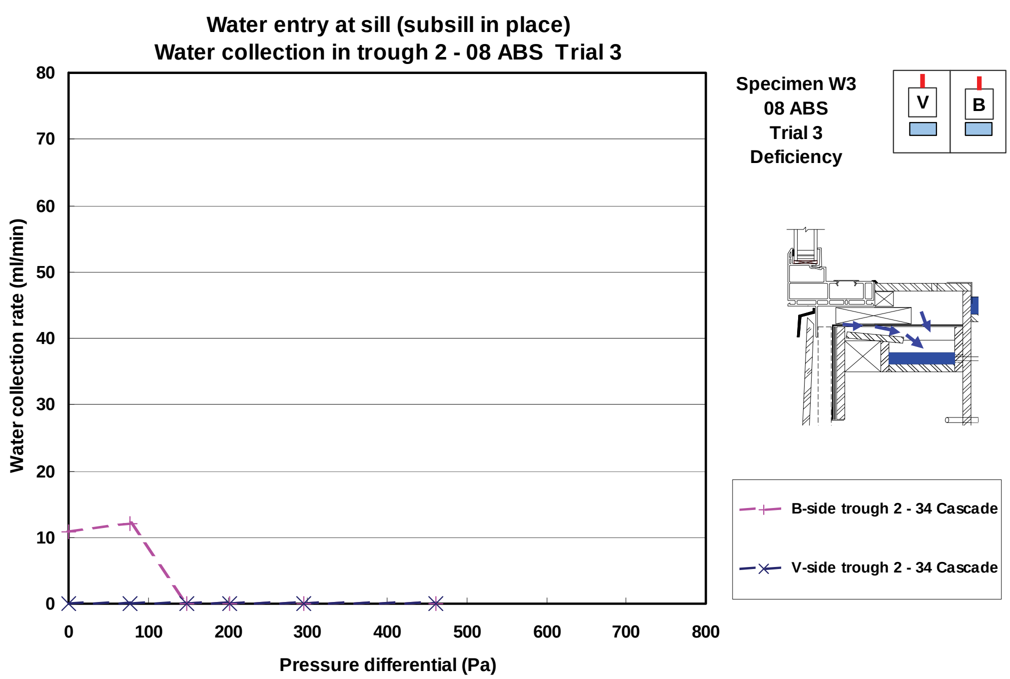


Figure 6-20: Specimen W3, Water collection to Trough 2 (removable subsill trough) test Trial 3, and Deficiency, 08 ABS

Summary of Results and Observations

- Two (2) variations of interface details were configured for a fixed PVC window incorporating mounting flanges and installed in a rainscreen wall. The windows were mounted either directly on 19-mm furring strips, or indirectly to the sheathing board with the use of shims consisting of portions of membrane placed on the backside and along the periphery of the flange at fastener locations.

- Little water entry was observed when no deficiencies were present in the specimen and limited amounts were collected when deficiencies were located along a vertical line.

- Water entry through the combination sliding-fixed window assembly was observed at pressures below the CSA performance rating of the fixed windows and rates of entry were substantial at higher test pressures; the entire assembly was however not rated as such.

- The consequence of missing sealant and backer rod along the horizontal joint between the cap flashing and the window frame was additional water entry behind the cladding.

- Although the nature of the entry at the deficiency was similar for both details, a greater proportion of entry was evident for that detail having a smaller gap for water to bridge as compared to the window installed on 19-mm furring strips.

- Hence for a given set of test conditions, a greater amount of water was expected to flow down the backup wall for the detail having the smaller 3-mm gap. This might be considered as an increased risk to water entry for elements below the entry location in the event that these have been improperly installed.

- The addition of a removable subsill trough (Trough 2) provided additional information on water entry that helped understanding water management of the respective window installation details.

- Cap flashing installed with no or little slope (i.e. level, flat), can act to collect water where it can pool and thereafter risk being redirected towards the interior.

- The geometric configuration of the different components in a wall, such as the cladding, the location of the window (in or out of plane with the wall), cap or head flashing, all can affect the water “load” at any of the wall-window interfaces; the path for water migration over the surface of the cladding and related wall components is complex and difficult to predict.

Chapter 7 — Results from Watertightness Tests on Specimen W4

Introduction and Objective of Test Program

Focus in this Chapter is made on the specifications for, and watertightness test results derived from, specimen W4. These installation details were those for windows that included integral mounting flanges and solutions for detailing such windows when incorporated in a non-rainscreen concealed barrier wall. As previously stated, the overall intent was to determine if, between different approaches, significant differences would be observed in respect to the water management of the respective details. There was, in this set of test Trials, particular interest in gaining some information on different approaches to the sealing of the sheathing membrane at the perimeter of the window frame at the flange and whether or not such approaches would provide adequate protection against water entry should there not be a seal applied at the window perimeter between the cladding and window frame. As well, there was interest in assessing the degree to which the different approaches would permit adequate drainage of the subsill.

A summary of the basic components incorporated in specimen W4 is given in Table 7-1. Configuration details are offered in the subsequent section.

Table 7-1: Summary of all window-wall cladding combinations selected for testing with emphasis on Specimen W4

Speci-men	Window Frame	Window Type*	Wall Type / Siding Installation	Variation (determine effect of)
W1	Box (Non-flanged)	Fixed	Rainscreen wall – clear cavity behind siding	Extra seal at junction of jambs and head of window R.O.**
W2	Flanged	Fixed	Concealed barrier wall – no clear cavity	Changes in protection of R.O.; back dam at subsill
W2		Combination – Operable sliding (upper) / Fixed (lower)	Rainscreen wall – clear cavity behind siding	Two subsill drainage methods for flat sill
W4			**Concealed barrier wall – no clear cavity**	**Seal sheathing membrane to window flange**

*All windows were fabricated of PVC; **R.O.: rough opening

Description of Test Specimen W4

Specimen W4 included PVC combination windows[†] having integral mounting flanges, that were installed in a concealed barrier wall assembly, hence a wall assembly having no clear cavity behind the cladding. Hardboard siding was affixed to 2-in. by 6-in. (38-mm by 138-mm) wood frame studs. A polyolefin-based spun-bonded textile product was used as sheathing membrane.

In both halves of Specimen W4 the sheathing membrane was installed after the installation of the window, as is often the case in current wood frame construction practice. However on the B-side, the sheathing membrane was sealed to the window frame at its perimeter using 50-mm wide strips of self-adhered elastomeric membrane whereas on the V-side, the sheathing membrane was lapped over the window flange without additional measures to ensure a seal.

Both sides had a self-adhered membrane covering the exposed face of the rough sill and rough jambs and the membrane was folded onto the sheathing board. On the V-side, the sheathing membrane was lapped over the window flange at the jambs and head and at the rough sill, the window flange laps over the sheathing membrane.

The interface between the cladding and the window jambs and sill did not in this instance include the use of a sealant or backer rod and hence there was a 6-mm opening present between the edge of the cladding and window frame. As well, no drip cap head flashing was used.

Horizontal sectional views for the B- and V-sides showing the wall-window interface at the jamb of specimen W4 are provided in Figure 7-1 in which differences between approaches are highlighted in the figure. Given the similarities between both details; the V-side is described in a smaller figure that serves to illustrates the differences along the jamb and emphasizes the lack of a self-adhered membrane that was used on the B-side detail at this interface location.

As well, a full vertical sectional view of the B-side of the specimen is provided in Figure 7-2, in which the V-side, as was done for the horizontal section view, is described in a small figure that illustrates the differences along the head and the sill that differ from those details of the B-side.

A complete set of configuration details for specimen W4 are provided in Appendix A. (Description of the Construction of W4 Specimen). Key elements of W4 construction include:

- Horizontal hardboard siding
- Concealed barrier wall; no clear cavity behind the siding (no furring strips)
- Combination PVC flanged window – top slider, bottom fixed (CSA rating: top B3, bottom B4)
- No sealant at 6 mm joint between siding and window frame; no J-trim
- No drip cap head flashing
- Rough sill and jambs with protective membrane
- Spun-bonded polyolefin membrane (sheathing membrane)
- 2-in. by 6-in. wood frame construction

[†] Horizontal sliding upper portion of 800-mm height, CSA rating B3; fixed lower portion of 400-mm height, CSA rating B4; total assembly not rated

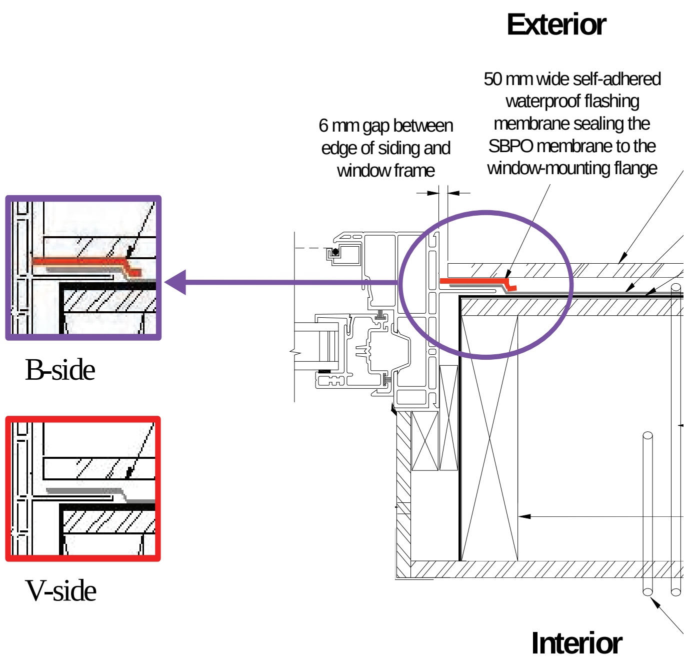


Figure 7-1: Horizontal Section view of Wall-Window Interface at Jamb – specified practice, Base-case (B-side) and variation of base case, (V-side)

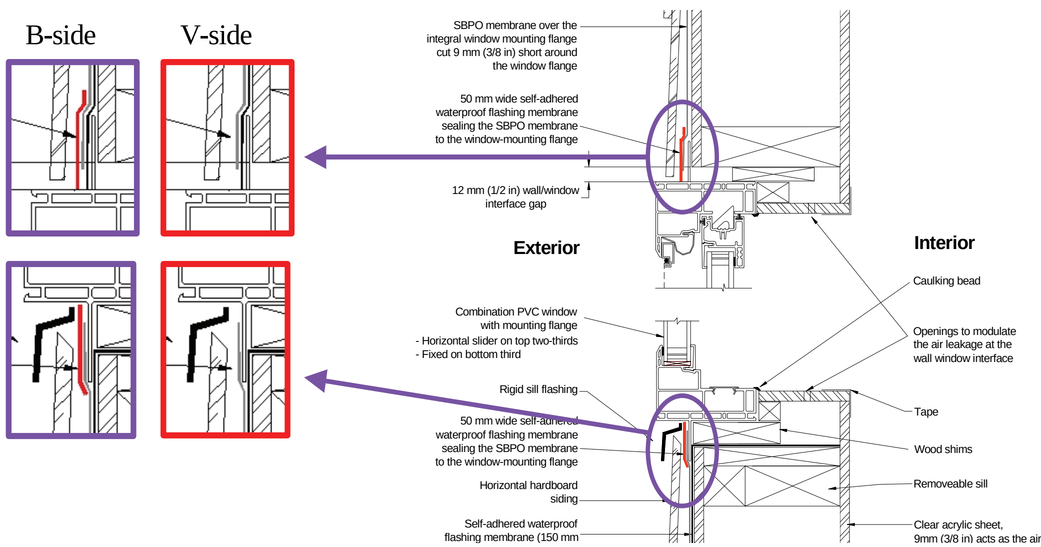


Figure 7-2: Vertical Section view of Wall-Window Interface – Base case and Variation

Following the initial water collection tests carried out on Specimen W4, and upon further investigation of water entry points along the wall-window interface, additional modifications to the specimen were made. This included adding a self-adhered membrane behind the sheathing membrane at the head of both the V-side and B-side of the wall, as shown in Figure 7-3. Another series of tests was then conducted to determine the effect of adding this membrane on the watertightness of the window installation.

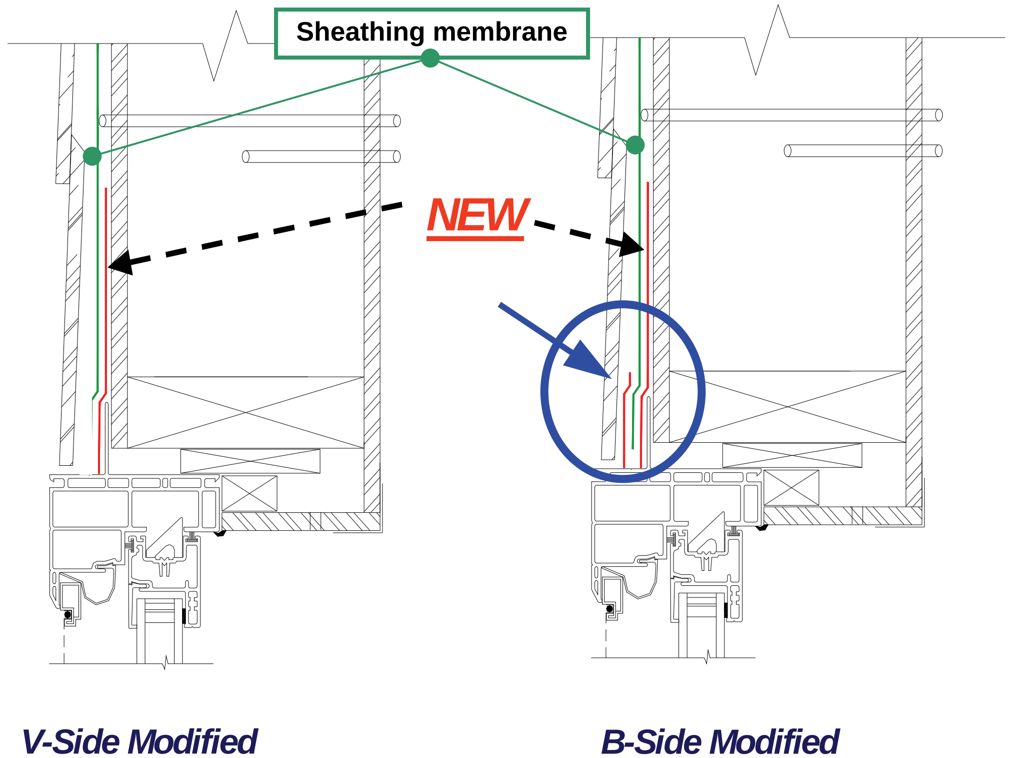


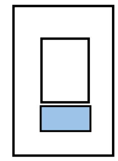
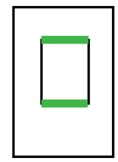
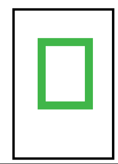
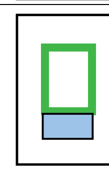
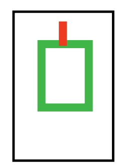
Figure 7-3: Modifications at head of Specimen W4 for Repeat Tests

Summary of Test Protocol

In total, 17 water collection tests were performed for Specimen W4 as originally built. These tests are described in Table 7-2. Each test was performed at a constant ABS leakage and a constant cascade rate, and consisted of up to 7 subtests at each of 7 different pressure differentials. During each subtest, pressure and level sensor data was collected every second over a period of approximately 15 minutes.

For the previous three wall specimens, tests were performed in the “as-built” condition, as well as with deficiencies incorporated to the cladding at the wall-window interface. These deficiencies were chosen to simulate potential failure of the jointing system that could occur due to improper installation or aging of the sealant. Given that the initial test results derived from Specimen W4 in the as-built condition (i.e. 6-mm open joint between cladding and window frame; no sealant or backer rod used) revealed significant amounts of water collection in relation to previous initial tests on specimens W1 to W3 inclusive, it was decided that the interface between the cladding and window frame would be sealed, as opposed to adding deficiencies. Since the testing sequence does not exclusively refer to the incorporation of deficiencies in the cladding or interface, these have been referred to as modifications and are listed in Table 7-2.

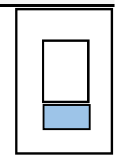
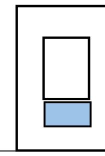
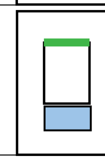
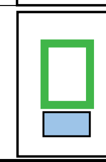
Table 7-2: Summary of Initial Water Penetration or Entry Tests for Test Specimen W4

Condition	ABS*	Cascade Rates (L/(min-m²))	Description
No Modifications	03	0.8 1.6 3.4	Original Configuration
No Modifications	08	0.8 1.6 3.4	Original Configuration
Trial 1 No Modifications and use of Subsill	08	0.8 1.6 3.4	Use of subsill collection trough and no modifications (No sealant at wall-window interface on cladding side) 
Trial 2 Modification	08	0.8 1.6 3.4	A modification with bottom and top of window-cladding interfaces sealed 
Trial 3 Modification	08	0.8 1.6 3.4	A modification with perimeter of window-cladding interfaces sealed 
Trial 4 Modification with Subsill	08	3.4	A modification with perimeter of window-cladding interfaces sealed and use of subsill collection trough. 
Trial 5 Modification	08	3.4	A modification with perimeter of window-cladding interfaces sealed; opening in cladding above window (narrow slit: 2 by 150-mm) 

* ABS – Air Barrier System leakage: 03 ABS – nominally 0.3 L/(s-m^2); 08 ABS – nominally 0.8 L/(s-m^2)

Following completion of an entire set of water collection tests on Specimen W4, a self-adhered membrane was added behind the sheathing membrane at the head of both the V-side and the B-side, sealing the window flange to the sheathing board. The wall was tested again to determine the effect of adding this membrane on water collection at the head of the window. This reduced test series included a set of 11 water collection tests. These have been referred to as “Specimen W4 repeat” and the test Trials are listed in Table 7-3. Throughout the test Trials for Specimen W4 repeat, the level sensor servicing the V-side collection trough 3 was accidentally disconnected. Hence no results for this trough are available from this series of repeated tests.

Table 7-3: Specimen W4 - Repeated Water collection Tests

Condition	ABS	Cascade Rates (L/(min-m^2))	Description
No Modifications*	03	0.8 1.6 3.4	Original Configuration, use of subsill collection trough – No sealant at wall-window interface on cladding side 
No Modifications *	08	1.6 3.4	Original Configuration, use of subsill collection trough – No sealant at wall-window interface on cladding side 
Trial 2 Modifications*	08	0.8 1.6 3.4	A modification with top window/cladding interfaces sealed and use of subsill collection trough 
Trial 3 Modifications*	08	0.8 1.6 3.4	A modification with all window/cladding interfaces sealed and use of subsill collection trough 

* V-side trough 3 level sensor disconnected – no water collection data collected

Variation in Data Collection Methods and Techniques

Each half of Specimen W4 was instrumented with 8 pressure sensors and 4 collection troughs, a summary description of which in provided below.

Pressure Sensors

Pressure taps connected to pressure sensors permitted measuring pressure differentials at different locations in the wall as shown in Figure 7-4 and Figure 7-5 respectively. Figure 7-4 provides a schematic of the location of pressure taps in proximity to the window jamb, such as locations at approximately the mid-height of the specimen given as 4-MS and -MC in Figure 7-5. Such taps measured the pressure differential in either the stud cavity (4-MS) or the cavity behind the siding (4-MC).

Water Collection Troughs

Water penetration at the window proper, entering unintended openings in the cladding and interface, or entering through deficiencies, was collected in troughs located as shown in Figure 7-6(b). A trough located at (1) in Figure 7-6(b) permitted collecting water that would penetrate the window between the lite and window frame; water accumulating at the subsill could be collected in a removable trough at (2), or in a trough located beneath the subsill at (3) which measured water drainage from the subsill to the trough; water finding its way behind the cladding and onto the backup wall would be collected near the base of the wall in the trough at (4).

Nominally, this permitted quantifying the amount and rate of water entry along different paths and differentiating the significance of these paths given different test conditions.

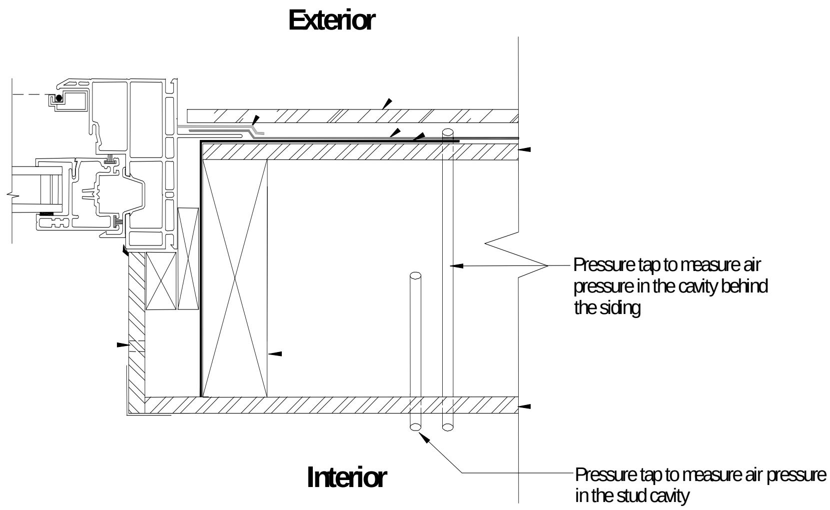


Figure 7-4: Pressure tap locations within wall section

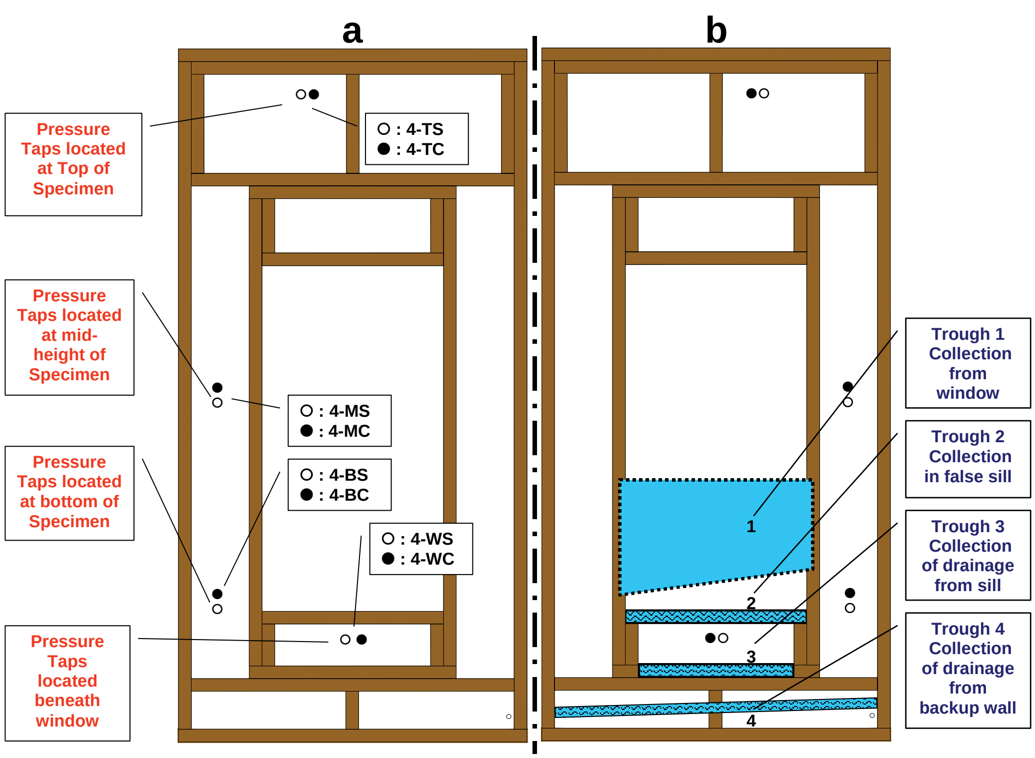


Figure 7-5: (a) Location of pressure taps along height of half-specimen and designated tap labels; (b) location of collection troughs 1 to 4 of half-specimen. Both sides of specimen had troughs located as shown in (b).

For example, water entering the subsill area, as shown in Figure 7-7(a), would drain from the subsill down the front of the waterproof membrane and be directed into collection trough (3) beneath the subsill. As shown in the figure, water was channelled to this trough using a protruding metal plate that was placed in a horizontal opening, a narrow slit, located ca. 180-mm below the sill edge. The plate did not extend to the backside of the cladding hence it only collected water that drained along the backup wall. As shown in Figure 7-7(a) and Figure 7-7(b), three of four collection troughs could be used in any given test sequence.

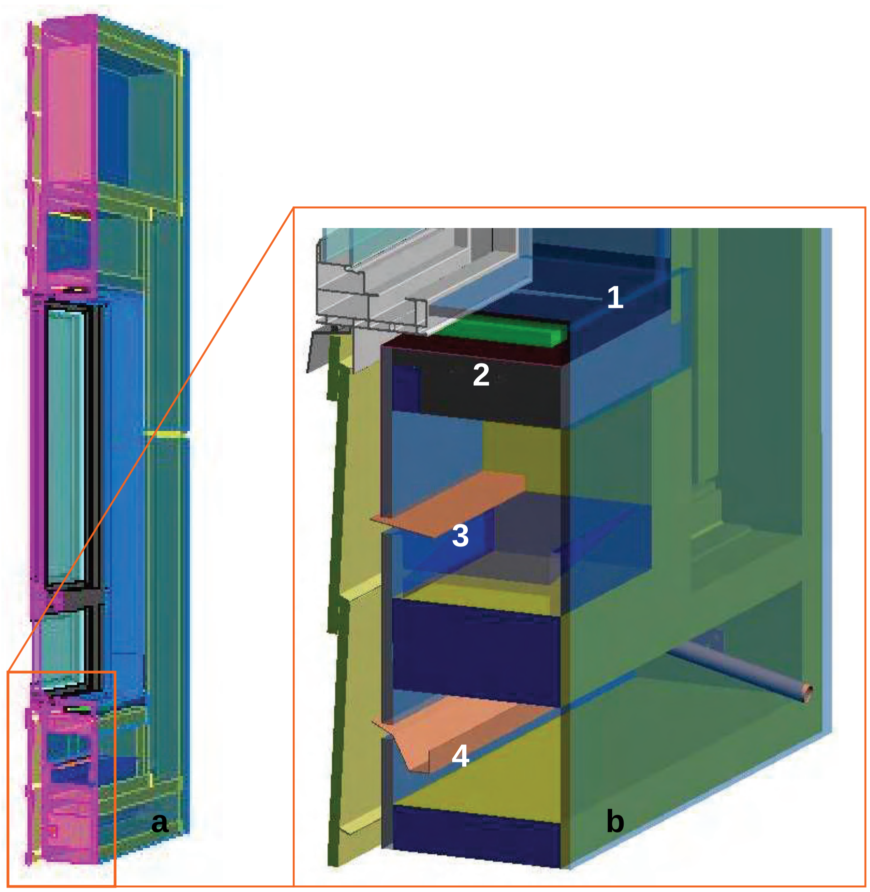


Figure 7-6: (a) Vertical wall section (inter.) showing location (b) of water collection troughs at (1) window on interior side of test specimen, (2) beneath window in removable trough; (3) beneath subsill for collection of water drained from subsill (see Fig. 6) and, (4) lower most trough for collection behind siding.

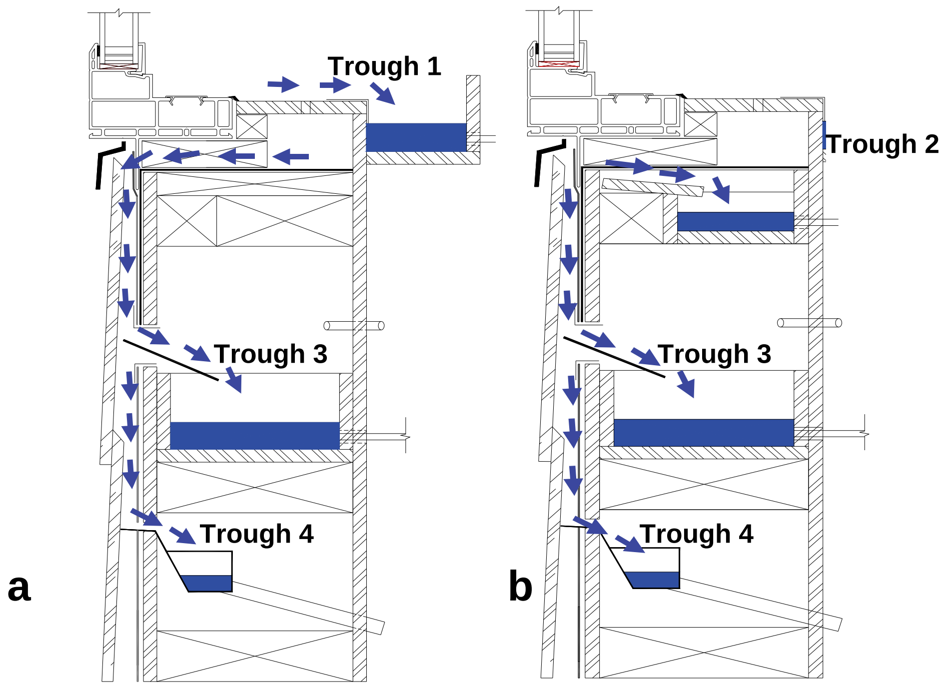


Figure 7-7: Collection trough locations (a) without subsill water collection and (b) with subsill collection in Trough 2, showing intended path of water drainage and collection.

Results from Initial Trials of Watertightness Performance – Specimen W4

Results of the initial test Trials to assess the watertightness performance of specimen W4 are reported in terms of (1) pressure drops across different components of the assembly and; (2) water penetration of and water entry to and through the assembly.

Pressure Drops Across Wall Assembly

A large pressure drop across the wall provides a driving force for water ingress. The percentage in pressure drop at different pressure tap locations for both air leakage conditions of the wall assembly and for the respective sides of specimen W4 is given in Table 7-4. Pressure drops in the cavity behind the siding (i.e. pressure taps 4-xC) for both sides of the wall were small (< 5%). Pressure drops to the stud cavity (i.e. pressure taps 4-xS) were high, up to 53% on the B-side of the wall, and 13% on the V-side. Pressure drops were consistently higher on the B-side of the wall than the V-side; the B-side had 50-mm wide strips of self-adhered elastomeric membrane at the perimeter of the window flange resulting in a much tighter plane of airtightness at this interface as compared to the V-side. The increase in ABS leakage resulted in increased pressure drops, particularly in the stud cavity.

Provided in Table 7-5 is the same information relating to percentage of pressure drop at different tap locations but in this instance, the subsill collection trough is in place. The addition of the subsill collection trough brought about substantial increases in pressure drop the stud cavity at the window (4-WS) for both sides of the wall. Pressure drops in the stud cavity for the B- and V-sides at all locations, and the B-side bottom stud cavity increased by more than 40%. The pressure drops in the V-side bottom stud cavity increased by approximately 20%. Generally, pressure drops on the B-side side of the wall were approximately double those on the V-side side.

Table 7-4: Stud and Cavity and wall-window interface Pressure Drops Without Modifications

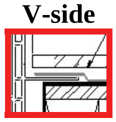
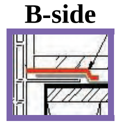
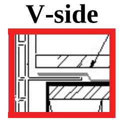
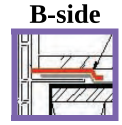
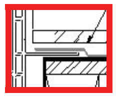
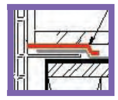
Pressure tap Location	**03 ABS**		**08 ABS**	
	V-side 	**B-side** 	**V-side** 	**B-side** 
4-TS	3-7%	8-15%	4-13%	38-53%
4-MS	<1%	N/A	~5%	N/A
4-BS	<1%	4-6%	~5%	26-49%
4-TC	<0.3%	<1%	<1%	<1%
4-MC	<0.3%	N/A	<1%	N/A
4-BC	<0.6%	1-2%	<3%	~5%
4-WS	< 0.7%	2-3%	< 1% @ 0.8 and 1.6 < 5% @ 3.4 L/(min-m^2)	~8% @ 0.8 L/(min-m^2) 11-19% @ 1.6 L/(min-m$^{2)}$ 10-22% @ 3.4 L/(min-m^2)
4-WC	< 0.1%	2-3%	< 2.5% @ 0.8 and 1.6 10-18% @ 3.4 L/(min-m^2)	~8% @ 0.8 L/(min-m^2) 9-19% @ 1.6 L/(min-m^2) 9-21% @ 3.4 L/(min-m^2)

Table 7- 5: Stud and cavity and wall-window interface pressure drops with subsill collection trough in place

Pressure tap Location	08 ABS with subsill trough	
	V-side 	B-side 
4-TS	40-53%	78-89%
4-MS	39-52%	N/A
4-BS	39-52%	76-87%
4-TC	<1.2%	<2.3%
4-MC	1-2%	N/A
4-BC	16-34%	26-52%
4-WS	23-39%	40-75%
4-WC	12-30%	41-76%

The air pressure reading for tap 4-WC was taken behind the siding near trough 3. The adjacent pressure tap located in the stud cavity (4-WS) was the pressure drop measured at trough 3. At the 03 ABS leakage rate, pressure drops were small in the wall-window interface (< 0.7%) on the V-side and up to 3% on the B-side. Pressure drops at both wall-window interface locations increased with an increase in ABS leakage. At the 08 ABS leakage condition, pressure drops varied with cascade rate, particularly at the lower pressure differentials – higher cascade rates resulting in higher percentage pressure drops. Pressure drops in the B-side wall-window interface were again higher than the V-side. Pressure drops at all locations increased with the addition of the subsill trough. Modifications to the wall did not result in any significant changes to the pressure drops as compared to the unaltered wall assemblies (i.e. original set-up).

Water Management of As-built Specimen (Open Joint between Cladding and Window)

As was previously described, specimen W4 did not include any sealant of backer rod at the cladding window frame interface; hence there was a 6-mm open joint between the cladding and window frame at the perimeter of both windows.

Water collection in trough 1 - at Window

Water began entering through the window proper above 200 Pa pressure differential. Water collection in trough 1 (water penetration of window) on the B-side was similar to water collection on the V-side, up to a maximum of 623 ml/min at the 03 ABS leakage condition and 1620 ml/min at 08 ABS condition. Maximums occurred at a cascade rate of 3.4 L/(min-m^2), and 700 Pa pressure differential. Water collection through the window displayed many dependencies: increasing with increase in pressure differential, increasing with increased air barrier system leakage and increasing with increased cascade rate (see Figure 7-8 and Figure 7-9).

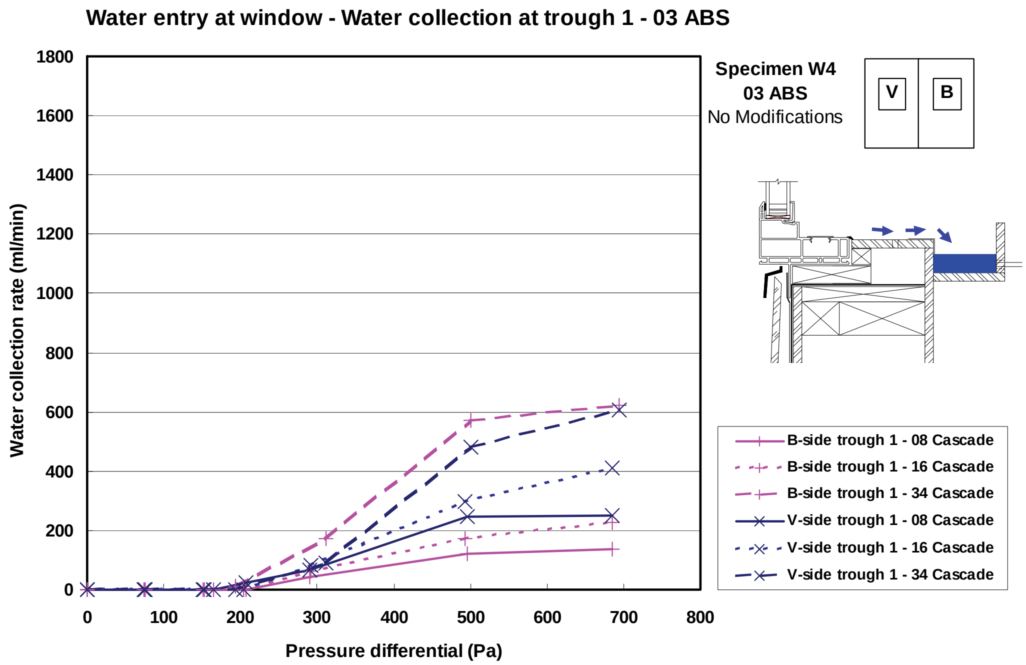


Figure 7-8: Specimen W4 as built condition – Water collection in Trough 1 (window), 03 ABS

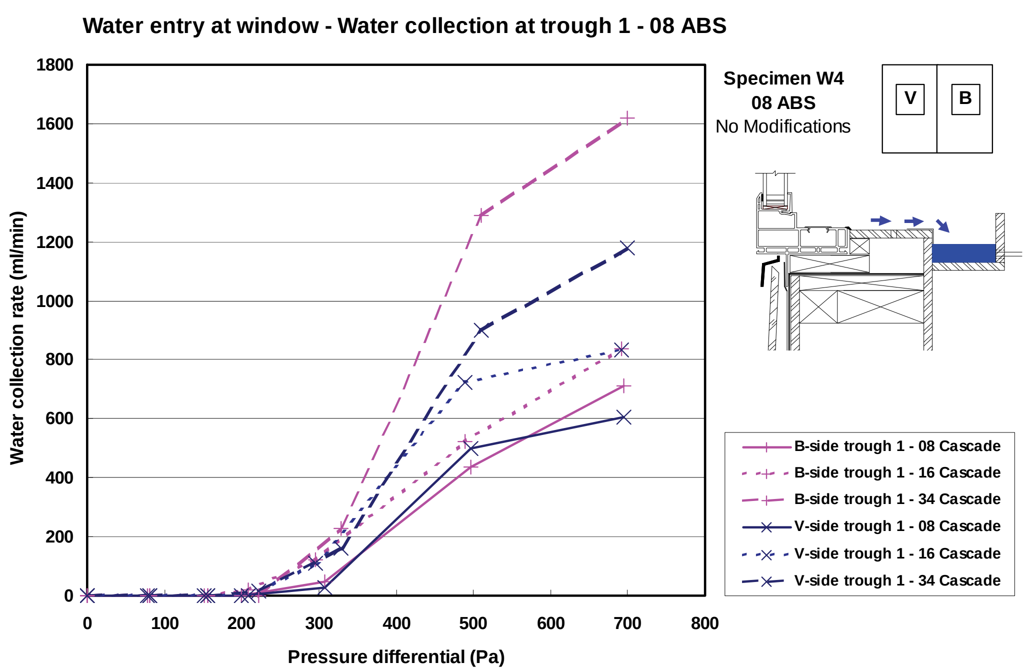


Figure 7-9: Specimen W4 as built condition – Water collection in Trough 1 (window), 08 ABS

Water collection to trough 3 (apparent drainage from subsill)

A large amount of water was collected in both the V-side and B-side of trough 3 throughout the trials. For test conditions of 03 ABS leakage (Figure 7-10), trough 3 on the V-side saw up to 790 ml/min of water, the B-side up to 402-ml/min water collection. At this low air barrier system leakage, water collection to the reservoirs on both sides was comparable at the lowest two cascade rates. At the highest cascade rate, water collection to trough 3 on the V-side exceeded that of the B-side. These results reflect the fact that the interface design included open joints at the perimeter of both windows.

At the higher air barrier system leakage condition, 08 ABS (Figure 7-11), water collection to trough 3 increased, and was similar on both sides of the wall. As well, rates of water collection increased with an increase in cascade rate: ca. 100 ml/min at 0.8 L/(min-m^2) cascade rate, ca. 550 ml/min at 1.6 L/(min-m^2) cascade rate, and ca. 1050 ml/min at the 3.4 L/(min-m^2) cascade rate. These water collection rates were fairly constant across the whole range of pressure differentials, with a slight reduction at low pressure differentials at the highest cascade rate.

The installation of the trough for subsill water collection (trough 2) brought about some changes to water collection in both sides of the wall (Figure 7-12). On the V-side, water collection to trough 3 decreased as a result at the two highest cascade rates, to ca. 700 ml/min and ca. 450 ml/min respectively, and increased at the lowest cascade rate. On the B-side, water collection decreased at the highest cascade rate to ca. 800 ml/min and remained similar to the tests without subsill collection trough at the lower two cascade rates.

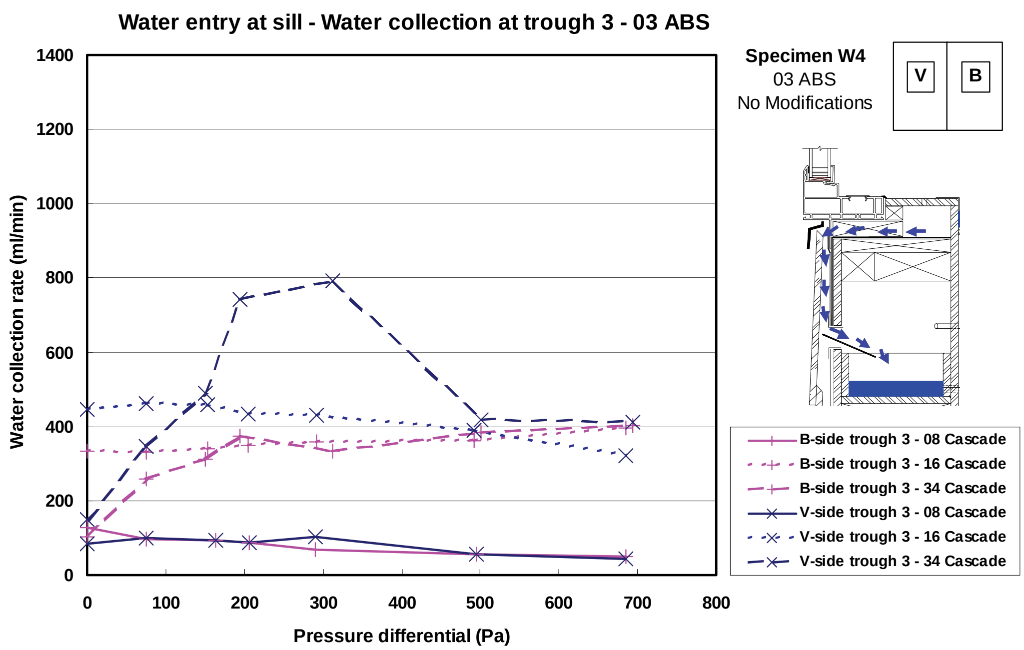


Figure 7-10: Specimen W4 as built condition – Water collection in Trough 3 (window), 03 ABS

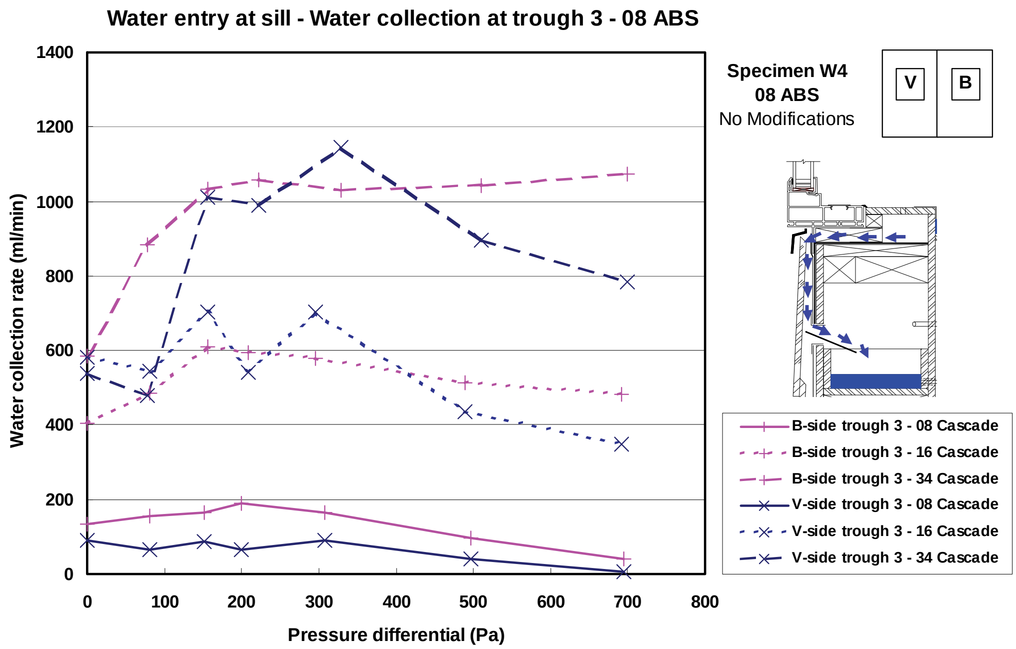


Figure 7-11: Specimen W4 as built condition – Water collection in Trough 3 (window), 08 ABS

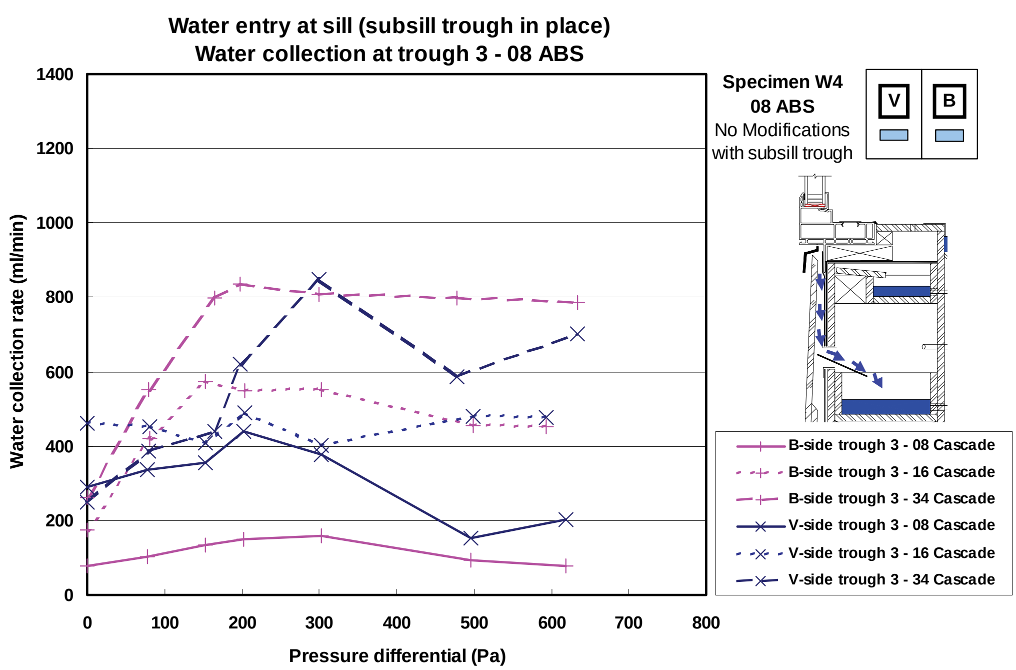


Figure 7-12: Specimen W4 as built condition – Water collection in Trough 3 (window), Trough 2 (Subsill collection) Installed, 08 ABS

Water collection to trough 2 (Subsill collection)

A large amount of water made its way to Trough 2 at the subsill at high pressure differentials (Figure 7-13). Water collection began above 100 Pa pressure differential on both sides of the wall, and rose to 370 ml/min on the B-side and 215 ml/min on the V-side. The maximum water collection on both sides of the wall occurred at the lowest cascade rate, 0.8 L/(min-m^2).

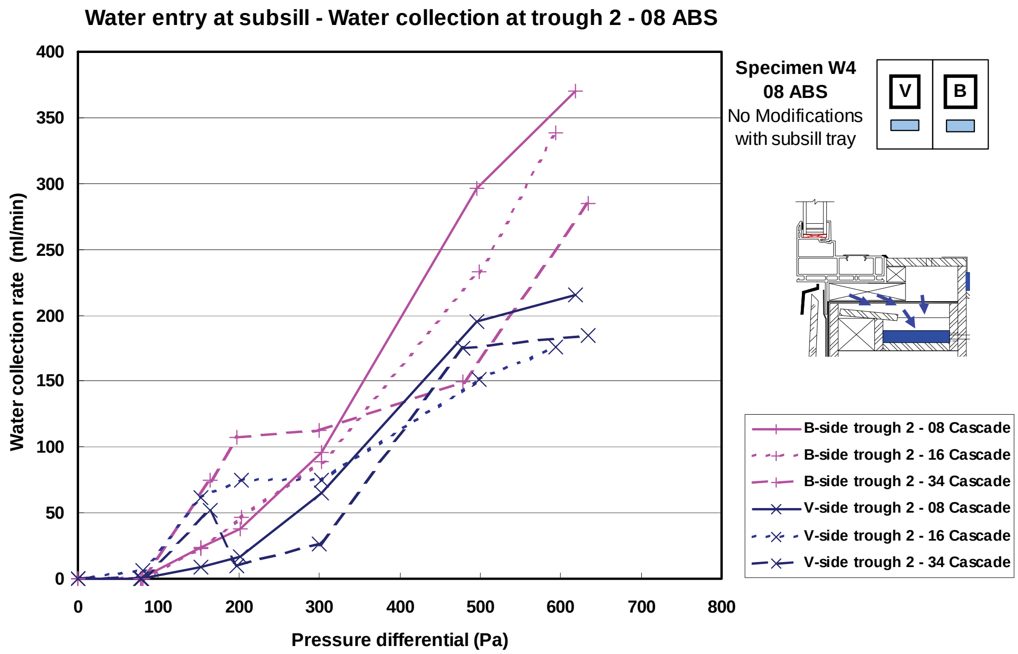


Figure 7-13: Specimen W4 as built condition – Water collection in Trough 2 (Subsill), 08 ABS

Water collection to trough 4 (behind cladding, at base of wall)

Similar amounts of water were collected to trough 4 (behind cladding) for the 03 ABS (Figure 7-14) and 08 ABS trials (Figure 7-15). The water collection on the B-side in trough 4 was generally higher that collected on the V-side, fluctuating around 150 ml/min and 75 ml/min respectively. Water collection to trough 4 did not show any consistent dependence on cascade rate or pressure differential. In tests with trough 2 (subsill) installed, collection to trough 4 on the V-side decreased at higher pressure differential whereas on the B-side, water collection rates varied and were not dependent in changes in pressure differential at the 3 different cascade rates (see Figure 7-16).

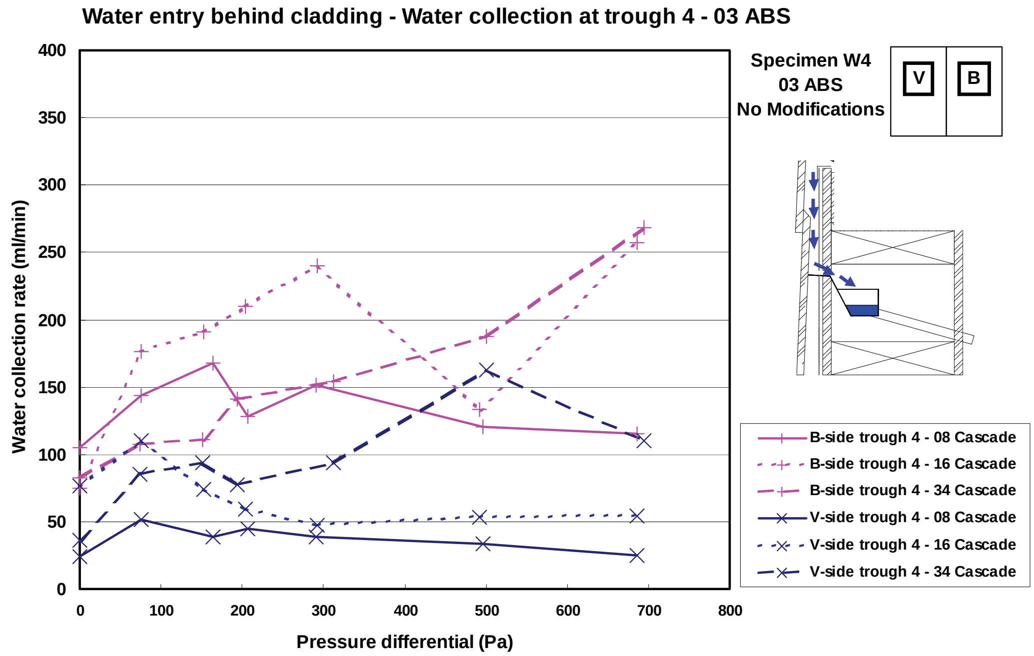


Figure 7-14: Specimen W4 as built condition – Water collection in Trough 4 (behind cladding at base of wall assembly), 03 ABS

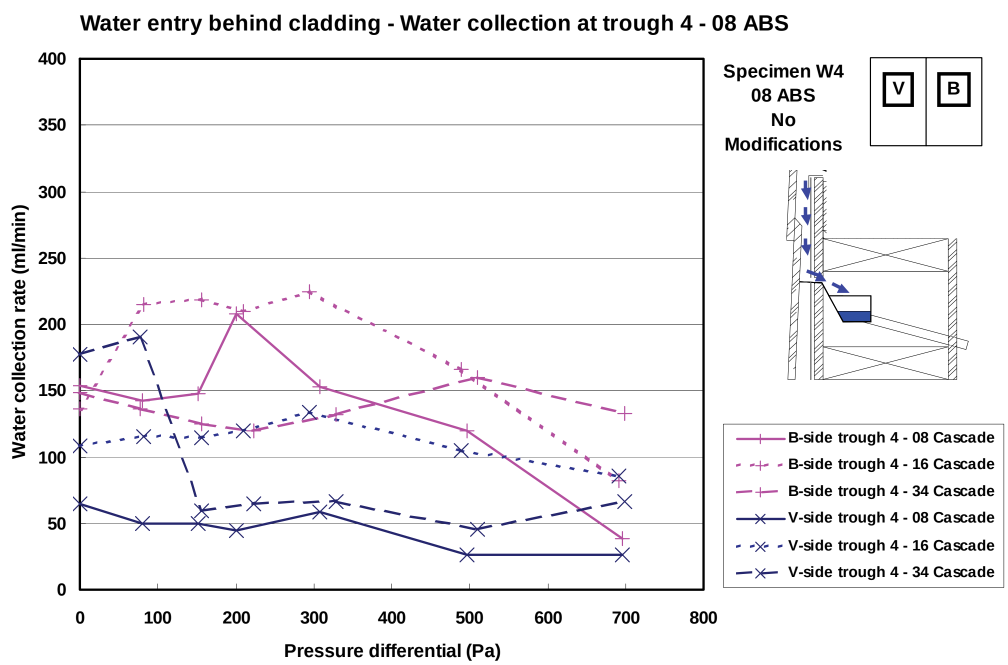


Figure 7-15: Specimen W4 as built condition – Water collection in Trough 4 (behind cladding at base of wall assembly), 08 ABS

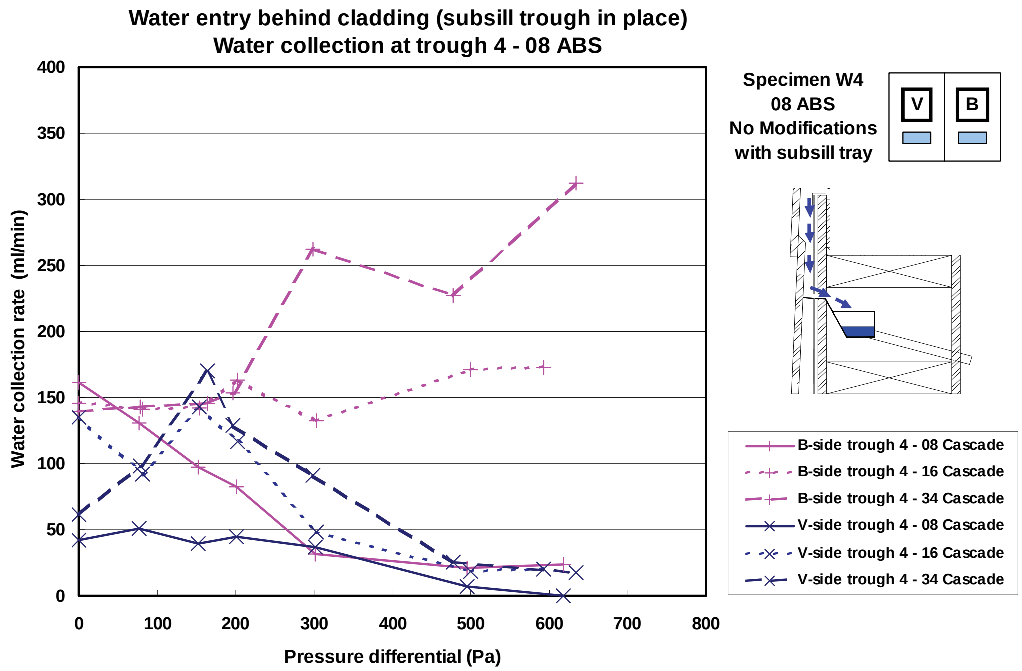


Figure 7-16: Specimen W4 as built condition – Water collection in Trough 4
(behind cladding at base of wall assembly), with Trough 2 (Subsill) Installed, 08 ABS

Water Management with Modifications

In total, three (3) modifications were tested. The first two involved sealing, to various degrees, the wall-window interface with sealant. The third modification was the introduction of a deficiency above the window in the fully sealed wall (as sealed in the second modification). Sealing the wall-window interface generally resulted in reductions in water collection. The addition of a deficiency above the window heads had little effect on water collection to any of the troughs.

Trial 2 modification (Sealing head and sill of cladding-window interface)

The cladding-window interfaces at the head and sill of the window were fully sealed for the modification introduced in Trial 2. This modification resulted in a large reduction in rates of water collection to trough 3 (apparent drainage from subsill) and 4 (behind cladding at base of wall) on both sides of the wall. The maximum rate of water collection to trough 3 (Figure 7-17) on the B-side was 65 ml/min, occurring at the 1.6 L/(min-m^2) cascade rate. On the V-side, water entered trough 3 only at pressure differentials below 500 Pa, and only for the two highest cascade rates. The maximum measured water collection rate to trough 3 on the V-side was 30 ml/min. Before this modification, the maximum water collection rate to trough 3 on both sides exceeded 1 L/min.

Water collection to trough 4 (Figure 7-18) was also reduced from the no modification case, to below 55 ml/min on the B-side, and below 30 ml/min on the V-side. As in the tests with no modification, more water entered the B-side pan than the V-side pan.

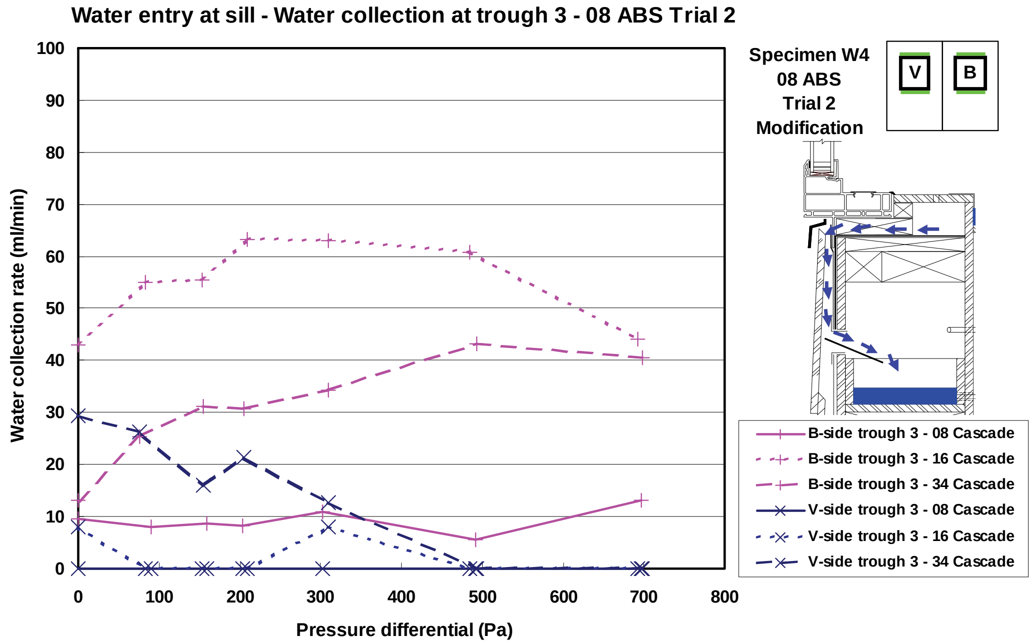


Figure 7-17: Specimen W4 as built condition – Trial 2: Water collection in Trough 3 (behind cladding at base of wall assembly), 08 ABS

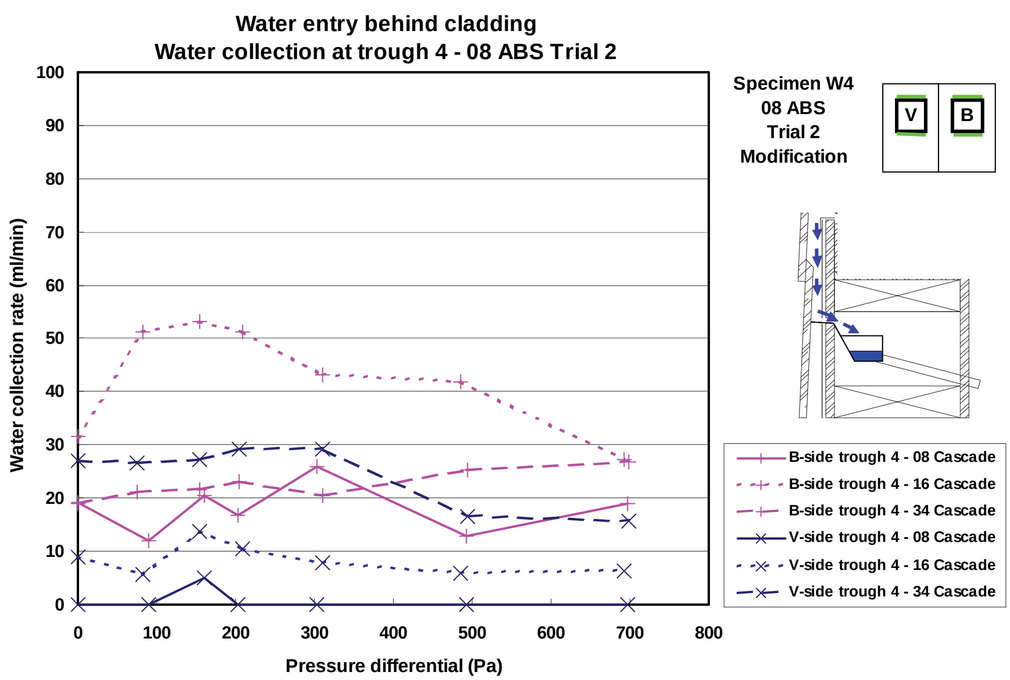


Figure 7-18: Specimen W4 as built condition – Trial 2: Water collection in Trough 4 (behind cladding at base of wall assembly), 08 ABS

Trial 3 modification (Sealant applied to entire perimeter of cladding-window-interface)

The entire perimeter of the cladding to window interface was sealed (i.e. jambs, head and sill) for this test Trial. As well, tests sequences in this test Trial were conducted with and without trough 2 (subsill collection) installed. The results for water collection to troughs 2 and 4 were similar for tests with and without trough 2 installed. Water collection to trough 3 () was almost completely eliminated on both the V-side and B-side of the wall, up to 13 ml/min on the B-side, and 5 ml/min on the V-side for a few test conditions.

Water collection to trough 4 (Figure 7-20) on the V-side of the wall remained below 25 ml/min for all test conditions completed in test Trial 3. These entry rates were similar to those measured in the previous modification (Trial 2). On the B-side, water collection to trough 4 varied considerably, rising as high as 130 ml/min at the highest cascade rate, and disappearing at low pressure differentials at the 1.6 L/(min-m^2) cascade rate. Generally, on the B-side water collection to trough 4 increased with an increase in applied pressure differential.

Water collection to trough 2 (subsill) was still present after the modification (Figure 7-21), however it was reduced by over two-thirds from earlier measurements (i.e. before modification). At a cascade rate of 3.4 L/(min-m^2), water began entering the B-side at 300 Pa pressure differential, reaching 109 ml/min at the highest pressure differential. On the V-side, water began entering at 150 Pa pressure differential, and reached a maximum of 31 ml/min.

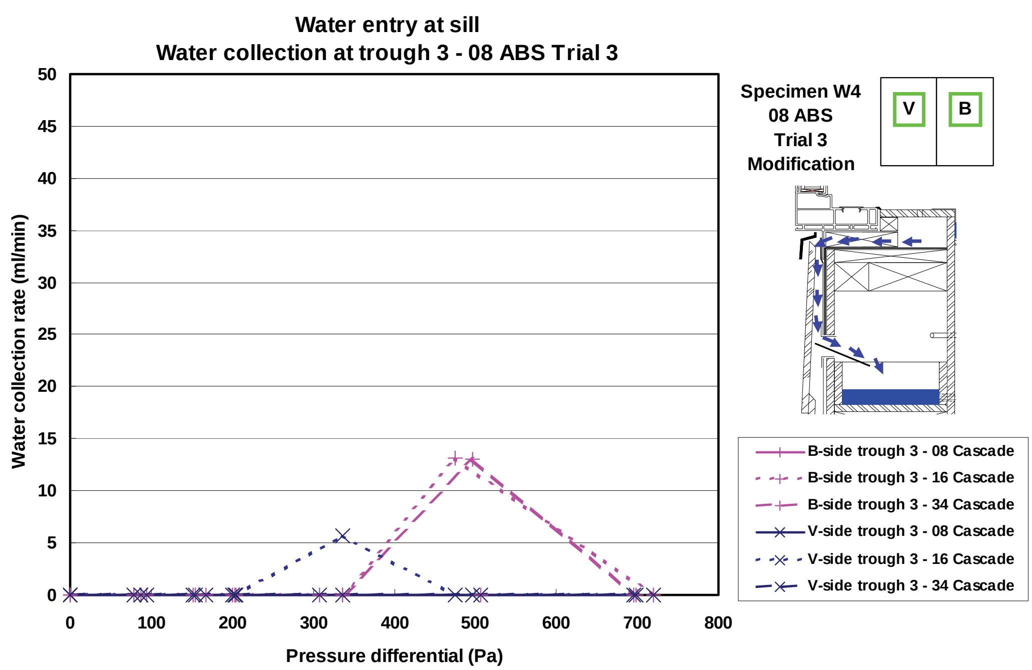


Figure 7-19: Specimen W4 as built condition – Trial 3: Water collection in Trough 3 (apparent drainage from subsill), 08 ABS

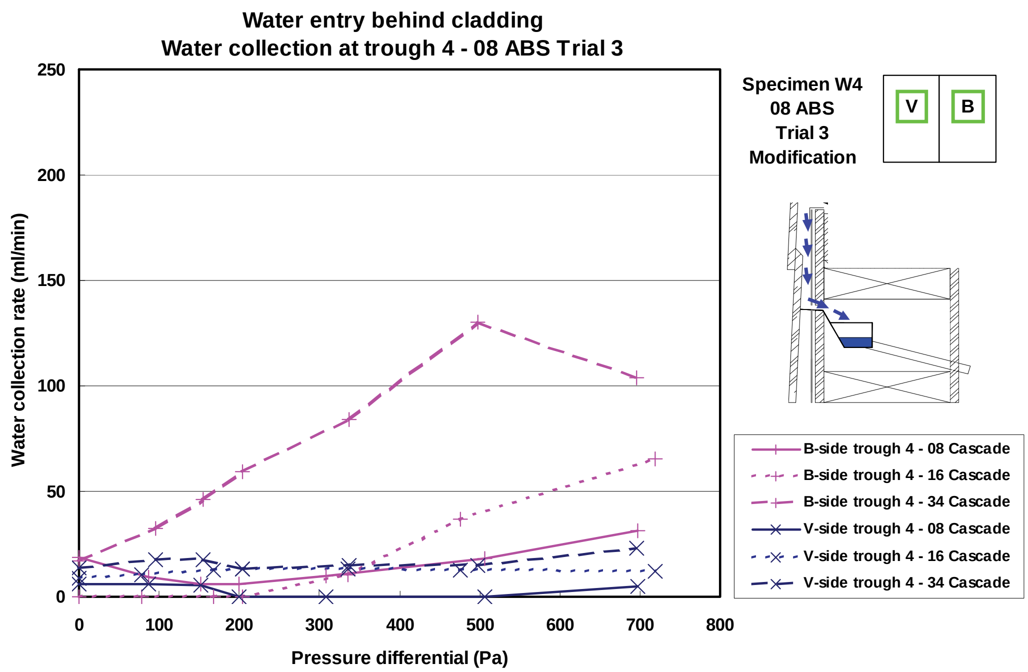


Figure 7-20: Specimen W4 as built condition – Trial 3: Water collection in Trough 4 (behind cladding at base of wall assembly), 08 ABS

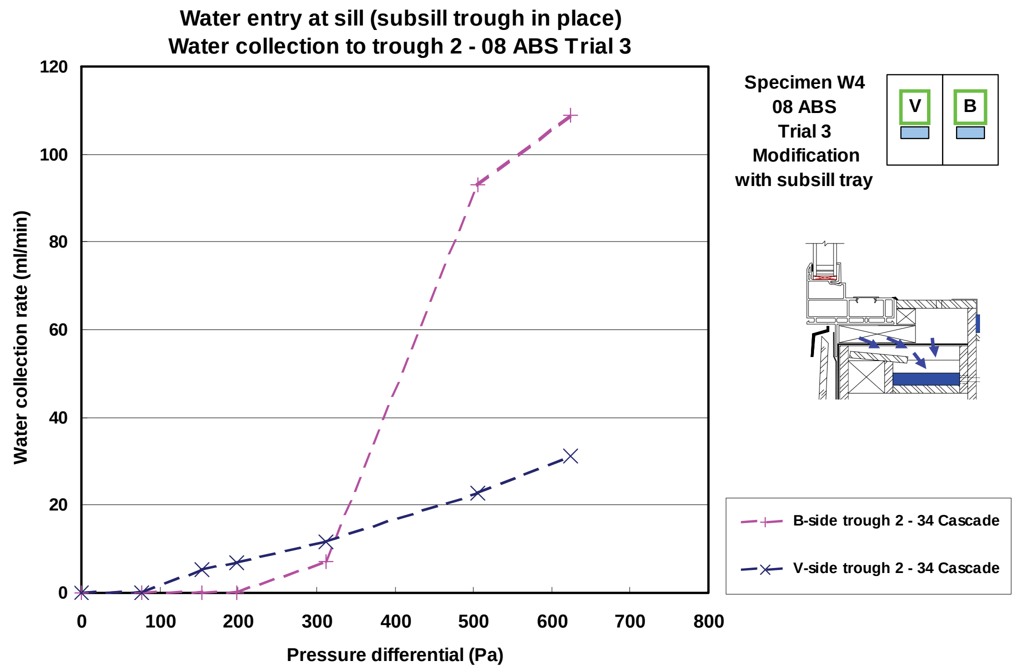


Figure 7-21: Specimen W4 as built condition – Trial 3: Water collection in Trough 2 (subsill collection), 08 ABS

Trial 4 modification (Vertical slit in siding above window)

A vertical slit was introduced in the cladding above the window for test Trial 4. No subsill water collection troughs (trough 2) were installed during these trials, and the wall assembly was only subjected to a cascade rate of 3.4 L/(min-m^2). In these test conditions, no significant water collection was measured to trough 3 (apparent drainage from subsill). Water collection rates to trough 4 were constant on both sides (V and B) at approximately 16 ml/min across all pressure differentials. This was a reduction from results obtained from tests of Trial 3, before the deficiency was introduced.

Discussion of Initial Results

Pressure Drops

Pressure drops in the stud cavity were high on both sides of the wall. These were the highest pressure drops measured over the course of testing all four wall assemblies. Specimen W2 was the other specimen that produced high pressures drops (~30%) at the 08 ABS condition. Specimen W2 and W4 share the commonality of having no furring strips or clear cavity behind the siding as well as a tighter connection between the sheathing membrane and the window frame.

Pressure drops on the B-side of the wall were higher than the V-side. As compared to the V-side, for which the sheathing membrane was not sealed to the window flange, the seal around the window of the B-side prevented air from flowing through the wall-window interface and transferring the pressure in the stud cavity.

The addition of the subsill collection trough affected pressure drops, increasing them to more than double at certain locations. This same effect was not recorded in specimen W3 when the subsill collection trough was added. The large gaps in the wall-window interface of specimen W3 likely negated any sealing effect from the collection trough. The interface of Specimen W4 was already tightly sealed, in particular on the B-side, hence the increase in resistance to the passage of air with the inclusion of the subsill collection trough was readily detected.

Measured pressure drops also showed some change with increase in cascade rate on the B-side of the wall at the 08 ABS leakage condition. This phenomenon had not been detected in previous wall tests. With increase in cascade rate, certain pressure drops increased by ~5% (Table 7-4). This may have been expected given that the B-side, having the highest resistance to air leakage of all previous walls, would be most affected by change in cascade rate. It is supposed that for a wall assembly exposed to a high cascade rate (e.g. 3.4 L/(min-m^2)), more water would be available to occlude small openings present in the assembly and this in turn would reduce the availability of air leakage paths that would otherwise promote pressure drops across vertical planes. Hence, it is thought that this effect may thereby increase the pressure drop across the backup wall.

The high-pressure drops in the stud cavity of Specimen W4 would be expected to create a large driving force for water entry. For Specimen W4, in addition to having the largest pressure drops of all four walls tested, it also had the most significant rates of water collection for all collection troughs.

Water Collection Through Windows

The windows of Specimen W4 were identical to those of Specimen W3: combination PVC flanged windows – top slider (CSA rating B3), bottom fixed (CSA rating B4). The CSA ratings indicate that the combination window should prevent water leakage up to and including an applied pressure differential of 300 Pa. Results showed that small amounts of water began entering the window at 300 Pa and necessarily, larger amounts entered at 500 Pa, up to 900 ml/min on the V-side and 1300 ml/min on the B-side. These amounts are much more significant than those measured in test on Specimen W3, with a maximum of 484 ml/min at the highest pressure differential.

Water Collection at the Wall-Window Interface

Specimen W4 lacked a bead of sealant, J-trim and drip cap flashing to prevent water from entering through the wall-window interface. In essence, the only component helping prevent water collection on the B-side of the wall was the 50-mm strip of self-adhered waterproof membrane used to seal the sheathing membrane to the window flange. Interestingly, on the V-side, even less apparent protection was offered, since the lapping of the sheathing membrane over the flange was the only measure to help prevent water from passing through the wall-window interface. With this interface design detail, a considerable amount of water would be expected to run straight down the backup wall behind the siding, to reach either trough 3 or 4. Should the use of a strip of adhered flashing membrane on the B-side provide adequate protection to water entry, one would expect to have less water on the subsill and hence less collection to trough 2 as compared to what might be collected on the less protected V-side.

As expected, significant amounts of water were collected in trough 3 on both sides of the wall, exceeding 1 L/min at the highest cascade rate. This water was not likely being drained from the subsill area. It is expected that water flowed down the backup wall to trough 3, unimpeded given the lack of sealant on the backside of the flange at the periphery of the window. Water collection to trough 3 increased with increase in cascade rate, a likely result of the unimpeded flow of water to the collection trough.

Trials with trough 2 in place (subsill) revealed that large amounts of water were reaching the subsill area as well. Water collection to this area was pressure driven, increasing with increase in pressure differential – larger pressure drops creating a bigger driving force for water collection. Water collection at the subsill was similar on both halves of the wall, reaching upwards of 150 ml/min at high pressure differential. This indicates that there was very little difference in the performance of the wall-window interface details in preventing water collection on the B-side as compared to the V-side of the wall. Hence, one can suggest that the strip of self-adhering membrane was ineffective at sealing the interface to water penetration.

Water collection in trough 4 was as well important, in the range of 50-250 ml/min. More water was collected on the B-side than the V-side of the wall. The water collected in this trough was water that, in part, bypassed collection to trough 3, perhaps originating at the head or jambs of the window.

During tests on Specimen W4, water was observed at the head of the window on the B-side of the wall (see Figure 7-22), whereas no water was observed on the V-side of the wall. Following the initial tests on Specimen W4, the wall was deconstructed to identify possible paths of water collection at the window head. This revealed that the self-adhered membrane on the B-side window had lost adhesion to the sheathing membrane and created "fish mouths" at various locations around the perimeter (Figure 7-23). These fish mouths provided a path for water ingress, helping to channel the water over or around the window flange (Figure 7-24). The formation of these fish mouths also offered an explanation as to why the subsill water collection was similar on both sides of the wall; an added layer of self-adhered membrane on the B-side did not provide enhanced protection against water entry. Fish mouths may develop from differences in the degree of flexibility and "memory" of the more rigid self-adhered membrane in relation to the substrate.

Figure 7-22: View of B-side rough head from below

Figure 7-23: Formation of "fish mouths" around the perimeter of the B-side window

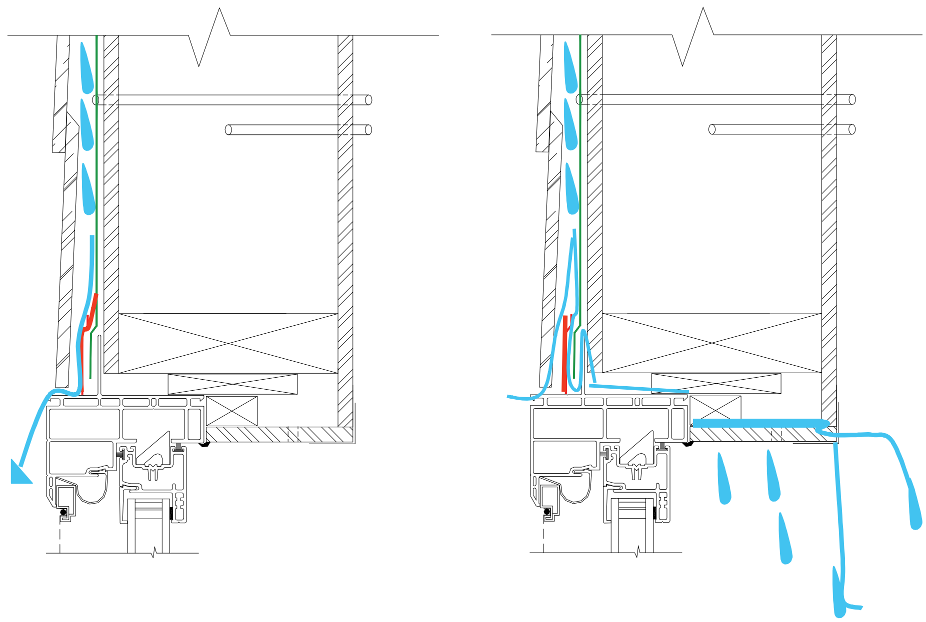


Figure 7-24: Path of water collection at the head of the B-side window

The addition (Trial 2) of sealant at the head and windowsill (joint between cladding and window frame) substantially reduced water collection to trough 3 and 4 on both sides of the wall. Water collection to both troughs 3 and 4 remained higher on the B-side of the wall than the V-side. This indicates that the majority of water entering trough 3 originated at the windowsill. The use of sealant at the joint between the windowsill and cladding evidently eliminated the most direct route for water collection to trough 3. Water collection to trough 4 also originated at the windowsill and head of the window.

Sealing the interface at the jambs, in addition to the head and sill of the window (Trial 3) resulted in an almost complete elimination of water collection to the trough 3, even without the subsill collection trough (trough 2) installed. Water collection along the jambs had accounted for only a small portion of water reaching the reservoir, less than 5%. This is likely due to the fact that vertical joints are not as susceptible to water entry, as these only come into contact with a small portion of water that cascades down the wall.

The water collection rate to trough 4 was similar to that which was measured prior to the modifications to the wall-window interface. Water collection to trough 2 was still present after sealant was added to the joint at the head and windowsill. However, it was reduced by over two-thirds as compared to earlier tests in which modifications had not yet been made. Rates of water collection to the subsill collection trough (trough 2) were higher on the B-side than the V-side. These results show that in this specimen, water collection to the subsill could not be completely eliminated through the addition of sealant alone. Water was still able to find a route to the subsill area despite the addition of a seal around the wall-window interface. Rates of water collection to trough 3 and without the subsill (trough 2) installed were low, whereas water collection to the subsill was relatively high. Therefore, it appears that neither subsill was successful at draining water to the exterior of the backup wall. Water trapped at the subsill could potentially cause mould growth and structural problems.

As in previous CMHC wall tests, cutting a slit in the cladding above the window resulted in no significant change in water collection data. Because of its vertical orientation, this deficiency only came in contact with a small quantity of water.

Water Collection Dependencies

The large amounts of water entering Specimen W4 demonstrated water collection rate dependencies. The differences between restricted flow and unrestricted flow were also highlighted.

- **Water collection increased with increase in applied pressure differential.**
  There were large pressure drops in this wall, providing large driving forces for water collection. This relationship was true for water collection through the windows and water collection to the subsill collection trough. In both these cases, water collection paths were small and therefore water collection rates were restricted, allowing pressure to play a large role as a driving force for water ingress.

- **Water collection increased with increase in designated air barrier system leakage**
  The increase in designated air barrier system leakage created larger pressure drops in the stud cavity and wall-window interface of Specimen W4. Again, these pressure drops had the largest effect on the more restricted routes of water collection – through the window, and to the subsill.

- **Water collection increased with increase in cascade rate**
  This phenomenon was best demonstrated by water collection in trough 3 in the original tests at the 08 ABS condition without modification. Water collection to trough 3 during this trial increased by 400 ml/min each time the cascade rate was increased. Because of the large opening at the joint to the cavity behind the cladding, pressure drops across this interface were small, and water flowed freely to trough 3.

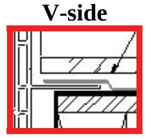
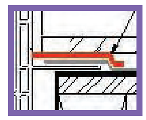
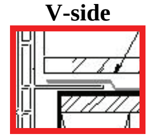
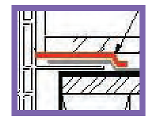
Results – Repeat Tests

Pressure Drops

Results from the repeated tests for the percentage in pressure drop in the stud an cavity behind the cladding across the wall assembly for the different tap locations is given in Table 7-6. A large pressure drop across the wall provides a driving force for water ingress. Pressure drops recorded in the wall stud and cavity during the Specimen W4 Repeat tests were comparable to original tests without the subsill trough with the highest pressure drops on the B-side of the wall.

The “window cavity” reading is taken behind the siding near the reservoir. The “window stud” pressure is the pressure drop measured at the reservoir collection trough. Pressure drops in the Wall-Window interface were highest on the B-side of the wall. Measured pressure drops were also slightly higher (~10%) than the pressure drops measured in the original wall with subsill trough. Pressure drops, particularly on the B-side, varied with change in cascade rate, increasing with increase in cascade rate. Modifications to the wall did not result in any significant changes to the pressure drops in wall assemblies not incorporating modification.

Table 7-6: Specimen W4 Repeat – Stud and Cavity Pressure Drops Without Modification

Pressure tap Location	03 ABS with subsill trough		08 ABS with subsill trough	
	V-side 	B-side 	V-side 	B-side 
4-TS	9-17%	32-60%	41-45% @ 51-64% @ 3.4 CR	74-80% @ 1.6 CR 78-88% @ 3.4 CR
4-MS	8-15%	37-57%	41-44% @ 1.6 CR 50-64% @ 3.4 CR	73-78% @ 1.6 CR 77-87% @ 3.4 CR
4-BS	8-15%	30-56%	41-44% @ 1.6 CR 50-64% @ 3.4 CR	73-77% @ 1.6 CR 77-87% @ 3.4 CR
4-TC	<0.5%	<2%	<1%	<1%
4-MC	<5%	N/A	<5%	N/A
4-BC	4-10%	13-35%	23-28% @ 1.6 CR 29-50% @ 3.4 CR	22-33% @ 1.6 CR 37-41% @ 3.4 CR
4-WS	8-14%	29-46% @ 0.8 CR 37-53% @ 1.6 CR 42-57% @ 3.4 CR	36-40% @ 1.6 CR 47-60% @ 3.4 CR	64-71% @ 1.6 CR 68-82% @ 3.4 CR
4-WC	8-14%	29-46% @ 0.8 CR 37-53% @ 1.6 CR 42-57% @ 3.4 CR	36-40% @ 1.6 CR 47-60% @ 3.4 CR	64-71% @ 1.6 CR 68-82% @ 3.4 CR

CR: Cascade Rate; 0.8 CR: 0.8 L/(min-m^2); 1.6 CR: 1.6 L/(min-m^2); 3.4 CR: 3.4 L/(min-m^2)

Water Management Without Modifications

Water collection to trough 3 (apparent drainage from subsill)

Water collection to trough 3 was only measured on the B-side of the wall, due to a disconnected level sensor on the V-side. The results obtained for water collection to trough 3 on the B-side during repeat tests were similar to the original tests at the 1.6 L/(min-m^2) cascade rate (Figure 7-25 and Figure 7-26). At the higher cascade rate, the water collection to trough 3 on the B-side continued to increase at high pressure differentials and exceeded water collection amounts from the original tests. The maximum rate of water collection to trough 3 on the B-side of the wall was 1084 ml/min at the 03 ABS condition, and 1777 ml/min at the 08 ABS condition. Both maximums occurred at the highest cascade rate and pressure differential.

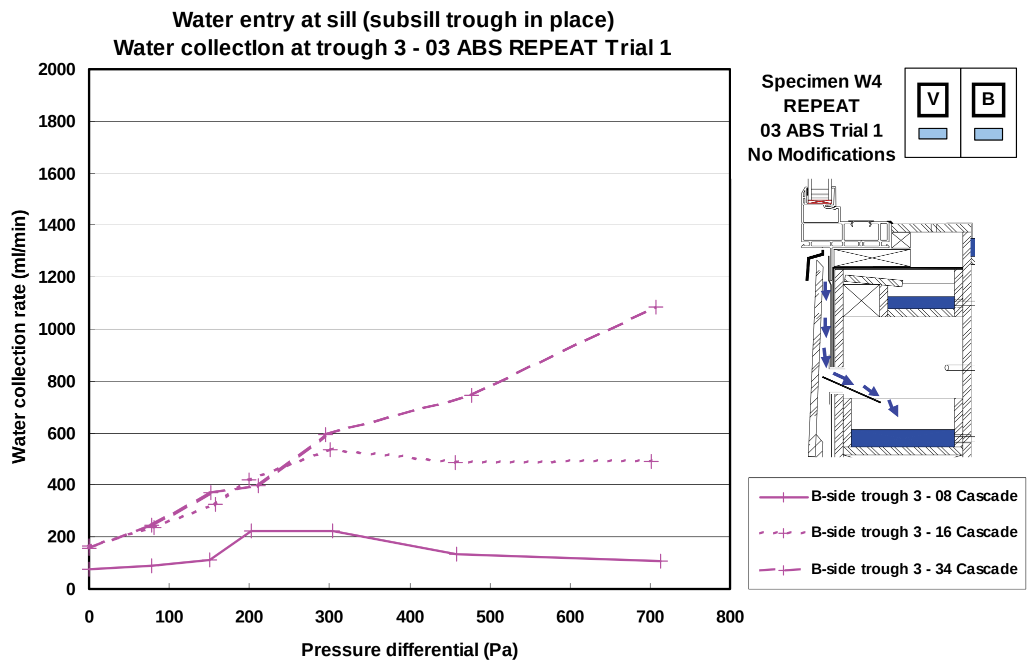


Figure 7-25: Specimen W4 as built condition – Trial 1 REPEAT: Water collection in Trough 3 (drainage from subsill), 03 ABS

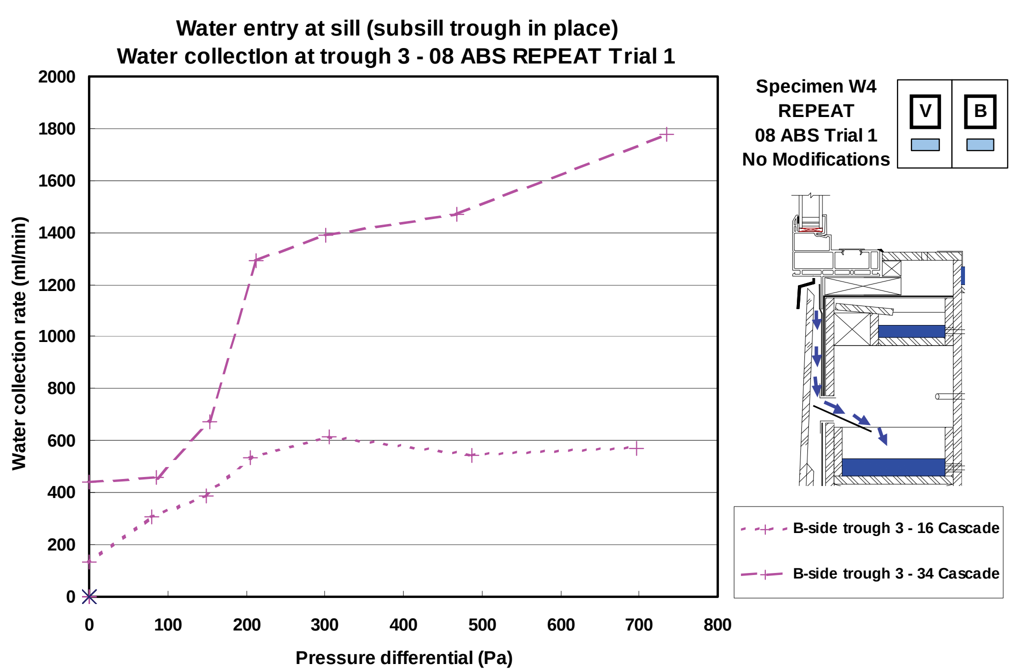


Figure 7-26: Specimen W4 as built condition – Trial 1 REPEAT: Water collection in Trough 3 (drainage from subsill), 08 ABS

Water collection to trough 2 (Subsill collection)

Water collection to trough 2 (subsill collection) during the repeat tests was lower than was obtained in the original tests. For the 03 ABS leakage test condition (Figure 7-27), small amounts of water (5-50 ml/min) were collected at the V-side subsill for most test conditions. On the B-side, water entered the subsill starting at 200 Pa pressure differential, and increasing up to 120 ml/min at the highest pressure differential and cascade rate.

At the 08 ABS condition (Figure 7-28), subsill water collection was similar on both sides of the wall. Only small amounts entered at low pressure differentials, water collection increased to around 150 ml/min at high pressure differentials. Water collection to the subsill during the original 08 ABS with subsill trial showed the same trends, but was much higher than the repeat test – reaching 370 ml/min on the B-side and 215 ml/min on the V-side.

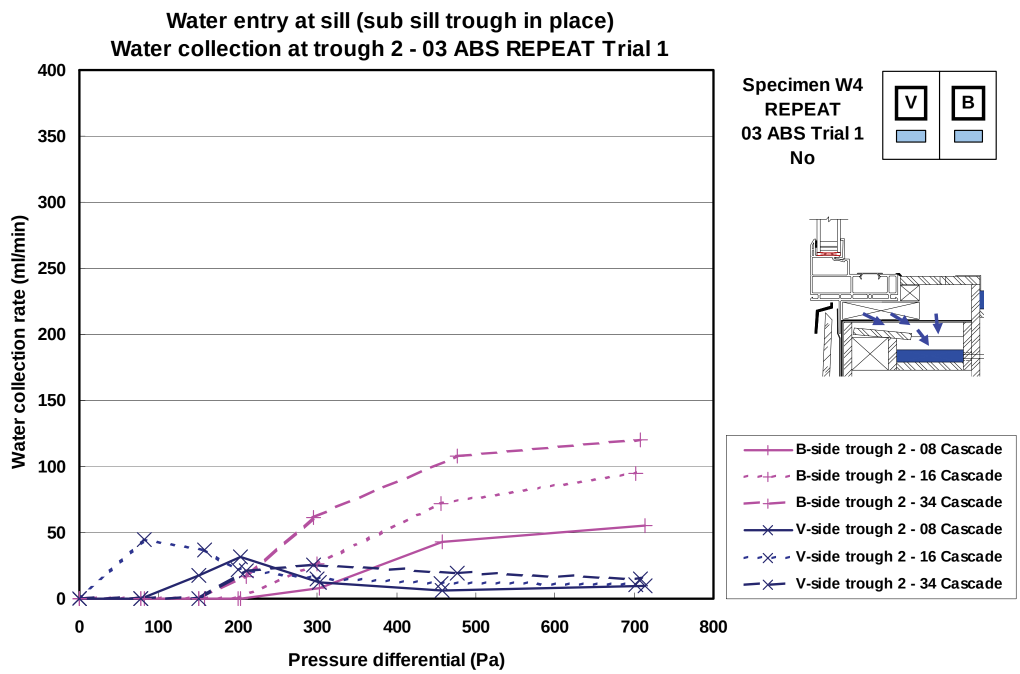


Figure 7-27: Specimen W4 as built condition – Trial 1 REPEAT:
Water collection in Trough 2 (subsill), 03 ABS

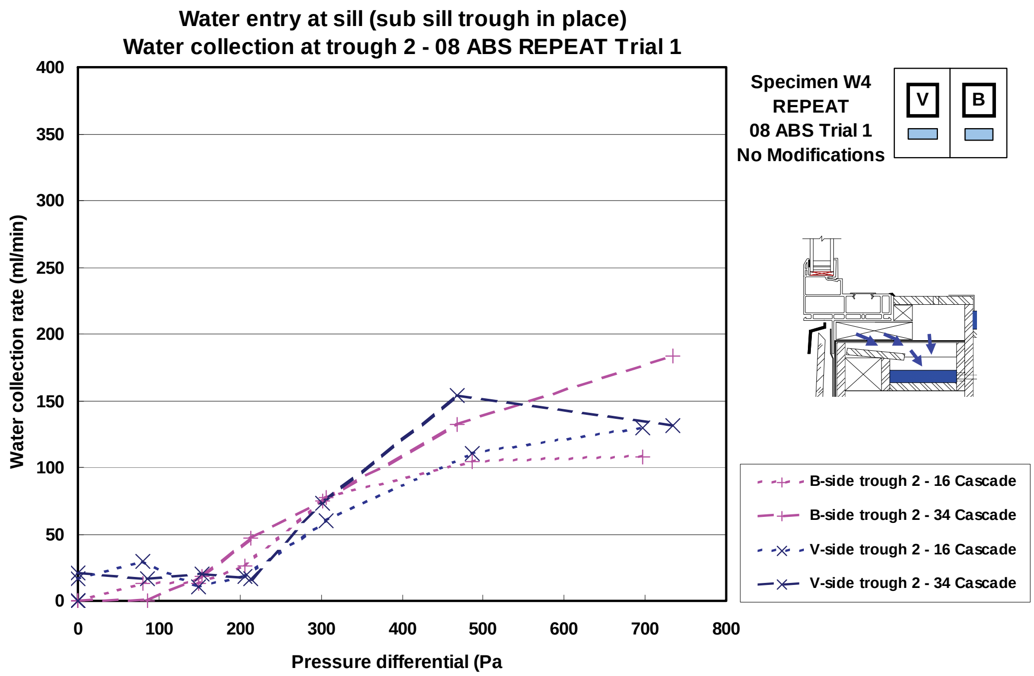


Figure 7-28: Specimen W4 as built – Trial 1 REPEAT: Water collection Trough 2 (subsill), 08 ABS

Water collection to trough 4 (behind cladding at base of wall)

Water collection to trough 4 (Figure 7-29 and Figure 7-30) during the repeat tests was in the same range as water collection during the original tests. However, at 08 ABS leakage condition (Figure 7-30), water collection rates to trough 4 on the V-side was similar to collection rates to trough 4 on the B-side. In the original tests, water collection to trough 4 on the B-side was consistently higher than that of the V-side. Water collection to trough 4 did not show any dependencies on pressure differential or ABS leakage.

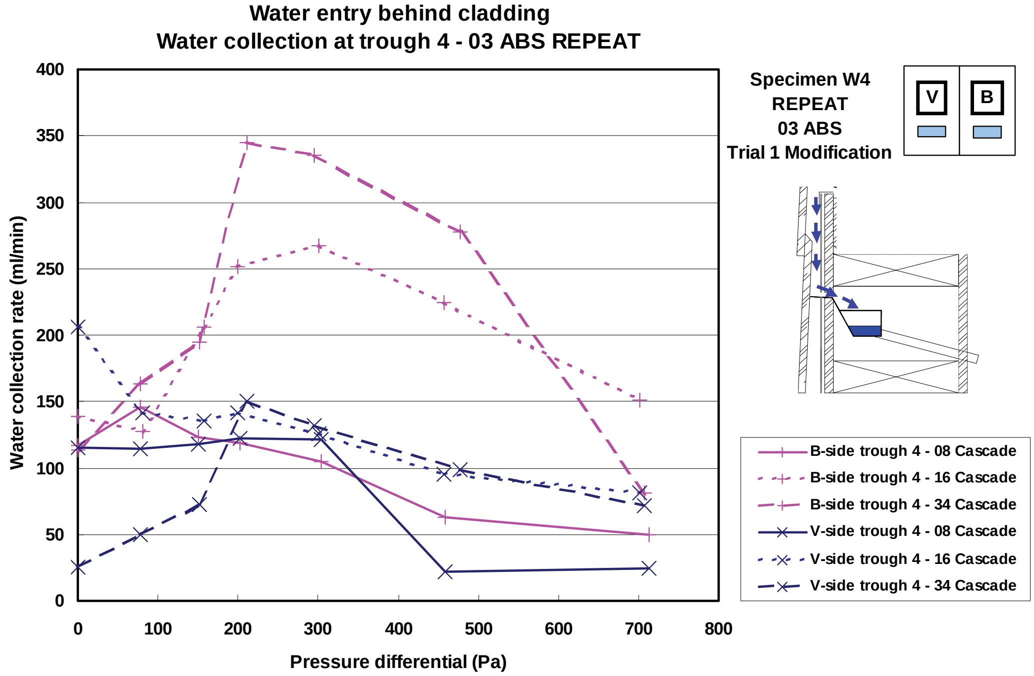


Figure 7-29: Specimen W4 as built condition – Trial 1 REPEAT: Water collection in Trough 4, 03 ABS

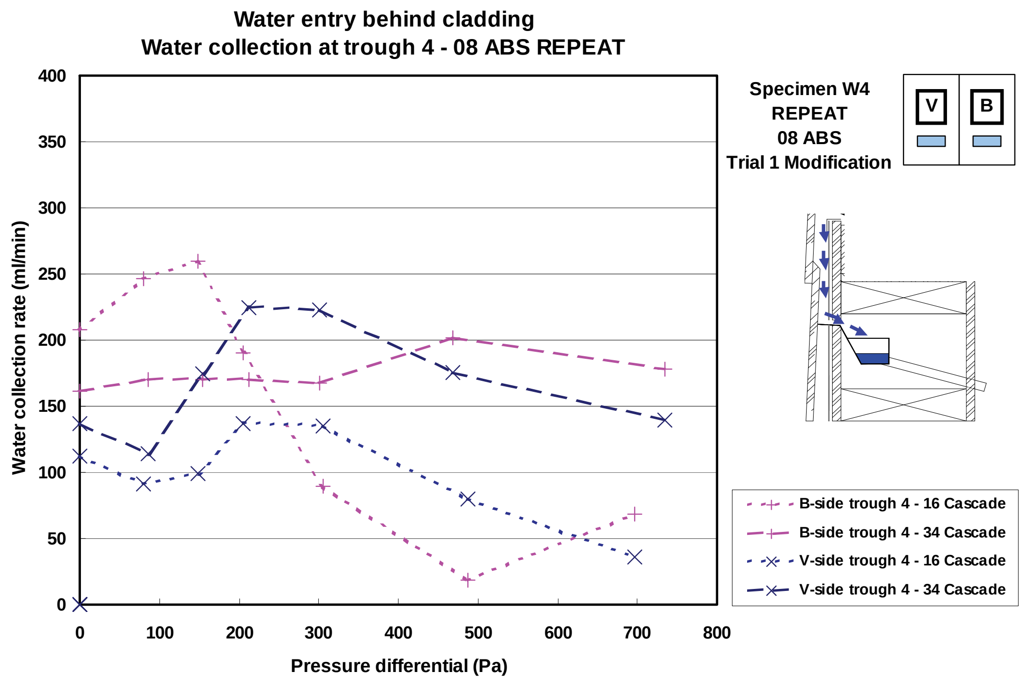


Figure 7-30: Specimen W4 as built condition – Trial 1 REPEAT: Water collection in Trough 4, 08 ABS

Water Management with Modifications to Specimen Interface Details

Trial 2 (Modification: Sealant added at window head)

Results obtained following this modification to the wall assembly, and shown in Figure 7-31, indicate that large amounts of water continued to be collected in trough 3 (apparent drainage from subsill) on the B-side, up to 1493 ml/min. As well, water collection to this trough showed dependencies on cascade rate and pressure differential. Water collection to trough 2 on the V-side was not measured.

Modifications undertaken as part of Trial 2 resulted in reduced water collection at the subsill (Trough 2) on the B-side (Figure 7-32). Water collection on the B-side began above 200 Pa and reached a maximum of 34 ml/min at high pressure differential. On the V-side, water collection was reduced at high pressure differentials and increased at low pressure differentials, as compared to the tests without modification. The maximum water collection on the V-side of the wall was 118 ml/min, occurring at 75 Pa pressure differential and 3.4 L/(min-m^2) cascade rate. On the V-side water collection did not show the same strong dependence on pressure differential as in the tests undertaken without modification.

Water collection to trough 4 (Figure 7-33) on both sides decreased with an increase in pressure differential. The magnitude of water collection to trough 4 at low pressure differential was similar to that obtained before the modifications. On the B-side, water collection to trough 4 was consistently higher than that of the V-side.

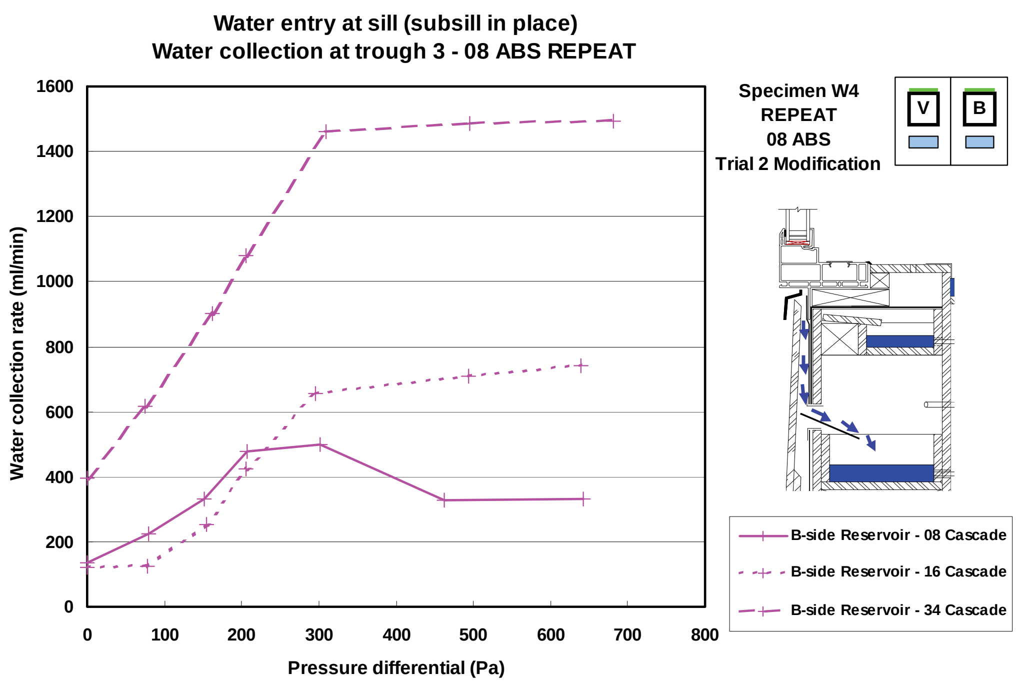


Figure 7-31: Specimen W4 – Trial 2 REPEAT: Water collection to Trough 3; 08 ABS

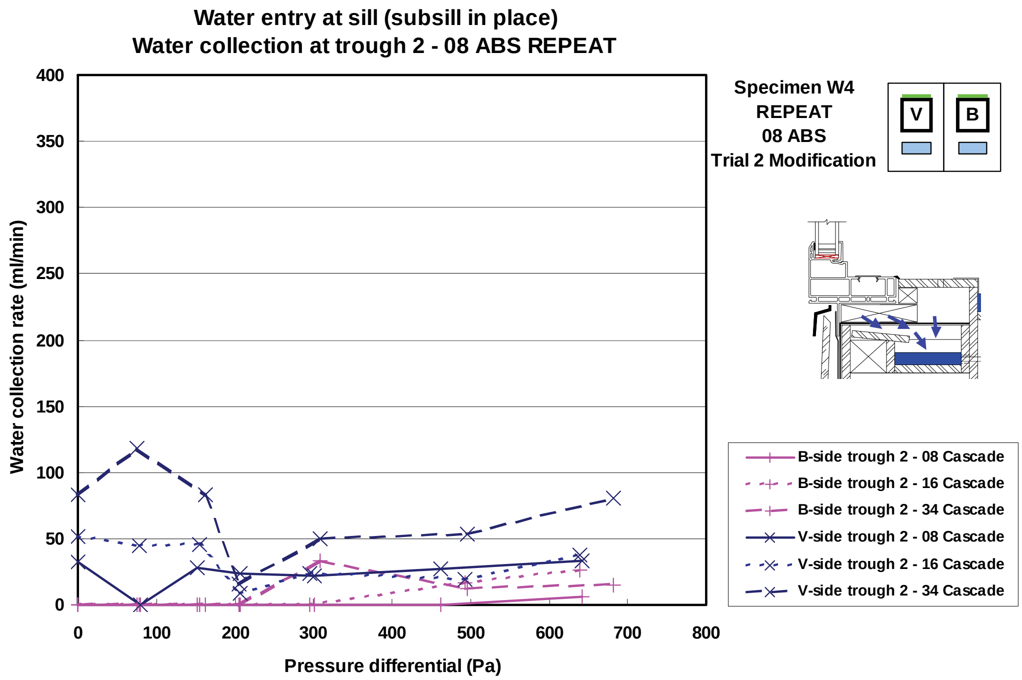


Figure 7-32: Specimen W4 – Trial 2 REPEAT: Water collection to Trough 2; 08 ABS

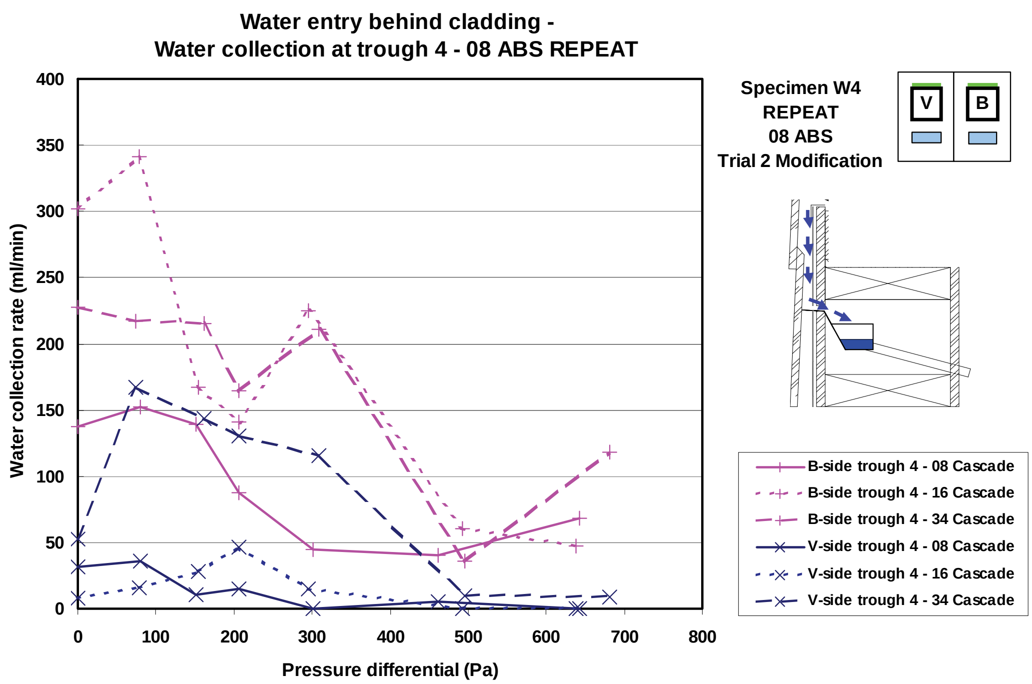


Figure 7-33: Specimen W4 – Trial 2 REPEAT: Water collection to Trough 4; 08 ABS

Trial 3 modification

Water collection to trough 3 on the B-side during Trial 3 was greatly reduced in comparison to results obtained from the previous trial (Trial 2). Water collection to trough 3 (Figure 7-34) increased with an increase in pressure differential up to 39 ml/min. Water collection to trough 3 on the V-side was not measured.

Water collection to trough 2 (subsill) was also reduced on both sides of the wall as compared to results obtained in Trial 2 (Figure 7-35). Only small amounts of water (up to 11 ml/min) entered trough 2 (subsill) on the B-side of the wall at high pressure differentials and cascade rates. Water collection to trough 2 on this side began at ca. 100 Pa pressure differential, and increased with increase in pressure differential to a maximum of 26 ml/min.

Water collection to trough 4 (Figure 7-36) on the V-side of the wall did not change substantially from results derived in tests of Trial 2. However, water collection to trough 4 on the B-side was almost completely eliminated at the two lowest cascade rates. Water collection at the highest cascade rate was minimal at low pressure differentials. Above 400 Pa, water collection to trough 4 on the B-side at the high cascade rate increased to 203 ml/min.

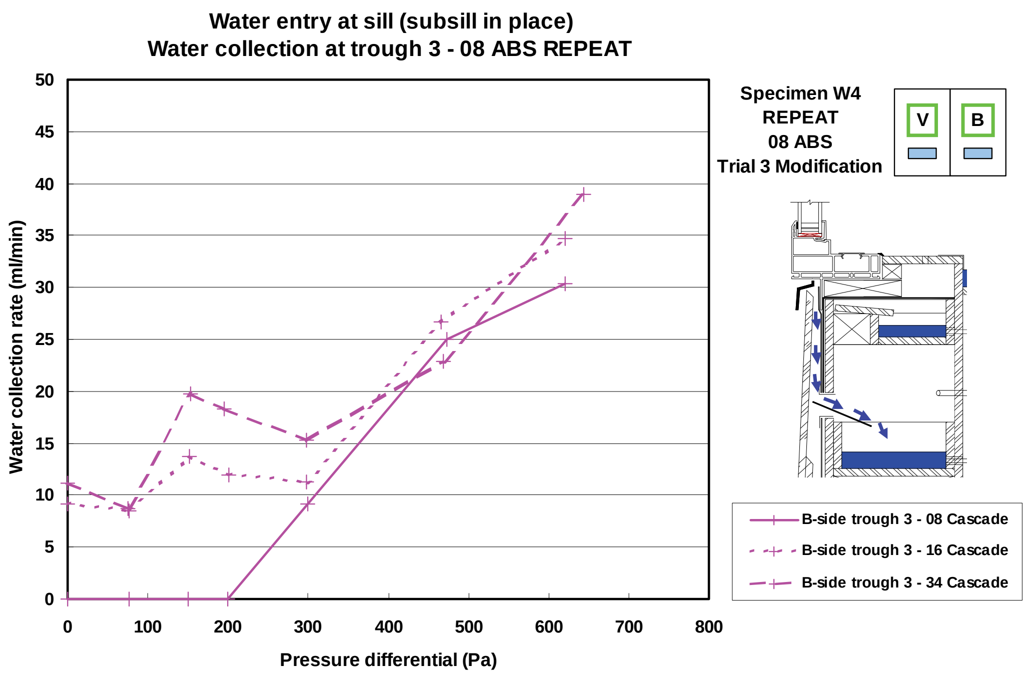


Figure 7-34: Specimen W4 – Trial 3 REPEAT: Water collection to Trough 3; 08 ABS

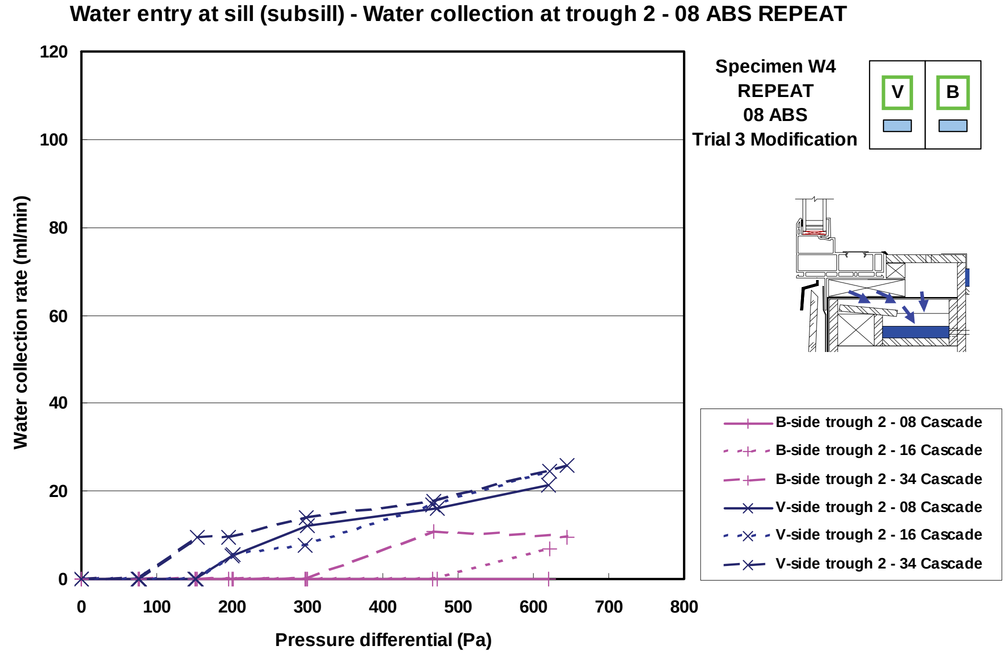


Figure 7-35: Specimen W4 – Trial 3 REPEAT: Water collection to Trough 2; 08 ABS

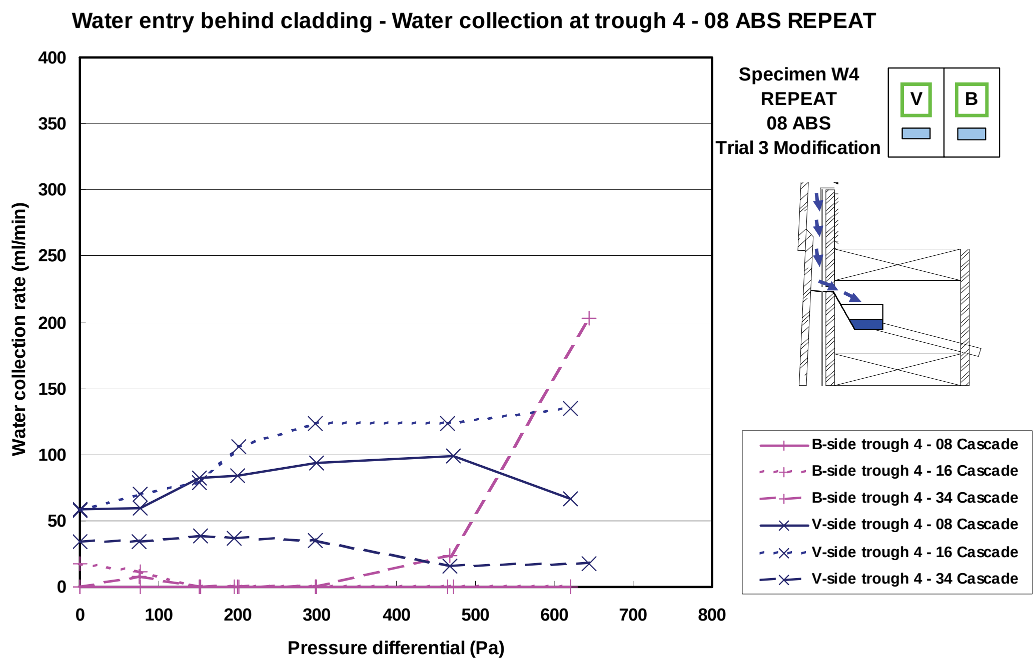


Figure 7-36: Specimen W4 – Trial 3 REPEAT: Water collection to Trough 4; 08 ABS

Discussion of Repeat Results

Because of the water collection observed at the head of the B-side of Specimen W4 during the initial test Trials, a self-adhered membrane was added behind the sheathing membrane at the head of both sides of the wall. The expectation was that this membrane would help prevent water ingress at this location given that is was shingled lapped with the sheathing membrane.

A decrease in water collection to trough 2 (subsill) was observed in the repeat tests from a maximum of 370 ml/min (B-side) and 215 ml/min (V-side) down to a maximum of 150 ml/min on both sides. An increase in water collection to trough 3 at high pressure differentials was also present on the B-side of the wall (no measurements of trough 3 water collection were taken for the V-side). In the repeat tests, no water ingress was observed at the head of the B-side window.

Repeated tests of Trial 2 differed from that of the initial tests in that these only involved sealing the head of the window (and not the sill). This modification did not reduce water collection to trough 3, indicating that the majority of water collection to this trough originated from the sill. However, the modification incorporated in Trial 2 did result in a large reduction in water collection at the subsill (trough 2). This indicates that a large quantity of water collection to the subsill originated at the head of the window. This is consistent with the reduction observed in results obtained from the repeat tests before modifications. Both the sealing and the added self-adhered membrane at the head of the window helped reduce water collection to the subsill.

Results obtained from modification to the specimen in Trial 3 were the same for both the initial and repeat tests – sealing around the entire perimeter of the window greatly reduced water collection to troughs 3 and 4 of the B-side of the wall. The water collection to trough 4 on the V-side remained unaffected, and water collection to trough 3 on the V-side was not measured. This modification further reduced water collection at the subsill to very small quantities that were only obtained at high cascade rates and pressure differentials. Modifications included in Trial 3 were more successful in the repeat tests of Specimen W4 than in the initial tests. This again highlights the fact that the added layer at the head of the wall was key in controlling water collection to the subsill area.

Summary of Results and Observations

The purpose of testing Specimen W4 was to determine the effect of sealing the water resistant barrier (sheathing membrane) to the window flange. To this purpose, the specimen was divided into two sides – the base case (B-side), included a 50 mm (2-in.) wide strip of self-adhered flashing membrane at the junction between the sheathing membrane and the window flange; and the Variation side (V-side), in which the sheathing membrane was not sealed to the flange. As well, the specimen included open joints at the perimeter of the cladding to window frame interface.

The wall specimen was tested under a number of different simulated wind and rain conditions. Modifications were made to the wall-window interface that included caulking along the sill and head of the window, caulking around the entire perimeter of the window, and introducing a deficiency in the cladding above the window.

During the initial tests of Specimen W4, water was observed building up at the head of the window on the B-side of the wall. Tests of Specimen W4 were later repeated to determine the effectiveness of measures to prevent this water ingress. Specifically, introducing an added layer of self-adhered membrane behind the sheathing membrane at the window head and in front of the window flange.

During the original tests of Specimen W4 (prior to any modifications), water collection was similar on both sides of the wall. A large quantity of water was collected on both sides, in all collection troughs. A large amount of water ran down the backup wall, originating at the windowsill. Water originating at the head entered the subsill area and did not drain on either side of the wall. Even with the wall-window interface fully caulked, water continued to enter the subsill area. Upon subsequent deconstruction of the specimen it was revealed that the strip of self-adhered membrane on the B-side of the wall had, over the course of the test period, lost adhesion to the sheathing membrane and formed pockets, or “fish mouths”, that created paths for water ingress at the head and jambs of the wall. Additionally, reverse lapping of this membrane at the head of the window on the B-side increased the likelihood of water collection.

During repeat tests, and as was found in previous tests, no large differences were evident between the performances of the two halves of the wall. The results of repeat tests did however show that the addition of a membrane behind the sheathing membrane, as might be expected, decreased, but did not eliminate, subsill water collection. Caulking at the head of the wall also helped reduce the amount of water collected at this location. With the wall-window interface fully caulked, water collection at the subsill occurred on both sides of the wall but only at the highest pressures and cascade rate.

Chapter 8 — Practical Considerations on Results from Evaluations of Wall-Window Interface Details to Manage Rainwater

Introduction

A series of tests were conducted at the NRC Dynamic Wall Test Facility (DWTF) to compare the effectiveness of various wall/window interface details to manage rainwater.

Accordingly, the test specimens were configured to permit comparisons among the different interface details when subjected to simulated wind-driven rain conditions in the DWTF. Wall specimens were designed to permit side-by-side comparison of two wall-window interfaces details (Figure 8-1). Hence, each 2440 mm by 2440 mm wall specimen included two large openings of 635-mm by 1255-mm, in each of which was placed a 610 mm by 1220 mm window together with a set of wall-window interface details. These details included those located at the head, the jambs and the sill. Half the specimen included a "base-case" (B-side), the other a "variation" (V-side), which typically could be an "upgrade" of detailing the interface that may or may not be common but nonetheless presented a research interest. Entry of water around either window opening was collected in troughs located behind the cladding and beneath the respective sills. Water was also collected at the window, just beneath the sill level, on the interior side of the specimen.

The composition of the walls was intended to be representative of low-rise residential construction with the exception of changes for clear sheathing materials. As such, the specimen consisted of: 38 by 138 mm (nominal 2-in. by 6-in.) wood studs, transparent acrylic sheet on the inside as the principal element of the air barrier system (ABS), an acrylic sheet on the exterior of the framing acting as the sheathing board, spun-bonded polyolefin membrane or asphalt impregnated kraft paper serving as sheathing membrane and an exterior horizontal hardboard siding installed on vertical furring strips for one set of test runs and directly against the back-up wall for a second set.

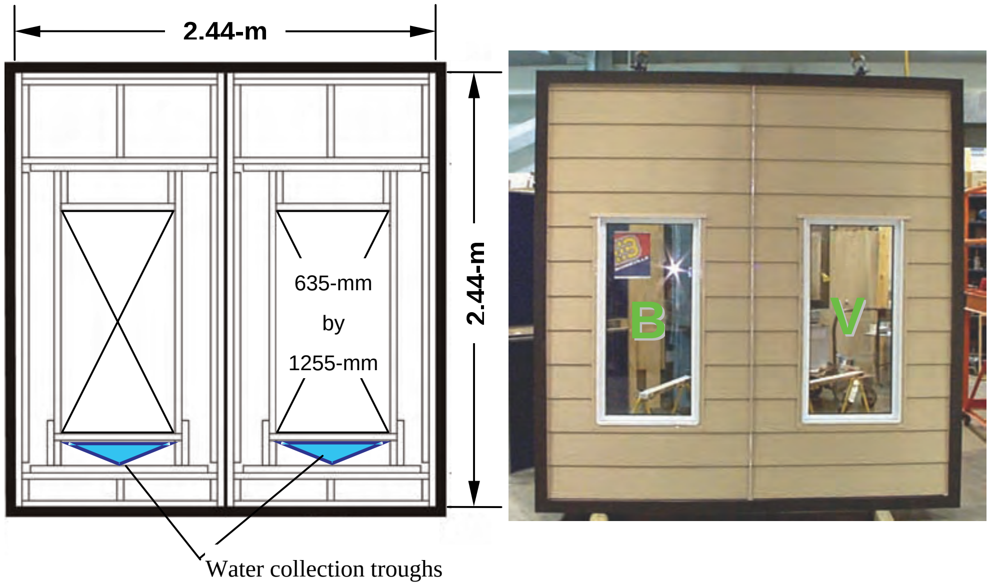


Figure 8-1: (Left) Typical layout of wall specimen framing for investigation of water management response of two side-by-side wall-window interface details (B and V-sides). Water collection troughs are located beneath the windowsill. (Right) Elevation view of exterior cladding of specimen

Clear acrylic sheets were used instead of common building materials given that their transparency provided a means to trace water entry from behind the sheathing board. The expectation was that the location and timing of water ingress could readily be observed using this technique.

The windows were selected on the basis of regional variations regarding features of the window frame that might affect the detailing of the wall-window interface for water management. The three types of PVC windows used in the project:

- Non-flanged (“box”) window frame, fabricated in Canada;
- Fixed flange integral to the frame, fabricated in Canada
- Combination fixed and operable (sliding) flanged window, fabricated in Canada

A summary description of the four different wall assemblies (referred to as SPECIMEN W1 to W4) is provided in Table 8-1.

The wall specimens were tested under a number of different simulated wind and rain conditions. Deficiencies were made to the wall/window interface to simulate component failure. Such failures might typically occur either prematurely in the near term of a components service life, or over a longer period of time due to the natural effects of ageing. These deficiencies included, for example, a slit in the cladding directly above the window, removal of portions of caulking and backer rod along the jamb between the cladding and window frame, and removal of a segment of caulking and backer rod along the windowsill. As well, the interface details in some test set-ups were also modified to better understand water entry phenomena and the paths for water migration behind the cladding and around the interface.

This chapter offers an overview of some practical considerations derived from results obtained from testing four (4) wall sets (SPECIMEN W1 to W4). Specifically, as these relate to: (1) the design and selection of components for the wall-window interface, and; (2) installation.

Practical concerns as they relate to design and design decisions, may, for example, take into account the selection of window details in relation to climate loads, the choice of flanged or box windows, the significance of flat sills or sills that incorporate slopes. Other such considerations in respect to the selection of material may include the importance of jointing products; self adhered flashing membranes and the use of tape to help seal the interface from water entry and air leakage. These items are discussed in the context of how the choice of product may affect water management at the wall-window interface as based on the results obtained in the experimental study.

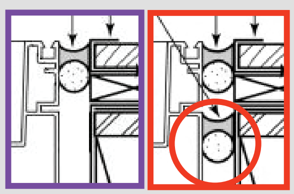
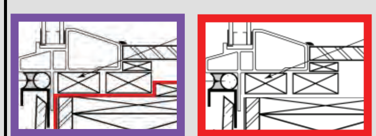
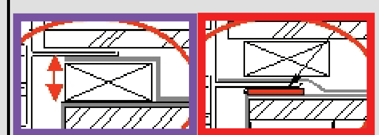
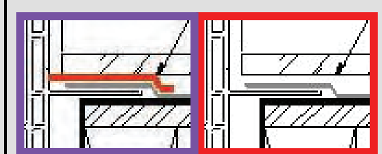
Although window installations may function adequately over an initial test series, the degree of robustness of the design is in large part, a measure of redundancy in design and proper and adequate care of installation. Both these aspects will be touched upon as they relate directly to practical concerns outside of the design and selection of components for the wall-window interface.

Given the many different possibilities for providing practical considerations in respect to results from the experimental work carried out in the wall-window interface project, this summary provides an overview of the information provided to guide practitioners in the design of interface details or the installation of windows.

1. Design decisions in regard to choice of:
    a. Installation method in relation to climate loads (No. 1)
    b. Components
        i. Windows & window openings
            1. Flanged or boxed? (No. 2)
            2. Installation of flanged windows (No. 3)
            3. Water penetration through windows (No. 4)
        ii. Self adhered flashing membrane and tape (No. 5)
        iii. Jointing products (No. 6)
    c. Redundancy in design
        i. Boxed windows – two seals or one? (No. 7)
2. Care and sequence of installation (No. 8)

Details on each of these topics, numbered from 1 to 8, are provided in the subsequent sections, some of which include figures to help illustrate the designs, as well as the paths for water entry and accumulation.

Table 8-1: Summary description of four wall assemblies

Designation ➔ Component / Item ➔	W1	W2	W3	W4
Siding type (H/V)	Hardboard	Hardboard	Hardboard	Hardboard
Clear cavity (Y/N)	Yes (19-mm)	No	Yes (19-mm)	No
Sloped sill (Y/N)	Yes	No	No	No
PVC window (F/O)	Fixed box	Fixed flanged	Fixed/Sliding flanged	Fixed/Sliding flanged
WR membrane	Window opening	Window opening		
Self adhered flashing	Subsill	Subsill variation		
Variation	Second seal at head and jambs	No back-dam, and no waterproofing membrane at head jambs and sill	Flange mounted on inserts at each fastener providing a nominal space of 3-mm between flange and sheathing board	Sheathing membrane in place lapped over the flange of window frame.
Relevant variation in interface details among different specimens	 B-side V-side	 B-side V-side	 B-side V-side	 B-side V-side

I. PRACTICAL CONSIDERATIONS — DESIGN AND SELECTION OF COMPONENTS

No. 1 – Indicator of severity of climate loads on building façade

The CMHC Best Practice Guide document currently uses the Moisture Index as one of the indicators for the severity of climate exposure of the Wall-Window Interface (WWI), with the depth of soffits, and other features of the window providing additional information on expected exposure conditions for windows. The study on climate elements undertaken for the WWI study can provide insights into useful indicators of climate exposure for wall-window interfaces and windows.

No. 2 – Selection of windows – flanged or boxed? Is there a difference in regard to performance? Reviewing details for flanged windows (W3 vs. W1) – Do these work?

Various types of windows are available on the market and contractors have access to both flanged (finned) windows and those without flanges, here referred to as ‘box’ windows. In the new construction market, flanged windows are typically used, as these are relatively quick and easy to install. Window replacements and upgrades, on the other hand, may use box (non-flanged) windows as these more easily installed in the window rough opening once the replacement window has been removed, given that there often is no ready access to the sheathing board where the flange could be used to secure the window. Which ever is used, wall-window interface details would of course differ in regard to installation. Would one expect flanged mounted windows to offer any less protection than a box window?

The comportment of interface details incorporating both boxed and flanged windows was investigated in the Wall-Window interface project. Details in regards to wall-window construction are provided in Table 8-1, and specific interface details for the flanged and box window are provided in Figure 8-2 and Figure 8-5 respectively.

Results indicated that if properly detailed and correctly implemented, as shown in the accompanying interface details, flanged and box windows have comparable performance in regards to drainage from the sill area. Proper detailing to help achieve adequate water management at the interface requires:

1. The moisture-sensitive materials be protected from water absorption by a waterproof layer;
2. The presence of a drainage system at the subsill that permits evacuation of water to the outside;
3. The use of drip cap flashing (with end dams) at the head of the window to reduce water loads on the window proper.

No. 3 – Reviewing details for flanged windows (W3) – would these work?

Flanged (finned) windows are typically affixed directly to the sheathing board with thought to ensuring that water and air tightness at those junctures can be accommodated with the application of caulking to the backside (interior) of the flange. This approach is intended to seal the perimeter of the window frame to the sheathing board and creates a plane of air tightness towards the front of the window installation. As well, once the perimeter is sealed, drainage from the subsill space is no longer possible and should the window leak into the subsill space, water would accumulate thus potentially causing moisture related problems at the subsill, the jambs or the interior finish. Is there a means of installing flanged windows that would permit adequate drainage from the subsill, as well as air and watertightness of the wall-window interface, should the interface in some way be compromised?

Testing undertaken in the Wall-Window interface study focused on determining the response of two different interface details, incorporating flanged windows, to the effects of wind-driven rain. The two details were tested simultaneously in a side-by-side configuration, details of which can be found in Table 8-1 (W3). The Base case side (B-side Figure 8-2), was built with a 19 mm airspace between the window flange and backup wall and the Variation side (V-side) featured a 3-mm airspace created by 3-mm spacers: folded pieces of membrane at the flange fasteners (Figure 8-3).

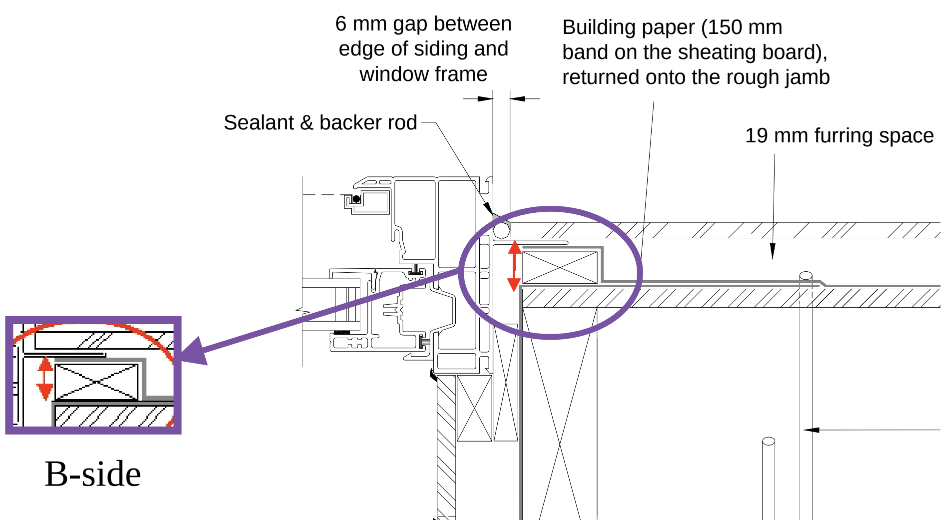


Figure 8-2: Base practice Construction W3 (Table 1) – Horizontal Sectional view of Wall-Window Interface at Jamb

Results showed that very little water entry was seen in the subsill area of either side of the wall and of the relatively minor quantities that did enter the subsill area of the B-side, these were successfully drained to the exterior. It should be noted that the rainscreen approach was used to install the cladding in both assemblies. This 19-mm air gap behind the cladding helped reduce both the amount of water and the pressure differences at the wall-window interface thus reducing the likelihood of water entry along these junctures.

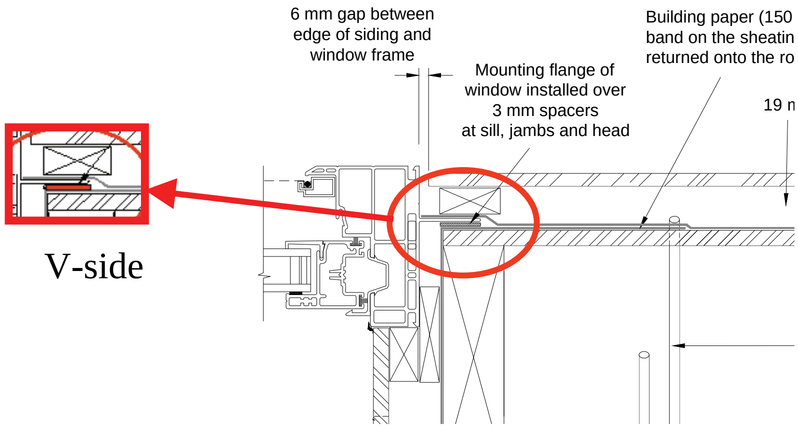


Figure 8-3: Variation Construction W3 (Table 1) – Horizontal Section of Wall-Window Interface at Jamb

No. 4 – Water penetration through windows

The three types of PVC windows used in the WWI study:

- Non-flanged (“box”) window frame, fabricated in Canada;
- Fixed flange integral to the frame, fabricated in Canada
- Combination fixed and operable (sliding) flanged window, fabricated in Canada

It should be noted that the purpose of the study was not to determine the performance characteristics of the windows themselves but to focus on the performance of interface details. However, given that these windows nonetheless were subjected to simulated wind-driven rain conditions what can be observed from the results obtained in the study?

Not surprisingly, sliding windows had the lowest performance rating and when subjected to extreme tests conditions likewise performed poorly. Of the fixed windows used, these had varying performance with window leakage detected at or below their respective performance rating. In one instance a window performed above the expected rating and did not leak under any of the test conditions. This indicates the disparate nature of window performance and is in line with that suggested by Rickets [1] on the variability in watertightness and air leakage performance of windows in his study of window performance.

No. 5 – Use of self adhered flashing membrane and tape – are these the panacea to water entry and control of air leakage? What to look out for

Self-adhered flashing (SAF) membranes are typically specified for use in window installation because of their apparent ability to seal interfaces along the many different components of the wall-window interface. They can be cut to protect the head, jambs and sill and many different methods are available to use these components as pan flashing. However these should be used with some knowledge of their performance characteristics as not all of these materials readily adhere to all substrates to which they are applied and neither is adhesion necessarily long-term.

1. Ricketts, D. R. (2002), “Water Penetration Resistance of Windows: Study of Manufacturing, Building Design, Installation and Maintenance Factors”, Study 1, Canada Mortgage and Housing Corporation, Ottawa, December, 86 p.

This suggests that when installed, SAF membranes should be shingle lapped as any other flashing component, as is indicated in the different window installation guides*. Self-adhered flashing membrane is comprised of two components: a thin plastic topsheet and an adhesive, the topsheet acting as a substrate for the adhesive. The primary types of adhesive used in SAF membrane are either bitumen-based or butyl-based products each of which can vary in formulation. Information on the different adhesives used for SAF membranes that relate to their physical characteristics, durability and performance in use from laboratory studies, can be found in [2, 3, 4].

For example, in the WWI study of W4 a bitumen-based SAF membrane was used to seal the perimeter of the window frame to the sheathing membrane (see also Practical Considerations No. 8). In this case the SAF membrane was much thicker and less flexible than the sheathing membrane to which it was applied. Additionally, the sheathing membrane was not perfectly flat and perfect adhesion was not apparently achieved even though the installation was carried out with great care. Efforts were made to ensure that application of the SAF was made to a clean and dry substrate, and manual pressure was applied to its surface in an attempt to achieve a secure bond to the sheathing membrane. Nonetheless, it was evident that loss of adhesion occurred some time after the installation was complete. The loss in adhesion between the SAF membrane and the sheathing membrane may be due to incompatibility between products, but other aspects such as the conformability of the SAF topsheet may also be important. The degree of conformability of the sheet material (i.e. ability to conform to different shapes) in part depends on the sheeting thickness with thinner sheets being more conformable to surfaces to which they are applied. The use of a more conformable plastic topsheet would perhaps have lessened the tendency for the 'fish-mouthing' that was evident in W4; additionally, the fact that this SAF membrane was not shingle lapped exacerbated the loss in adhesion as the resulting deficiencies offered openings for water entry.

There are other factors to consider, although these were not the focus nor formed part of the current study. For example, the degree of adhesion of such materials may be reduced at low temperatures as it is generally acknowledged that adhesives are less effective in bonding to other materials at lower temperatures. Manufacturers of adhesive based materials provide information on the lowest temperatures at which materials could be used in service and these should be closely observed. As well, materials necessarily shrink upon a reduction in temperature and the resulting dilation may augment the effect of reduced adhesion at low temperature.

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* CSA A440.4; ASTM E2112; FMA/AAMA 100

2. Zima, A.D., Weston, T.A., Katsaros, J.D. and Hagood, R. (2004), "Comparison of Butyl versus Modified Asphalt Window Flashing Adhesives", in: Durability of Building and Construction Sealants and Adhesives, Wolf, A. (Ed.), STP1453-EB, ASTM, West Conshohocken, PA, 18 p. DOI: 10.1520/STP12568S

3. Katsaros, J.D., (2005), Adhesive Characterization & Durability of Self-Adhered Flashings, Journal of ASTM International (JAI), Vol. 2 (10); 17 p. (DOI: 10.1520/JAI12494

4. Crowder-Moore BJ, Weston TA, Katsaros JD, (2006), Performance Testing of Flashing Installation Methods for Brick Mold and Non-Flanged Windows, Journal of ASTM International (JAI), Volume 3(1); 20 p. DOI: 10.1520/JAI12490

The physical characteristics of SAF membranes necessarily vary among the different types of manufactured components. Most manufacturers of SAF offer a butyl-based adhesive system, and these have generally been shown to be more stable and offer more durable adhesion at various in-service conditions. Whichever type of SAF membrane is used, consideration should be given to its long-term behaviour given the context of its use in-service. This implies obtaining information not only on expected material performance over time, but also the likely fault tolerance of the installation as SAF membranes of any type may fail over time or prematurely due to installation faults, and the consequences of failure in terms of water penetration may be more significant when these deficiencies are located along planes of heightened pressure difference and accumulation of water.

No. 6 – Use of sealants and caulking compounds – are these necessary?

The use of caulking and other joining products is often specified for sealing between siding and window frames, or between J-trim and frame, and around other penetrations. Given that such products typically age when exposed to the climate elements, and over time lose their elasticity and degree of adhesion to the substrate to which they have been applied, they cannot be relied upon to provide a continuous seal over the life of the window installation. Indeed, given the expected loss in performance due to aging and the level of attention typically dedicated to the application of caulking, one can expect caulked joints and interfaces to leak and hence these cannot be relied upon to prevent water ingress. And nor should they, as these products should be viewed as useful in retarding the ingress of water and supporting other measures to render the second line of defence effective where appropriate.

No. 7 – Design for redundancy: two seals or one? (Results from W1)

The primary purpose of the evaluation of Specimen W1 was to determine whether a secondary seal at the junction between the window frame (head and jambs only) and the water-resistive membrane could provide benefits as a redundancy when imperfections are present. Figure 8-4 and Figure 8-5 show horizontal sectional views of both wall-window interface details; "Base case" and a "Variation" respectively.

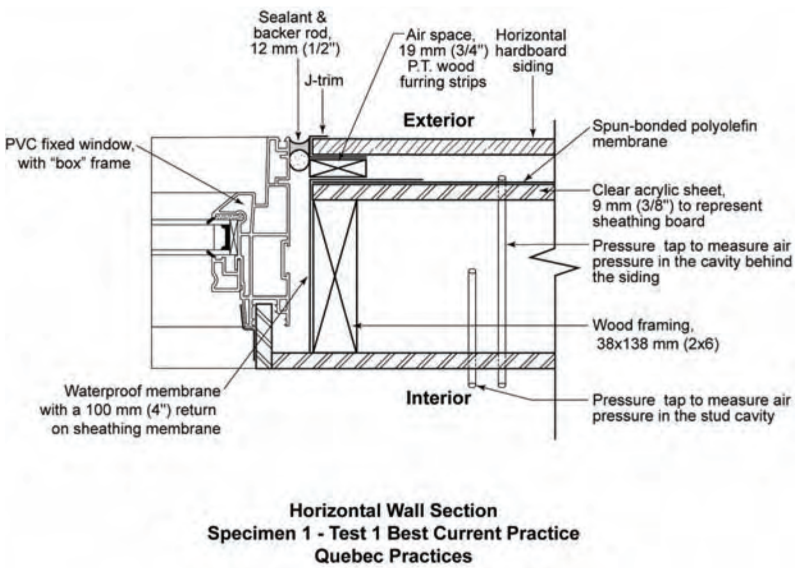


Figure 8-4: W1: Horizontal section – Base case

The tests results indicated that the addition of an extra seal and backer rod ("V-side") at interface between the window frame head and jambs reduced the likelihood of water entry. When tested in various conditions to simulate wind-driven rain, the comportment of the "B-side" offered a lower degree of watertightness, more water entry, in relation to "V" given that there was a more significant increase in rate of collection at the sill for "B" as compared to "V".

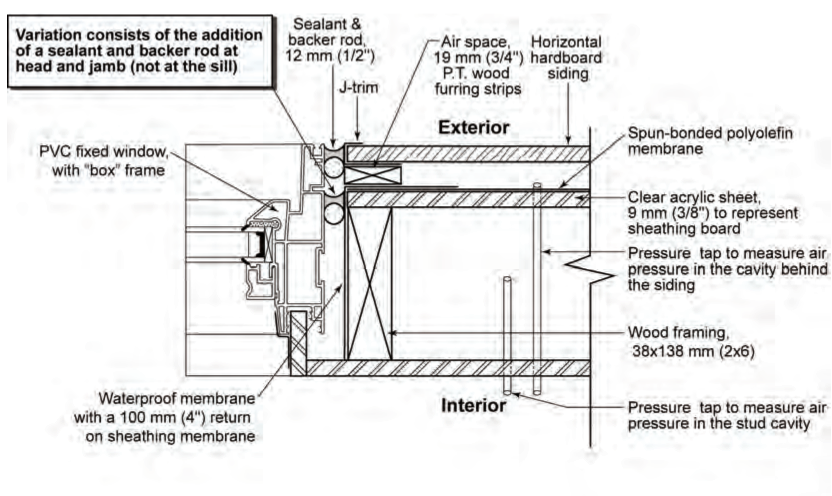


Figure 8-5: W1: Horizontal section – Variation

II. PRACTICAL CONSIDERATIONS OF INSTALLATION — DEGREE OF CARE AND SEQUENCE OF OPERATIONS

No. 8 – Lapping of Self-Adhered Flashing Membranes

The compatibility between self-adhered membranes, flashings and substrates affects the waterproofing ability of the interface. Poor compatibility may result in the formation of funnels that can provide a path for water ingress past the second line of protection against water penetration. Proper shingle lapping of self-adhered membranes with the sheathing membrane is a better practice for rainwater management than face-taping the self-adhesive membrane over the sheathing membrane (Figure 8-6). The importance of shingle-lapping layers of mechanically attached sheathing membranes has long been recognized as critical for the proper management of water ingress of wall systems at the plane of the second line of protection.

Shingle lapping of self-adhered membrane with the sheathing membrane will not contribute to the airtightness of the sheathing membrane assembly (contrarily to the double intent of waterproofing and airtightness using a face-taping method).

Background

Strips of self-adhered flashing membranes can be installed at the wall-window interface to obtain a weatherproof seal at the joint between the window frame and the wall sheathing membrane. Certain window installation procedures specify that the flashing membrane should be installed over the flange of the window frame at the jambs and head, and under the window flange at the rough sill. Other procedures, used in the field, consist of installing a self-adhered membrane around the perimeter of the rough opening to seal the window flange to the sheathing membrane.

Test specimen

One half of the wall specimen (Table 8-1; W4, B-side) included a 50-mm wide self-adhered flashing membrane installed over the interface between the flange of a PVC window frame and a spun-bonded polyolefin sheathing membrane. The other half of the wall (V-side) specimen included no seal of any sort at the joint between the sheathing membrane and the window frame. The sheathing membrane was lapped over the window flange and cut about 6-mm short of the edge of the perimeter of the window frame.

Observations

Observations during testing as well as after the de-construction of the V-side of the test specimen indicated that delamination of the self-adhered membranes from its substrate occurred early on in the test sequence (Figure 8-7). Following which, those areas where the membrane delaminated became points for water accumulation (funnels) and eventual ingress past the second line of protection (i.e., the sheathing membrane) of the wall system. Indeed, several small funnels developed over the length of the joint (Figure 8-8).† Once water passes beyond the second line of protection there is potential for water entrapment in areas where moisture-sensitive materials may be present and where also, drying potential may be reduced. Hence, premature deterioration of the moisture sensitive components of the wall may result from such water ingress.

At the window head detail, the B-side of the specimen (having self-adhered flashing membrane lapping over the sheathing membrane) exhibited a much lower performance at managing water ingress than the V-side of the specimen (without any flashing membrane, just an overlap of the sheathing membrane over the window flange). On the B-side, the water cascading down the face of the sheathing membrane got trapped in funnels formed in the self-adhered membrane, and eventually found its way to the interior side of the window flange, flooding the interior side of the window head (Figure 8-9). No such pattern of water accumulation was observed to collect at the window head of the V-side of the wall specimen. Additional tests on the specimen with a modified window head detail ensuring proper lapping of the self-adhered membrane with the sheathing membrane (self-adhered membrane behind the sheathing membrane but in front of the window flange) were carried out and no water ingress on the window head was observed. This suggests that proper lapping of elements without necessarily ensuring a seal may in some cases be sufficient to provide adequate water resistance of the joint. Sealing the interface may not necessarily provide superior performance and may indeed create paths of water entrapment when a face-taping method of installation is used and the integrity of the seal fails.

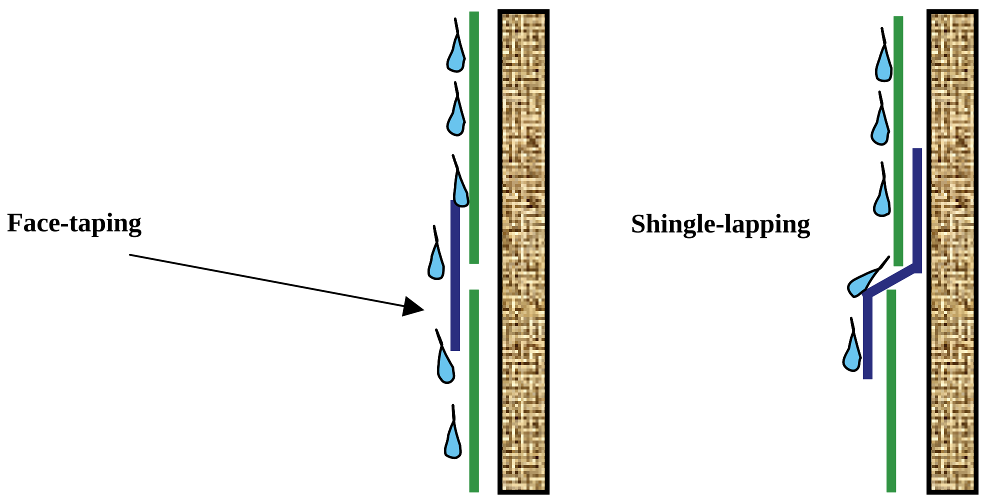


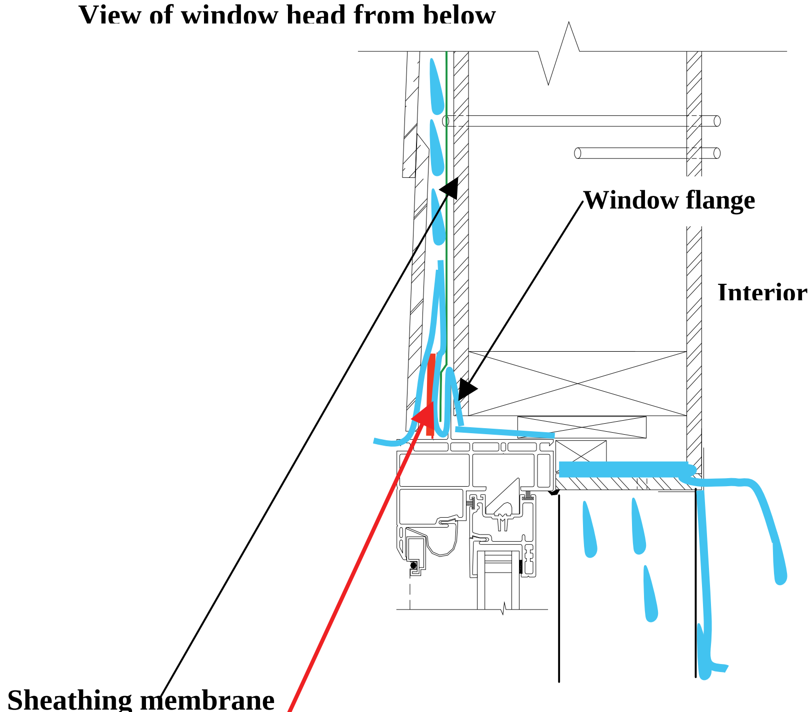
Figure 8-6: Difference between shingle-lapping and face-taping
(Cross-sectional view of joint between 2 materials)

† Deconstruction of another wall specimen (for another JRP partner) built with a different sheathing membrane and a different self-adhered flashing membrane than specimen W4 exhibited similar delamination of the self-adhered membrane and the creation of water funnels.

Figure 8-7: Location of delamination, and in some cases, loss of cohesion between plies of the self-adhered flashing membrane

Figure 8-8: Locations (red arrows) along the interface between the window and sheathing board where the flashing membrane delaminated from the sheathing membrane and formed funnels in which water accumulated

View of window head from below



Cross-sectional view of window head

Figure 8-9: Water ingress at window head of specimen during a test

Appendix A

Description of Full-Scale Wall Specimens W1 to W4

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SUMMARY

Four (4) full-scale 2400 mm by 2400 mm wall Specimens were designed and built with input from a project partner (Canada Mortgage and Housing Corporation) and the building envelope industry. The Specimens were meant to represent several variations in window type and installation as well as in wall design as these variations related to approaches for rainwater management. Review of literature as well as direct input from several building envelope consultants and building contractors across Canada indicated that there were a multitude of variations – small and large - between construction practices everywhere.

The full-scale Specimens include the following features:

- Box and flanged PVC window
- Fixed and operable windows
- 2-in. by 6-in. wood-frame construction
- Paper and polymeric water resistive barrier membranes
- Direct-applied siding and siding applied on a drained clear air space
- Hardboard horizontal lap siding
- Several methods to detailing the wall/window interface

The Specimens have since been tested in NRC laboratories with the objective to characterize their ability to manage water penetration when subjected to withstand incremental climatic loads of wind and rain (by the simultaneous action of air pressure difference and spray rate).

1. INTRODUCTION

This report provides a description of the four full-scale wall Specimens designed and built for testing their water management ability in the NRC Dynamic Wall Testing Facility (DWTF). Each Specimen description includes horizontal and vertical cross sections for each half of the Specimen (V and B-sides), as well as photographs taken during the construction, illustrating each step of material installation.

2. SELECTION OF WINDOWS AND WALL/WINDOW INTERFACE DETAILS

Literature was reviewed, be it MEWS review of practices, recent SPECIMEN research reports on windows and their installation or installation standard manuals or code proposed changes for the next edition of the National Building Code. A group of Canadian field building envelope specialists also provided input into what was currently best practice and typical practices of detailing the wall/window interface of wood-frame buildings in their respective geographical region of practice, that is the West Coast, the Prairies, and Quebec. This review highlighted significant differences in regional practices across Canada for the detailing of the wall/window interface and the wall assembly as well. These differences can be related to climate severity as well as traditional practices.

The selection of wall/window detailing for investigation of the project was based on:

- Current industry issues related to water management at the wall-window interface. These included:
- Shielding the window junctions from moisture loading using end dams at both extremities of window head flashing,
- Allowing redundancies in the assembly for collection and evacuation of water that may get beyond the first line of defence,
- Designing the detailing based on the assumption that the window frame was not completely watertight and would leak sooner or later and thus allow water inside the wall assembly.
- Representation of best as well as typical regional Canadian practices. Practices varied by region and the project aimed at providing information on the comparative performance of a diverse array of practices.

Here are some of the regional differences related to rain penetration control strategies this review highlighted, and which were taken into account in the testing program:

- On the West Coast flanged windows were predominantly used and the cladding (particularly traditional stucco) tended to be installed over a 10 to 19 mm air space created by the installation of vertical furring strips. Best practices included installing water-resistant membrane over the rough framing of the opening and a waterproof membrane on the subsill, which was intended to drain into the air space behind the cladding. Thermal insulation was usually not placed in the 12-15 mm (1/2 to 5/8 in.) air space between the window frame and the rough opening.

- In the Prairies, flanged windows were also predominantly used and the cladding was typically installed directly against the backup wall. Typically no attempt was made to drain the subsill or protect the rough opening materials against water absorption. Best current practice included the addition of water-resistant membranes over the materials of the rough opening.
- In Quebec, box frame windows were common and the trend was to install the cladding over an air space. The gap between the window frame and the rough opening was usually filled with thermal insulation. Best current practice included the installation of a water-resistant membrane on the material making up the rough opening and a waterproof membrane on the subsill. The subsill was intended to drain into the air space behind the cladding. The research interest in this case has been about the benefit of “upgrading” this practice with additional features, to provide an extra level of redundancy.
- In the Atlantic Provinces, vinyl siding is the most common type of exterior cladding and is usually applied directly over the water resistive barrier. PVC flanged windows are typical. The most common water resistive membranes are polymeric-based. At the wall/window interface, it is common to use construction tape to seal the WRB to the window flange all around (the window is installed before the WRB). Another practice is to place strips of WRB over the sheathing board at the sill and jambs before installing the window over that. Another practice is to fold the WRB inside the rough opening prior to installing the window. Insulation fills the gap between the rough opening and the window frame; sprayed-in-place polyurethane foam or batt insulation is tucked in. Drip cap flashing at the head are not common.
- In Ontario, flanged PVC windows are common. The siding is usually direct applied onto the water resistive barrier. Predominantly sprayed-in-place polyurethane foam fills the gap between the rough opening and the window frame; Variations on the joint between the WRB and window frame are similar to the range of variations in the Atlantic Provinces.

3. SUMMARY OF VARIATIONS SELECTED

As the objective of the experimental work consisted of comparing the ability of different wall/window detailing to manage rainwater, the wall Specimens have been designed to allow side-by-side comparison of two wall/window interfaces details. Each 2440-mm by 2440-mm (8 ft. by 8 ft.; nominal size) wall Specimen includes two large openings. Each of these openings includes a window along with a set of wall-window interface details for the head, the jambs and the sill (Figure A3-1). The size of the windows is nominally, 610-mm wide by 1220-mm high (2 ft by 4-ft). The window width was selected so that two “window plugs” could be housed in the wall Specimen, a requirement for side-by-side comparison. The window height was maximized at 1220-mm, considering that about 610-mm of opaque wall above the window plug was needed to get a water cascading effect over the window head. Half of the Specimen includes a “best current practice wall/window interface detail” and the other half includes a more typical variation or an “upgraded” way of detailing the interface that may or may not be common but present a research interest.

Table A3-1 provides a summary of the essential features of the four Specimens, as well as the difference between the B-side and the V-side of each Specimen.

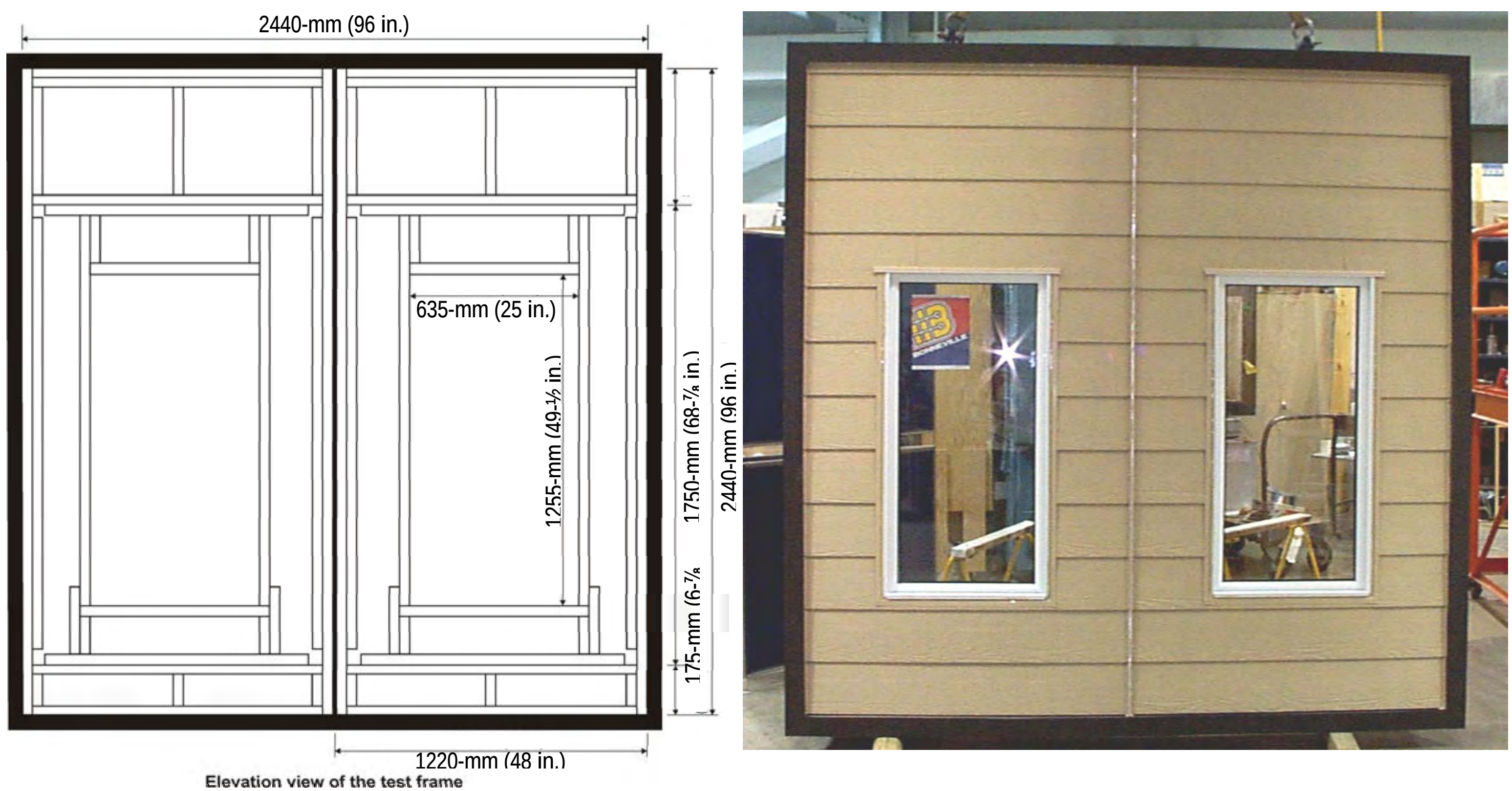


Figure A3-1: Typical layout of the wall Specimen for comparative investigation of the water management response of two side-by-side wall/window interface details (left). Elevation view of the exterior cladding of the Specimen completed (right).

Table A3-1: Summary of SPECIMEN Specimens Features

SPECIMEN	SPECIMEN W1	SPECIMEN W2	SPECIMEN W3	SPECIMEN W4
Objective: define effect of…on water management performance of assembly	An extra seal at jambs and head of R.O. window junction, for box frame fixed window, sloped subsill and rainscreen wall	Two levels of protection of R.O. members, back dam at subsill for flanged fixed window installed in concealed barrier wall	Two methods of creating drainage space at rough sill between window flange and WRB membrane. Flat sill with back dam used for combination flanged window installed in rainscreen wall	Two methods of joining WRB to window flange, for combination flanged window installed in concealed barrier wall
Siding	Horizontal hardboard lap siding Canexel (Louisiana Pacific / CCMC 07893-L) Installed on pressure-treated 1X2 furring strips fastened to studs	Horizontal hardboard lap siding Canexel (Louisiana Pacific / CCMC 07893-L)	Horizontal hardboard siding Canexel (Louisiana Pacific / CCMC 07893-L) Installed on pressure-treated 1X2 furring strips fastened to studs	Horizontal hardboard siding Canexel (Louisiana Pacific / CCMC 07893-L) Installed directly on back up wall
Window	Fixed solid PVC box frame (Bonneville / CCMC #12362-L) 2 ft wide X 4 ft high CSA A440 ratings: B7 (700 Pa); C5 (2000 Pa with 1/125 deflection); air leakage rate: 0.25 $m^3/h/$ m	Fixed solid PVC windows, with integral flange.: (CWD Windows; Series Consul) 2 ft wide by 4 ft high CSA ratings: B7 (700 Pa); C4 (1600 Pa with 1/125 deflection); air leakage rate: 0.25 m3/h/ m	Combination window, solid PVC with integral flange (CMD Windows; Series Ambassador) <u>Top</u>: Horizontal slider, 800 mm high (nominal), CSA rating: A3 (0.55 $m^3/h/m$), B3 (300 Pa), C4 (1600 Pa) <u>Bottom</u>: flanged fixed, 400 mm high; CSA rating air leakage: 0.25 $m^3/h/$ m; B4; C4	Combination window, solid PVC with integral flange (CMD Windows; Series, Ambassador) <u>Top</u>: Horizontal slider, 800 mm high (nominal), CSA rating: A3 (0.55 $m^3/h/m$), B3 (300 Pa), C4 (1600 Pa) <u>Bottom</u>: fixed, 400 mm high; CSA rating Air leakage: 0.25 $m^3/h/$ m, B4, C4.
Joint between cladding and window	▪J-trim around window frame. Size: 1 1/2 in. back leg by ¾ in. deep by 3/4 in. front leg. ▪Sealant & backer rod in 12 mm wide gap between window frame & J-trim at jambs & sill; not at head. Canexel Thermoplastic caulking.	▪ J-trim around window frame: Size: 1 ½ in. back leg by ¾ in. deep by ¾ in. front leg. ▪ Sealant and backer rod in 12 mm wide gap between window frame and J-trim at jambs and sill (not at head). Canexel Thermoplastic caulking.	▪ No J-trim around window frame ▪ Sealant and backer rod in 6 mm wide gap between window frame and siding and sill (not at head). Canexel Thermoplastic caulking.	▪No J-trim around window frame ▪No sealant/ ▪ 6 mm gap between edge of siding and window frame
Drip cap head flashing	Yes. Preformed PVC. No end dams	Yes. Preformed PVC. No end dams	Yes. Preformed PVC. No end dams	No
Water resistive barrier (WRB)	Tyvek Homewrap (DuPont) Installed before window	Tyvek Homewrap. Manuf: DuPont Installed before window	JumboTex 60 minutes (Fortifiber) Installed after window	Tyvek Homewrap (DuPont) Installed after window.
Flashing membrane	Self-adhered membrane Ice and Water Shield (WRGrace)	Self-adhered membrane Ice and Water Shield (WRGrace)	Self-adhered membrane Vycor Plus (WRGrace)	Self-adhered membrane Vycor Plus (WRGrace)
Joint between WRB and window frame	B-side includes a seal at external face of jamb and head joints between window frame and self-adhered membrane installed over WRB. V-side does not include such seal.	Both halves: Self-adhered membranes seal jambs of window flange to WRB. Self-adhered membrane seals head of window frame to sheathing board.	▪WRB laps over window flange (at jambs and head). No seal. ▪ WRB laps under window flange and self-adhered membrane, at sill. No seal.	B-side has 50 mm strip of self-adhered flashing membrane at joint between WRB and window flange (all four sides). V-side has WRB lapping over window flange at jambs and head. Window flange laps over WRB at rough sill.
Rough opening (R.O.)/window interface	Both halves: ▪Self-adhered membranes cover all exposed faces of R.O. ▪Rough sill: 6% slope with flat back, open to drainage cavity behind siding ▪ No insulation	B-side has additional protection for water management: back dam, self-adhered membrane on rough sill extending over rough jambs and lapping over WRB membrane. V-side does not include these elements. Both halves: Rough sill: flat; closed by window flange on exterior; No insulation	Two types of R.O. subsill drainage: B-side has 19 mm air space between window flange and backup wall. V-side has 2-3 mm air space between flange and backup wall, created by folded pieces of membrane at flange fasteners. Both halves: No insulation	Both halves: ▪ No insulation ▪ Rough sill: flat; closed by window flange on exterior ▪ Self-adhered membranes cover exposed face of rough sill and rough jambs; folds onto sheathing board.
Framing & Insulation	2X6. No insulation in stud cavity/	2X6. No insulation in stud cavity/	2X6. No insulation in stud cavity/	2X6. No insulation in stud cavity/

NB. Boxes edged with a thick border describe the difference between B-side and V-side of the Specimen.

SPECIMEN W1

4. SPECIMEN W1

Figure A4-1 shows the window profile inserted into the rough opening. The windows were (nominally) 610-mm (2-ft) wide by 1220-mm (4-ft) high. The window width was selected so that two “window plugs” could be housed in the wall Specimen, a requirement for side-by-side comparison. The window height was maximized at 1220-mm, considering that about 610-mm of opaque wall above the window plug was needed to get a water cascading effect over the window head. The CSA A440 rating for this fixed PVC box frame window was: B7 C5 and an air leakage rate of 0.25 m^3/h/m. Figure A4-2 shows the wood-framing schedule of the 2440-mm (8-ft.) by 2440-mm (8-ft.) test frame.

The composition of the walls intends to be similar to low-rise residential construction with the exception of changes for clear sheathing materials. The wall Specimen consists of: 38-mm by 152-mm (2-in. by 6-in.) wood studs, clear acrylic sheet on the inside to act as the air barrier element, acrylic sheet on the exterior of the framing to act as the sheathing board, spun-bonded polyolefin membrane to act as sheathing membrane and an exterior horizontal hardboard siding installed on vertical furring strips creating a 19- mm air space behind the siding. Clear acrylic sheets are used in lieu of common building materials for the benefits their transparency provides from a water tracing point of view. Through the acrylic sheets, researchers will observe visually the location and timing of water ingress beyond the sheathing membrane.

Figures A4-3 and A4-4 show the wall-window detailing for the “Best Current Practice” half of the test Specimen, while Figures A4-5 and A4-6 provide the wall-window detailing for the “Variation” half of the test Specimen. The difference between the two detailing consists of an additional seal joining the window frame to the sheathing board, at the jamb and head of the rough opening for the Variation half of the test Specimen. This creates an additional level of redundancy in the event that the external seal gets rendered deficient during service life.

Figures A4-7 to A4-29 provide visual records of the construction of the Specimen. The Specimen was built in 2003.

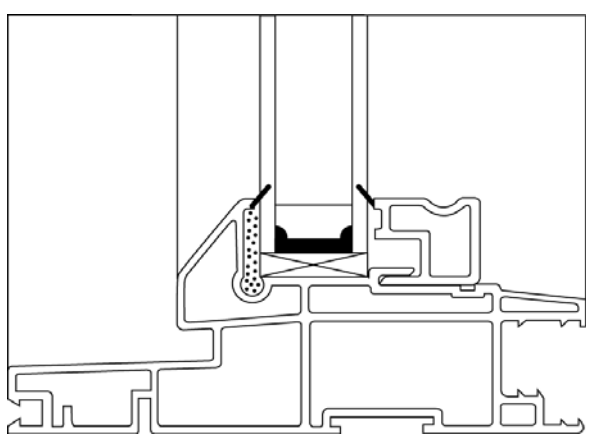


Figure A4-1: Vertical section through fixed PVC window profile, with non-finned window frame (“box frame”)

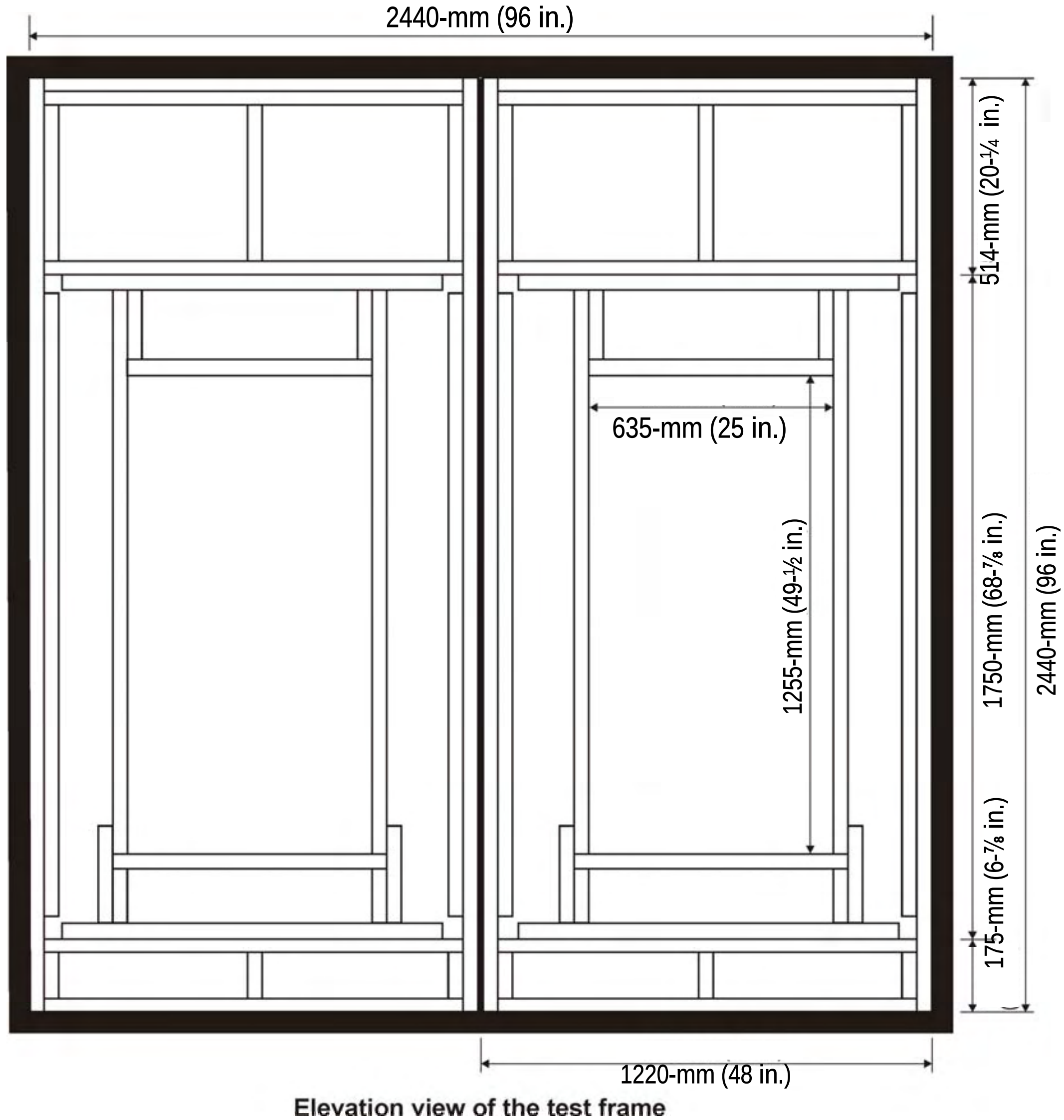


Figure A4-2: Elevation view of the test frame

SPECIMEN W1

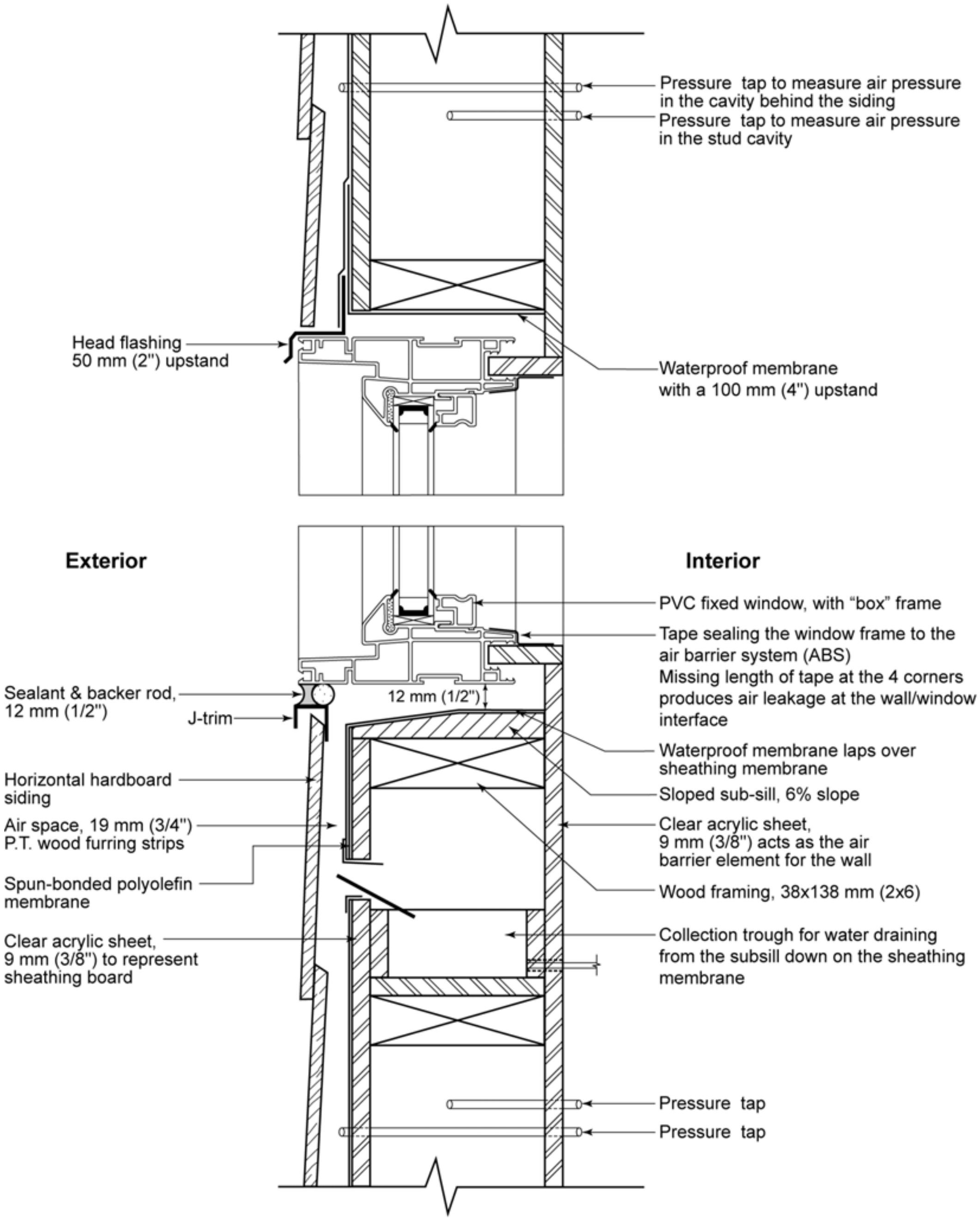


Figure A4-3: Specimen W1 B-side (Vertical section)

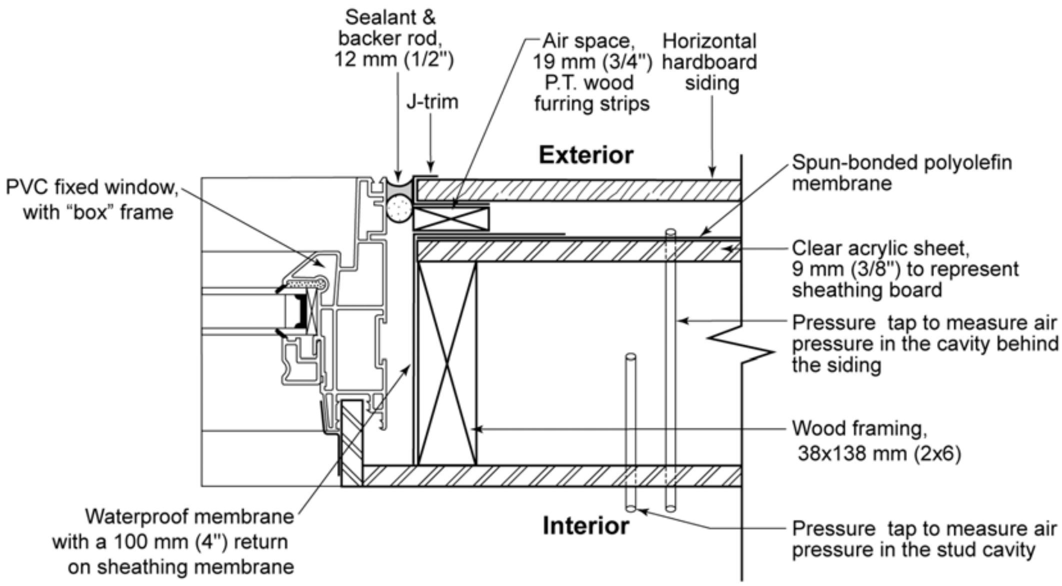


Figure A4-4: Specimen W1 B-side – (horizontal section)

SPECIMEN W1

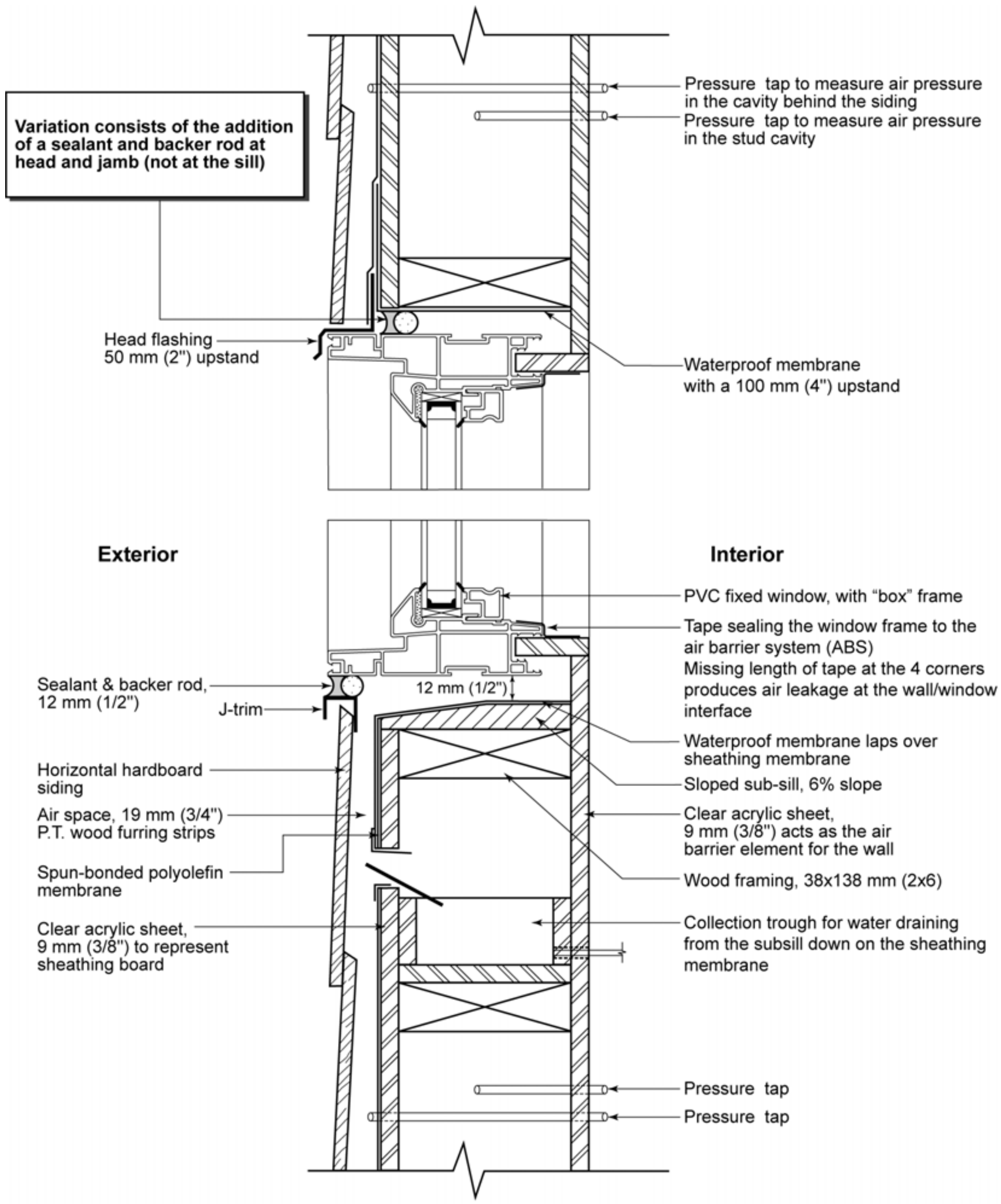


Figure A4-5: Specimen W1 V-side (Vertical section)

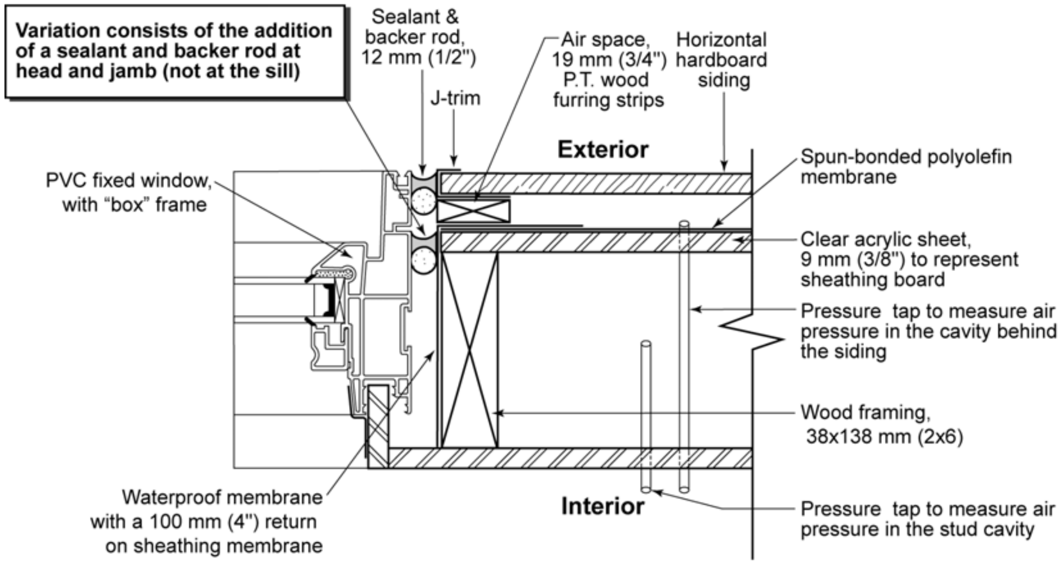


Figure A4-6: Specimen W1 V-side (Horizontal section)

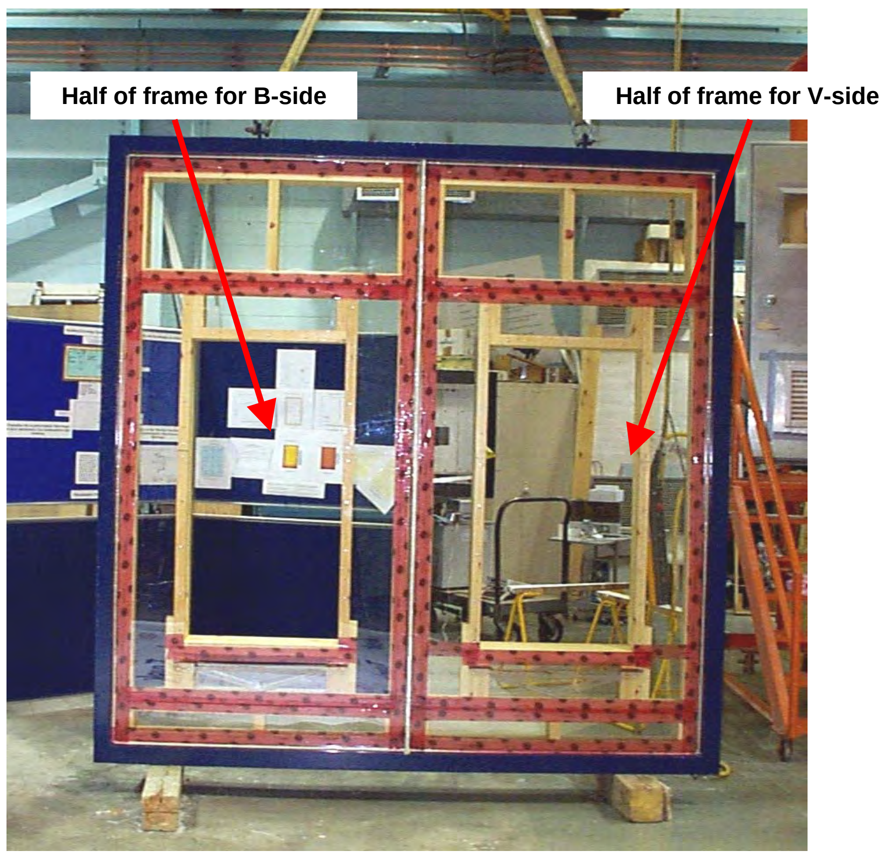


Figure A4-7: Elevation view of wood framing of the test Specimen

SPECIMEN W1

Figure A4-8: Laying out the spun-bonded polyolefin membrane

Figure A4-9: Membrane in place cut at the perimeter of the rough opening

Figure A4-10: Sloped rough sill

Figure A4-11: Installation of flashing membrane onto the rough sill

SPECIMEN W1

Figure A4-12: Protection of the rough sill with waterproof membrane

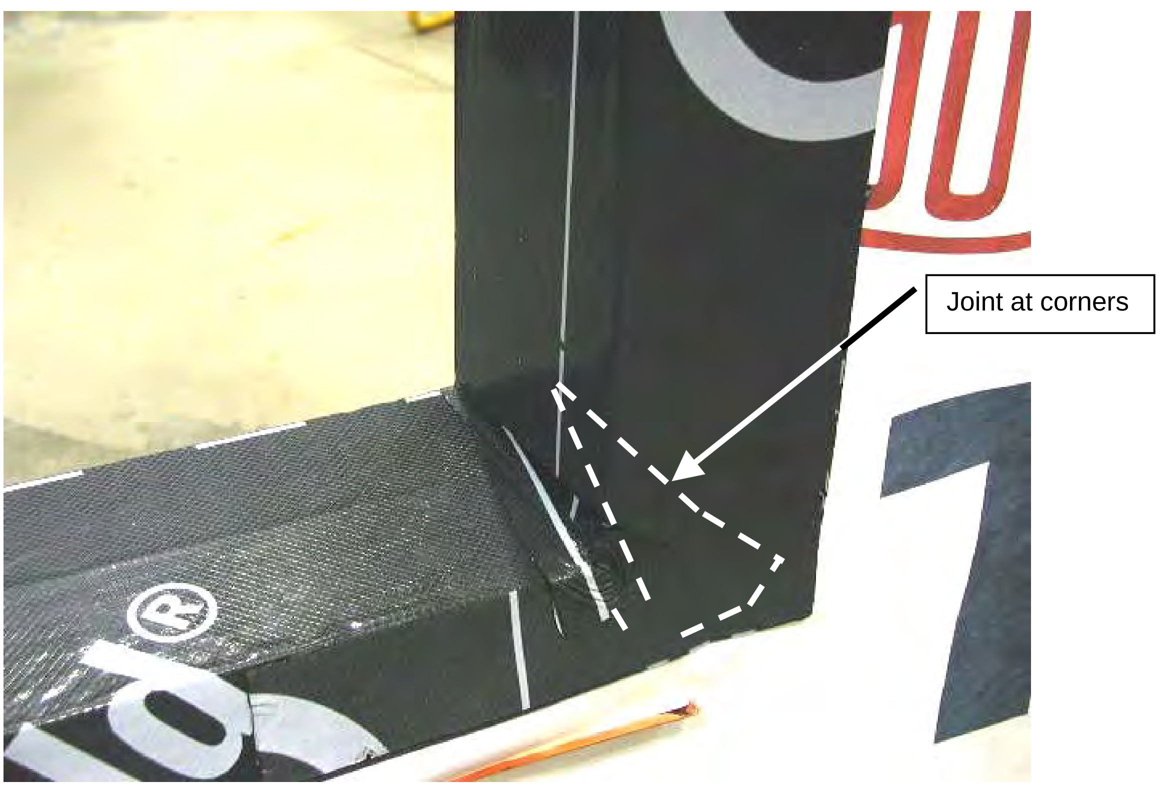


Figure A4-13: Treatment at the sill to ensure continuity of membranes at bottom corners- junction between the sill membrane and the jamb membrane

Figure A4-14: Slot for the water collection trough for water running down from the rough sill on the WRB membrane

Figure A4-15: View of jamb, sill and head treatment with waterproof membranes at the wall/window interface

SPECIMEN W1

Figure A4-16: Anchorage of the non-finned window frame (“box frame”)

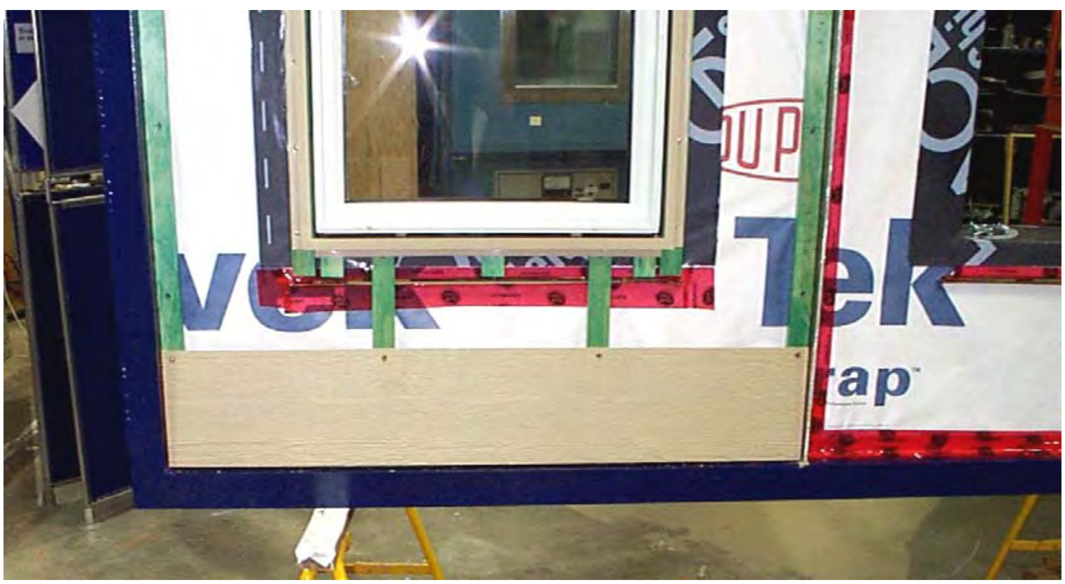


Figure A4-17: Detailing at the sill of the wall/window interface. Same for both halves of the Specimen

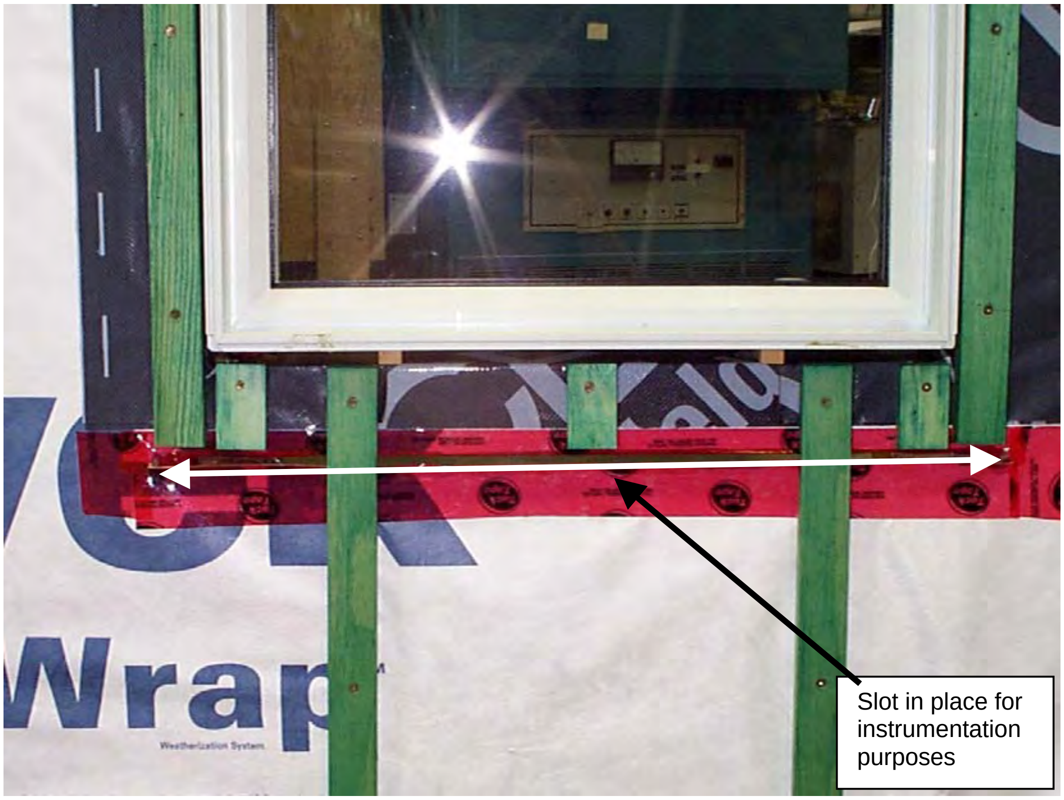


Figure A4-18: Elevation view of the wall/window joint at the sill

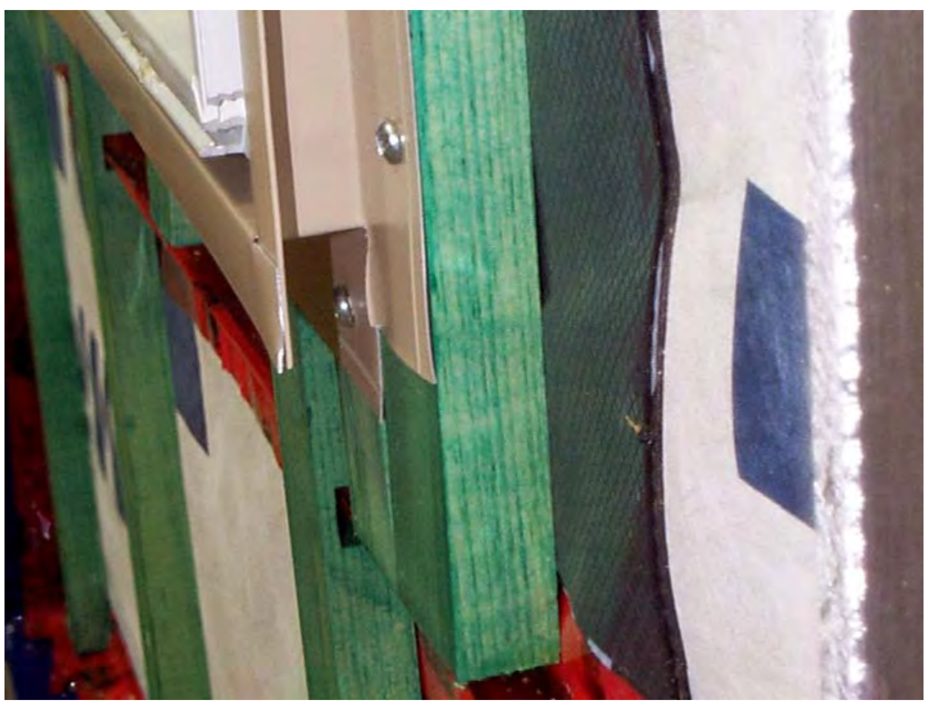


Figure A4-19: View of the bottom corner of the J-trim installation on the furring strips at the sill/jamb corner

SPECIMEN W1

Figure A4-20: B-side half of the Specimen is ready for siding installation

Figure A4-21: Installation of the hardboard siding on furring strips

Figure A4-22: View of the wall/window interface at the jamb

SPECIMEN W1

Figure A4-23: Upper corner of the wall/window interface detail

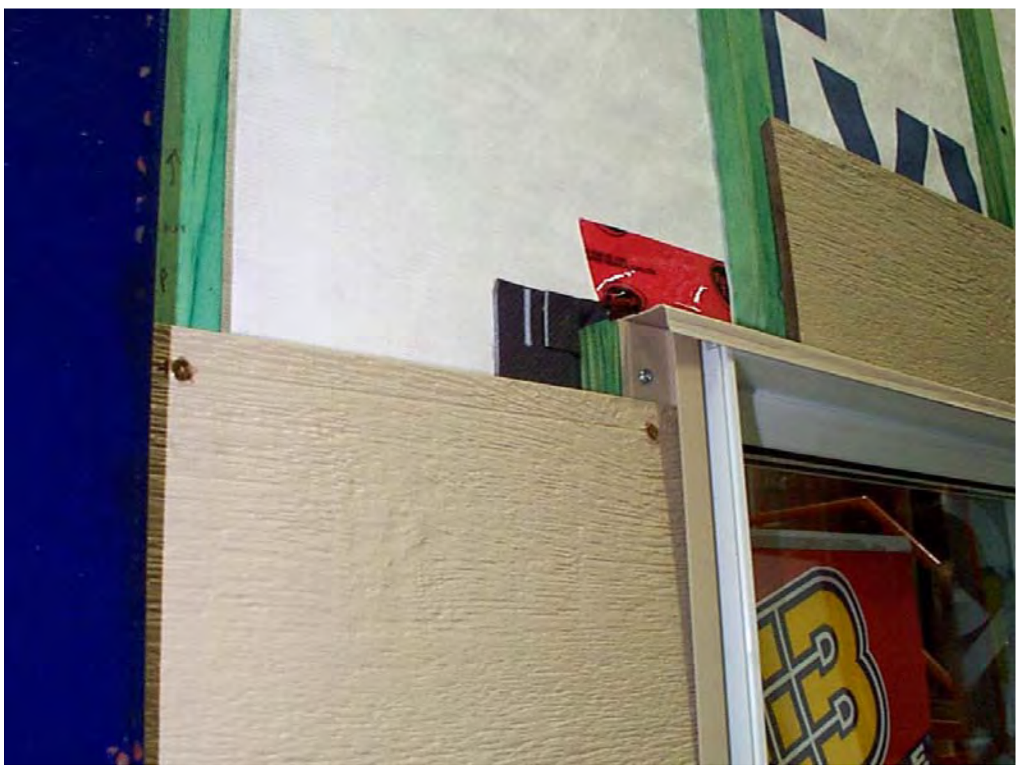


Figure A4-24: Window head detail with the siding being installed

Figure A4-25: Additional sealant and backer rod was placed at the jambs and head of the junction between the window frame and the waterproof membranes, in the plane of the sheathing board. This intends to provide a secondary seal against water entry in case the external bead of sealant fails during service life.

Figure A4-26: Installation of hardboard siding

SPECIMEN W1

Figure A4-27: Descending view of the air space behind the siding

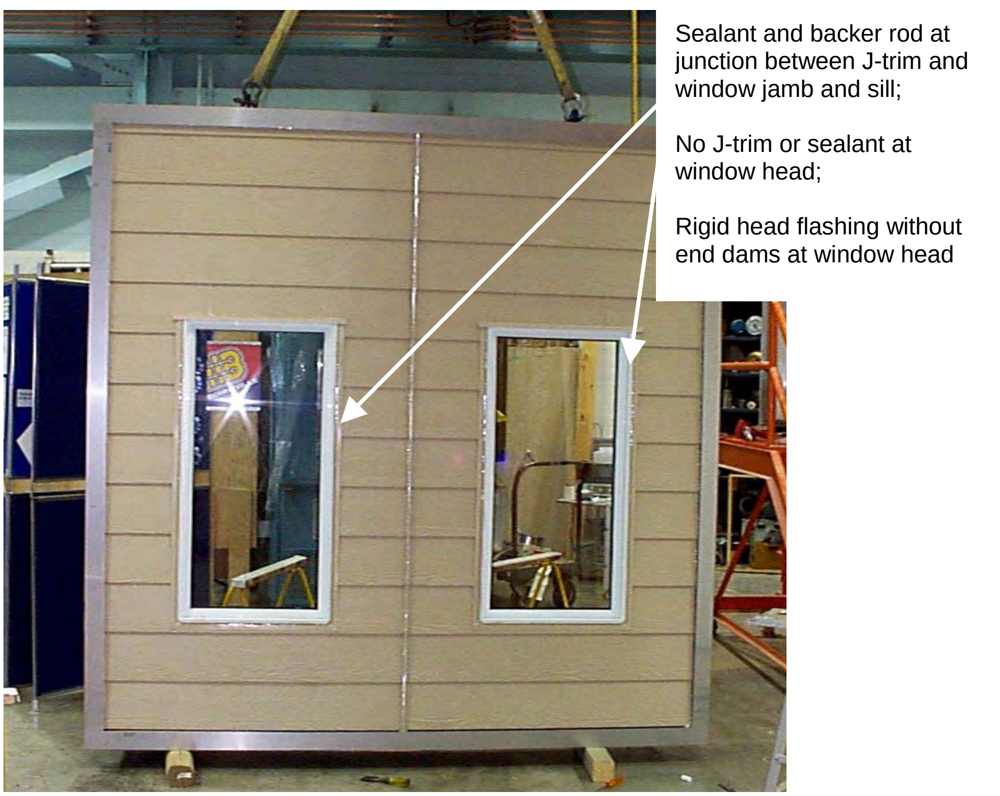


Figure A4-28: Exterior of Specimen construction complete

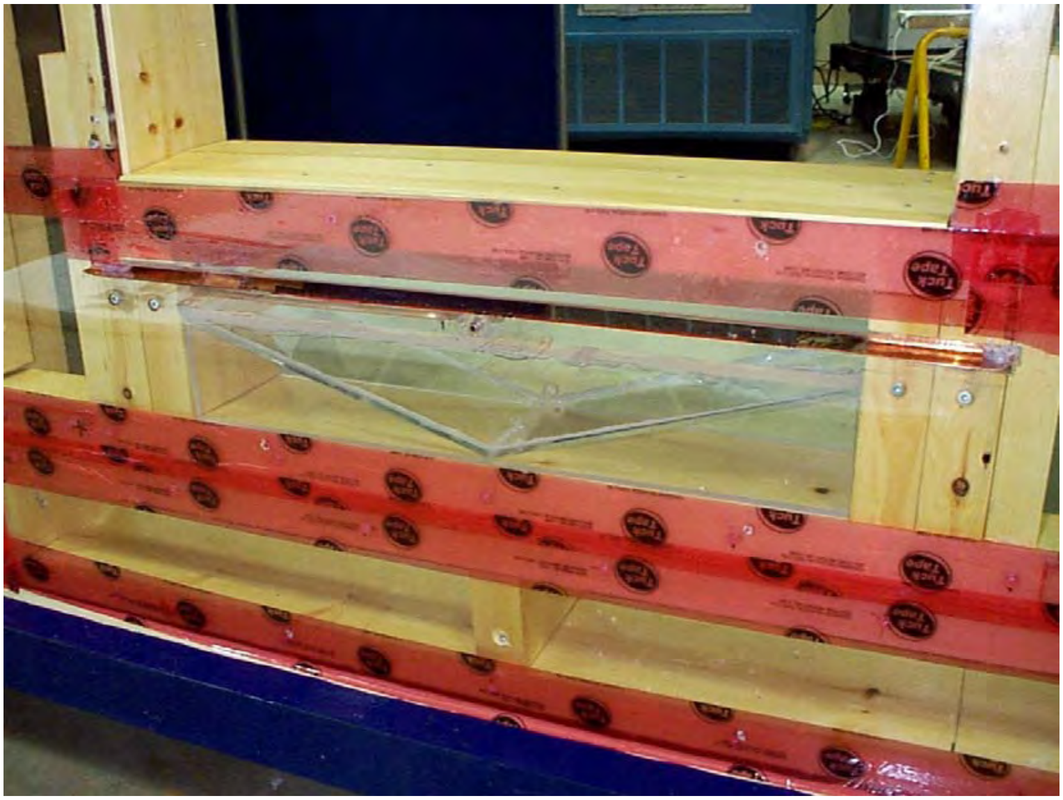


Figure A4-29: Back view of the clear acrylic through installed below the rough sill for water collection

SPECIMEN W2

5. SPECIMEN W2

Figure A5-1 shows the window profile inserted into the rough opening. The windows are (nominally) 610mm (2-ft.) wide by 1220-mm (4 ft.) high. The window width was selected so that two "window plugs" could be housed in the wall Specimen, a requirement for side-by-side comparison. The window height was maximized at 1220-mm, considering that about 610 mm of opaque wall above the window plug was needed to get a water cascading effect over the window head. The CSA A440 rating for this fixed PVC flanged frame window was: B7 C4 and an air leakage rate of 0.25 m^3/hr-m. Figure A5-2 shows the wood-framing schedule of the 2.44-m X 2.44-m (8-ft. by 8-ft.) test frame.

The composition of the walls intends to be similar to low-rise residential construction with the exception of changes for clear sheathing materials. The wall Specimen consists of: 38 X 152-mm (2-in. X 6-in.) wood studs, clear acrylic sheet on the inside to act as the air barrier element, acrylic sheet on the exterior of the framing to act as the sheathing board, spun-bonded polyolefin membrane to act as sheathing membrane and an exterior horizontal hardboard siding installed on vertical furring strips for one set of test runs and directly against the back-up wall for a second set. Clear acrylic sheets are used in lieu of common building materials for the benefits their transparency provides from a water tracing point of view. Through the acrylic sheets, researchers will observe visually the location and timing of water ingress beyond the sheathing membrane.

Figures A5-3 and A5-4 show the wall-window detailing for the "B-side" half of the test Specimen, whereas Figures A5-5 and A5-6 provide the wall-window detailing for the "V-side" half of the test Specimen. The difference between the two details consisted of an additional seal joining the window frame to the sheathing board, at the jamb and head of the rough opening for the V-side of the test Specimen. This creates an additional level of redundancy in the event that the external seal gets rendered deficient during service life.

Figures A5-7 to A5-23 provide visual records of the construction of the Specimen.

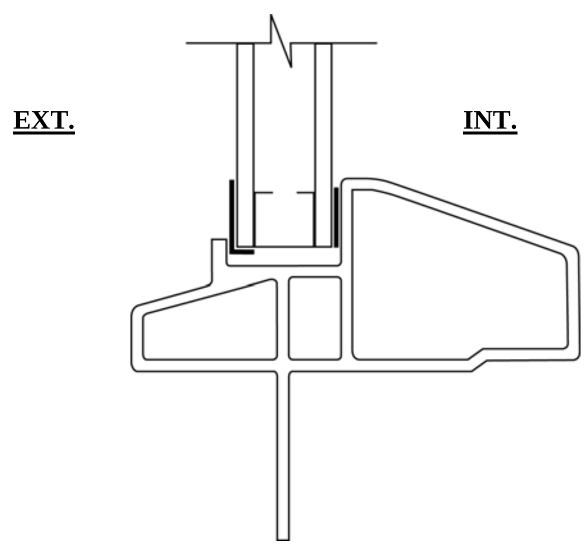


Figure A5-1: Vertical section through the fixed PVC window profile, with a finned window frame

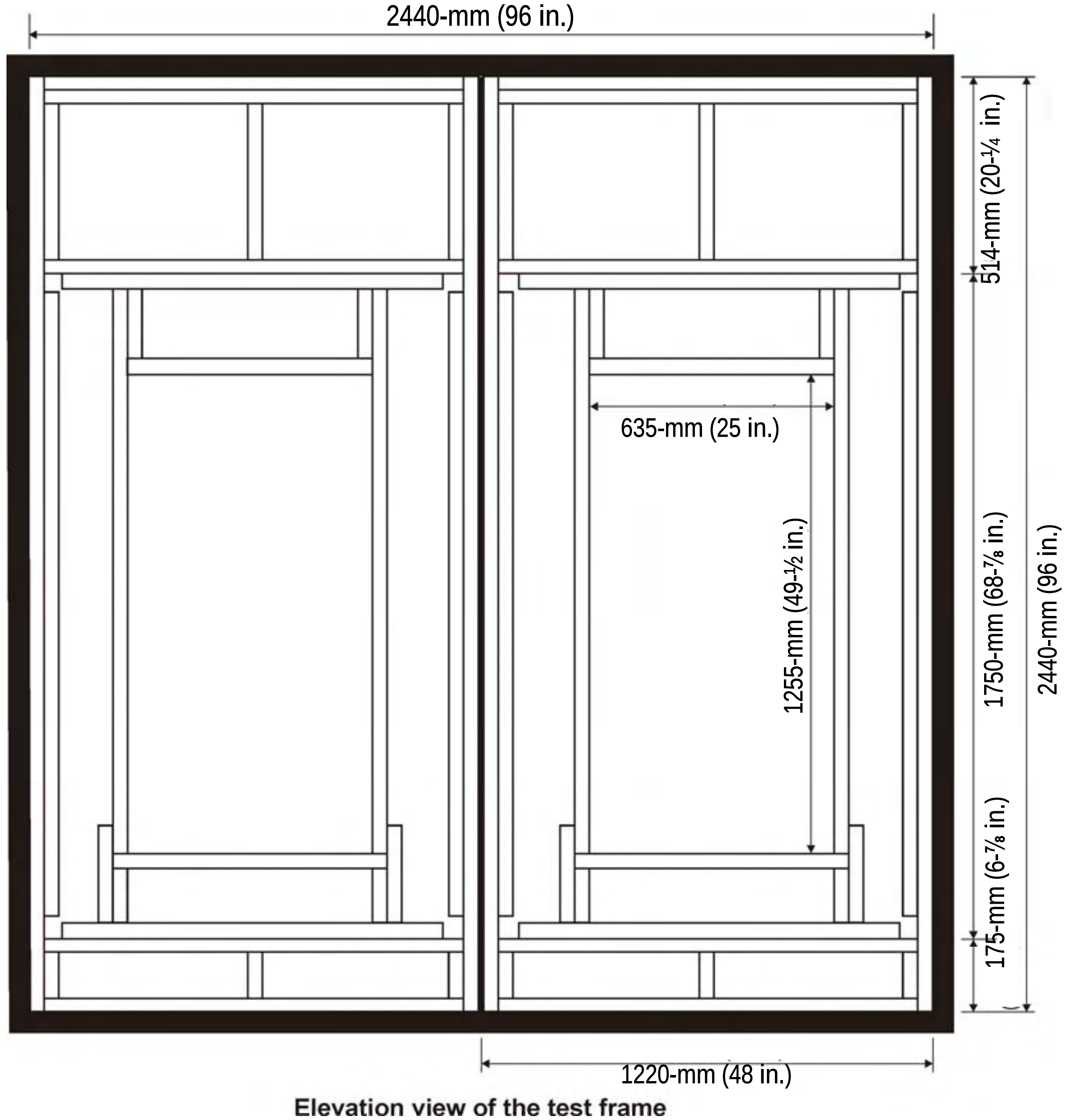


Figure A5-2: Elevation view of the test frame

SPECIMEN W2

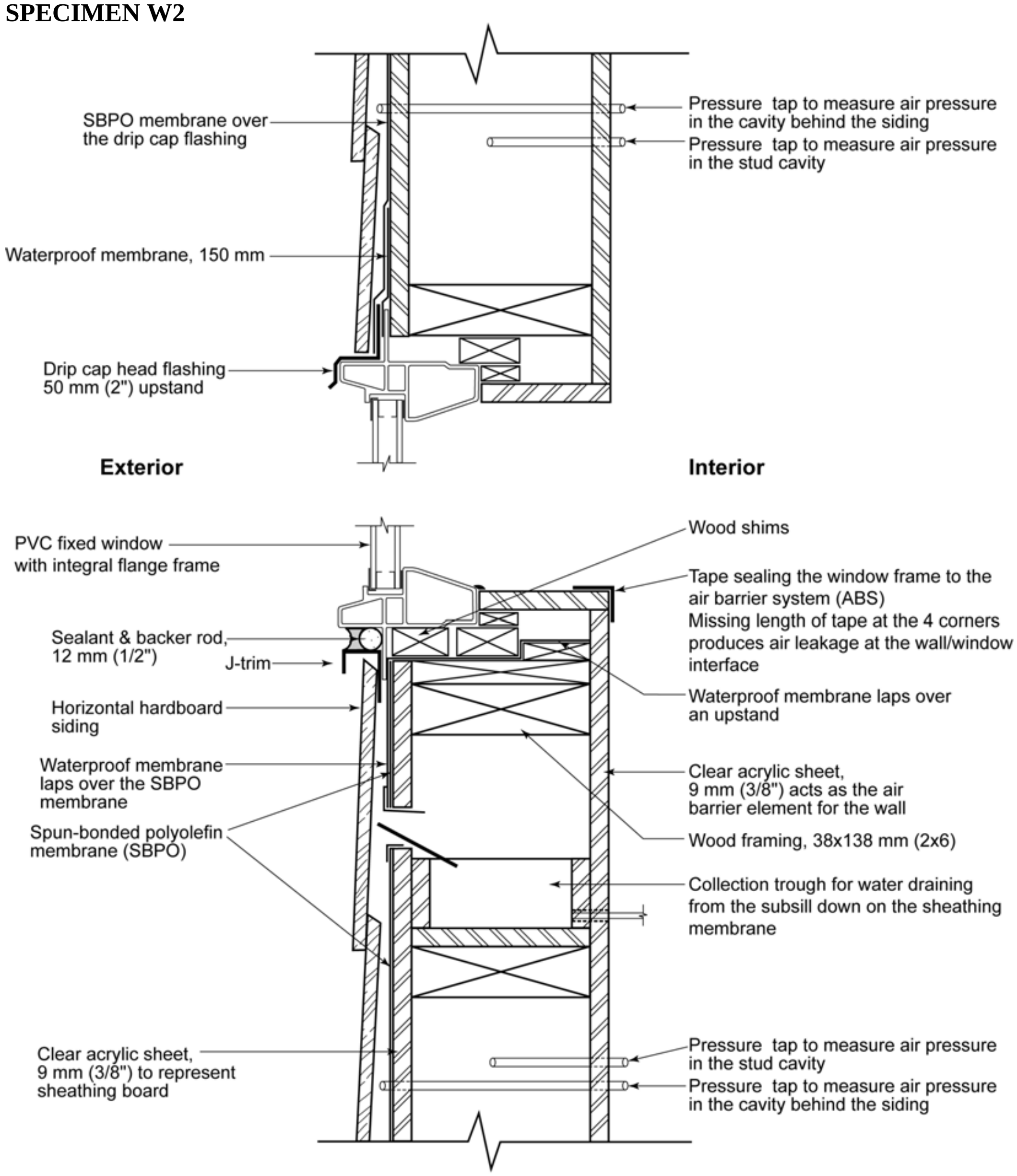


Figure A5-3: Specimen W2 B-side (Vertical section)

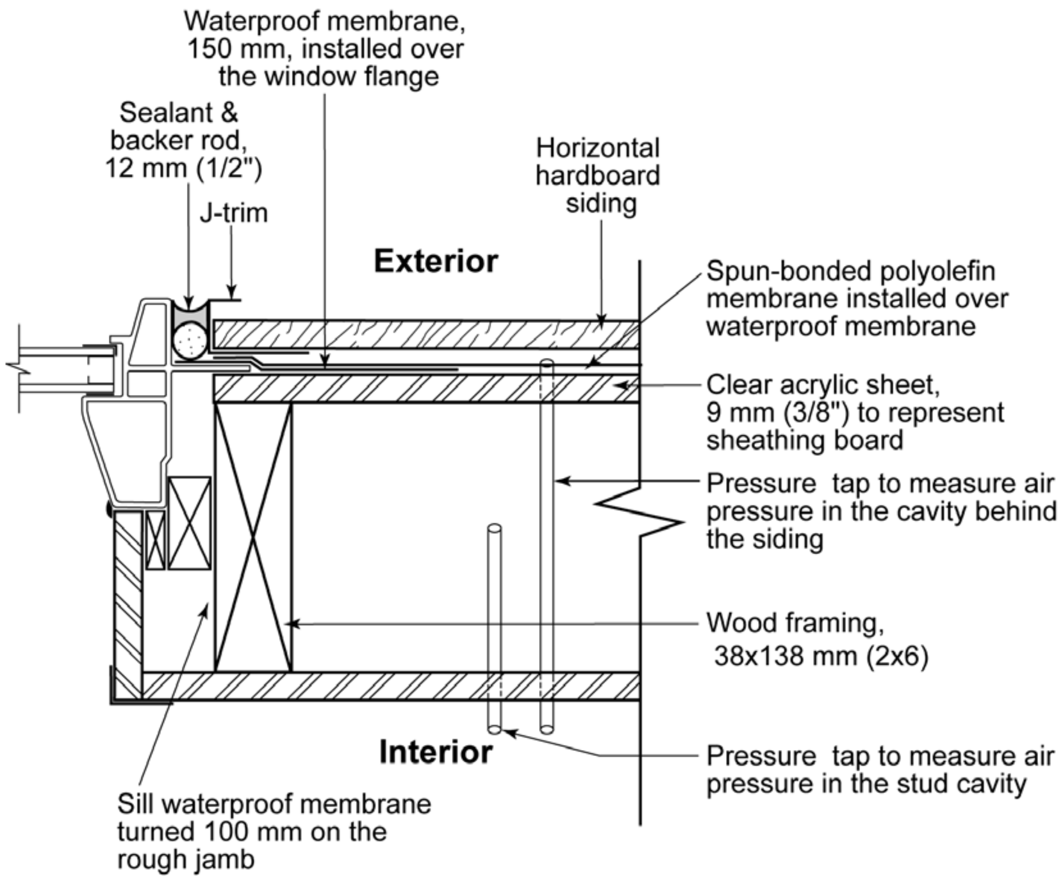


Figure A5-4: Specimen W2 B-side (horizontal section)

SPECIMEN W2

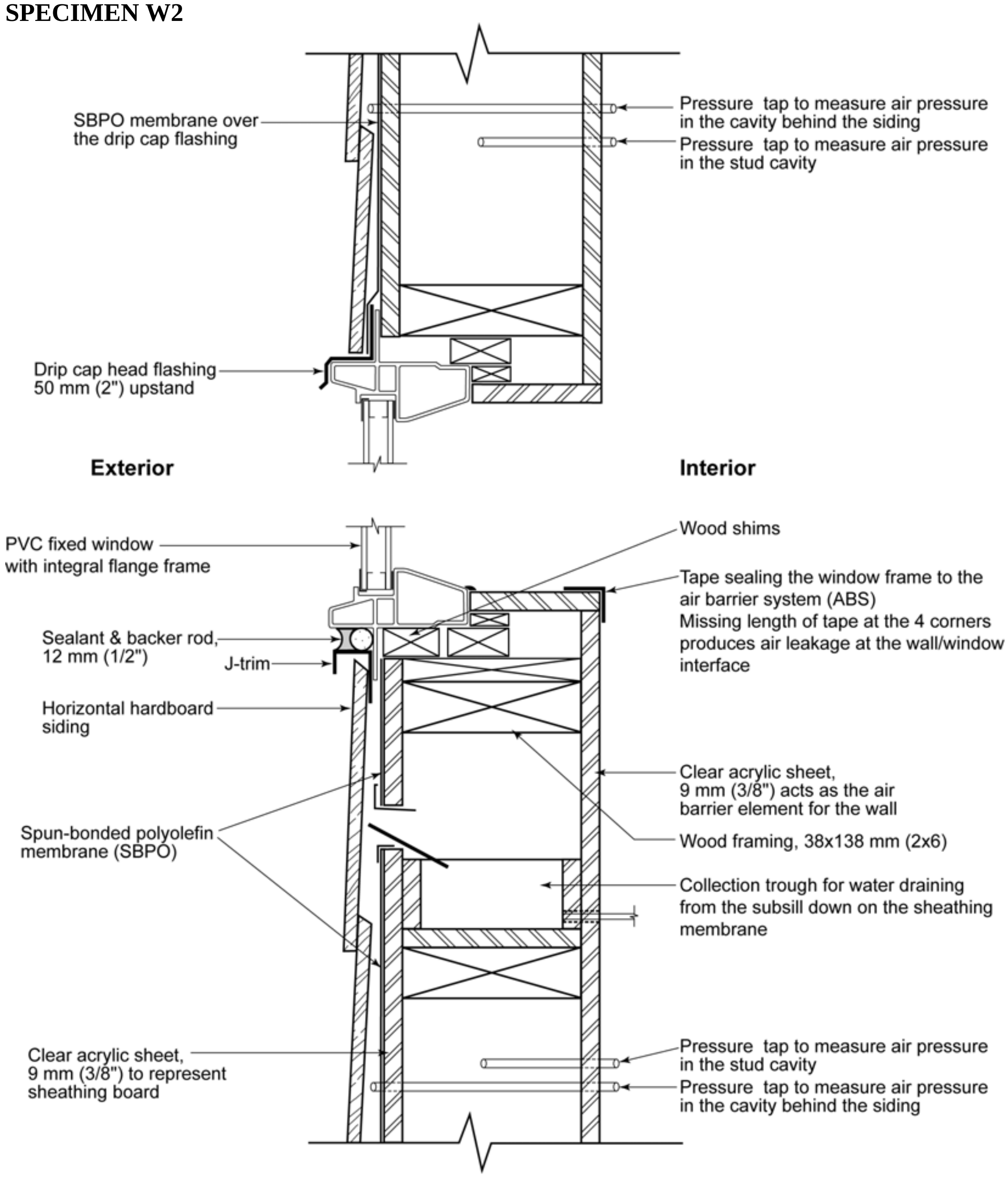


Figure A5-5: Specimen W2 V-side (Vertical section)

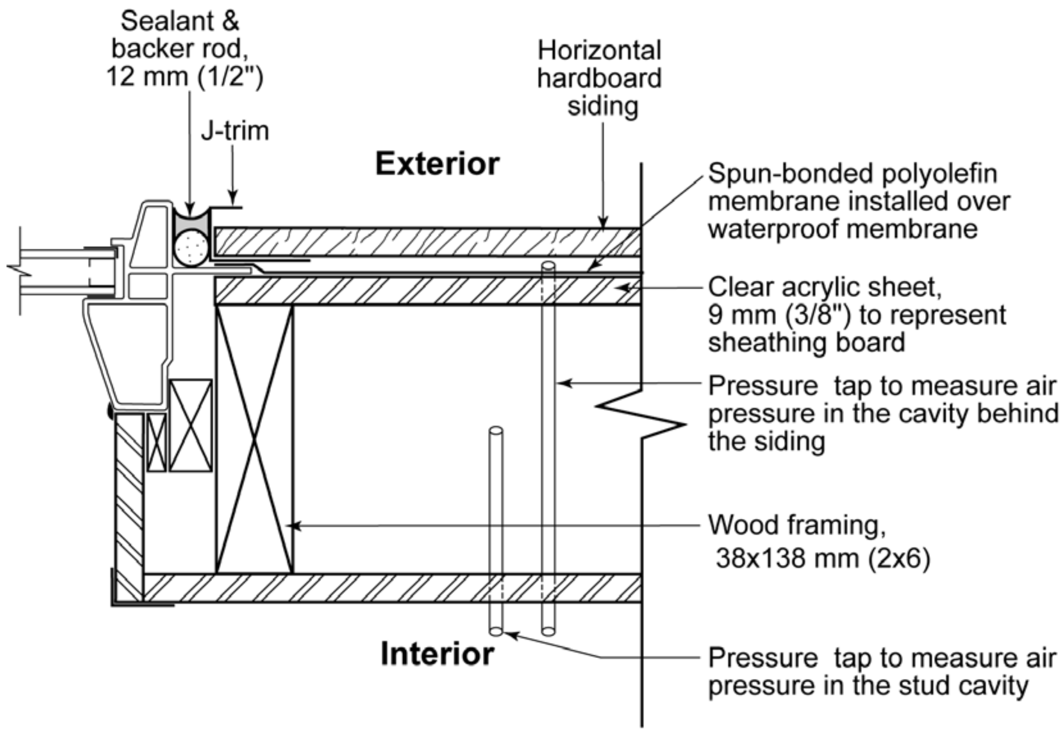


Figure A5-6: Specimen W2 V-side (Horizontal section)

SPECIMEN W2

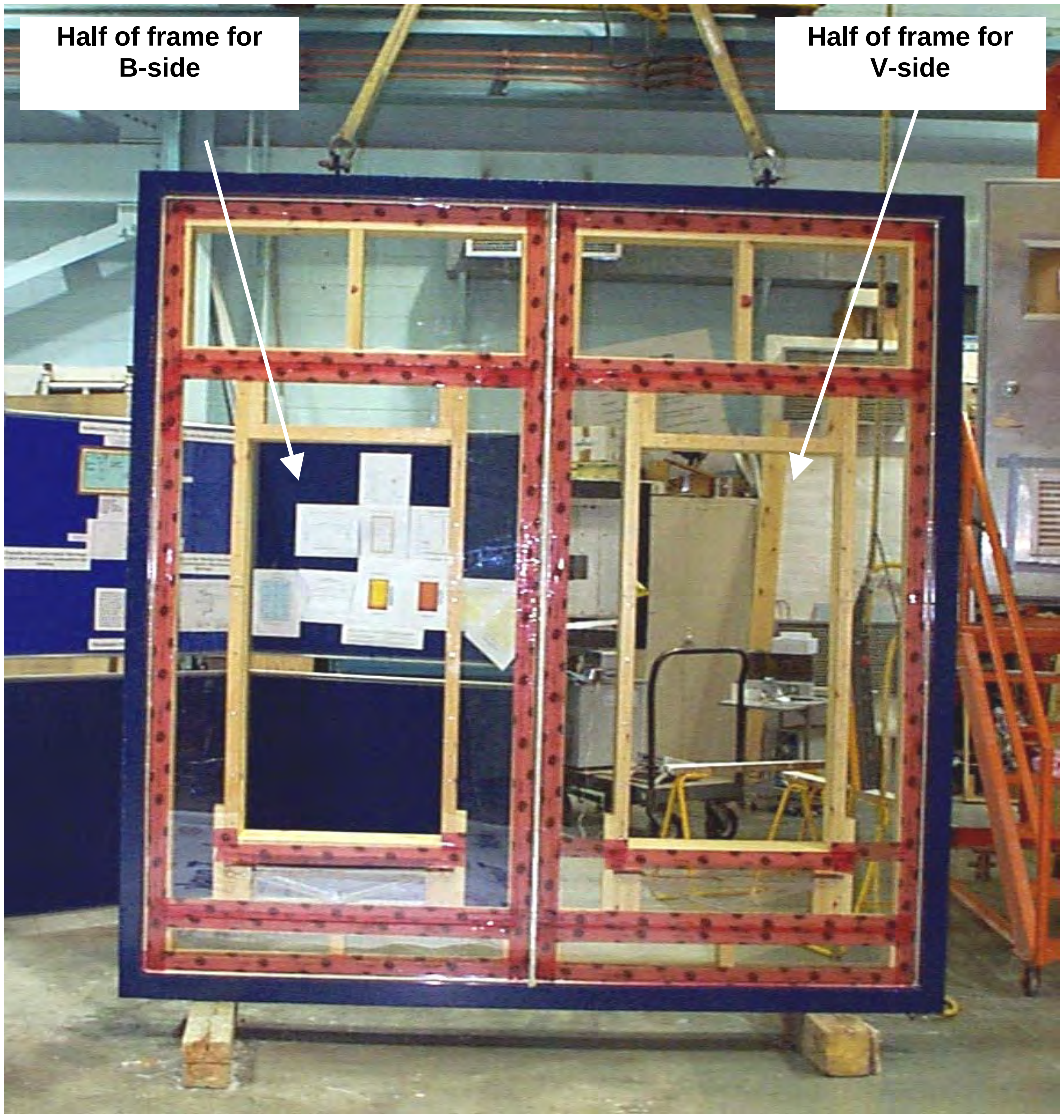


Figure A5-7: Elevation view of wood framing of the test Specimen

Figure A5-8: Specimen W2 B-side – Detail at sill and lower part of jamb

Figure A5-9: Specimen W2 B-side – Placement of wood shims at the sill, over the self-adhesive membrane

SPECIMEN W2

Figure A5-10: Specimen W2 B-side – Fastening of the flanged window to the structure, over the clear acrylic sheet acting as sheathing board

Figure A5-11: Specimen W2 B-side – Installation of the self-adhesive membrane at jambs and head, sealing the flange to the sheathing board

Figure A5-12: Specimen W2 B-side – Placing of the waterproof self-adhesive membrane at the head, over the jamb membrane and over the window flange

Figure A5-13: Specimen W2 B-side – Placement of the rigid head flashing (drip cap), extending 25 mm (1 in.) on each side

SPECIMEN W2

Figure A5-14: Specimen W2 B-side (left of photo) – Water resistive membrane installation completed

Figure A5-15: Specimen W2 B-side – Water resistive membrane completed

Figure A5-16: Specimen W2 B-side (left side) – Hardboard siding installation with J-trim at sill and jamb (not at the head)

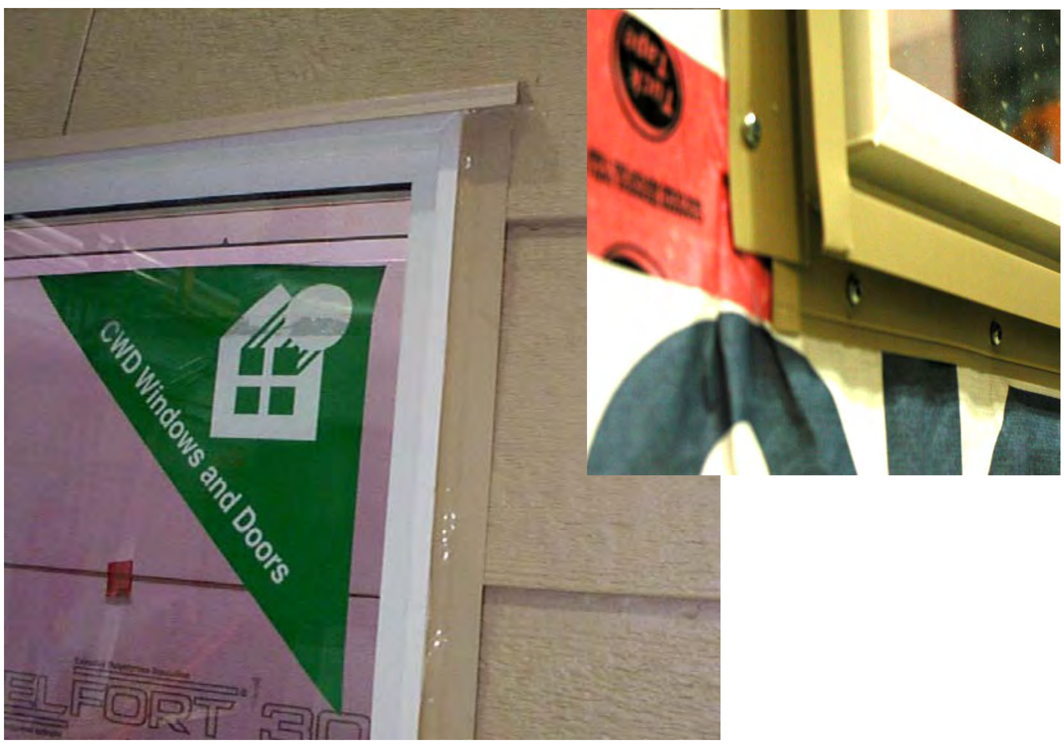


Figure A5-17: Specimen W2 B-side – Sealant installation in the gap (12 mm) at the joint between the J-trim and the window frame (left); J-trim at lower left corner of the window (right)

SPECIMEN W2

Figure A5-18: Installation of the hardboard siding on both halves

Figure A5-19: Rear view of the two halves of the Specimen (B-side on the right)

Figure A5-20: Rear view of the Specimen W2 V-side – no membrane protecting the wood members making up the rough opening

Figure A5-21: Specimen W2 V-side – Window flange is over the WRB at sill, and under the WRB at the jambs and head

SPECIMEN W2

Figure A5-22: Specimen W2 V-side – View of the frame corner, drip flashing and J-trim, prior to installation of backer rod and sealant

Figure A5-23: Specimen W2 V-side – View of the trough used to collect water

6. SPECIMEN W3

Figure A6-1 shows the window profile inserted into the rough opening. The window combined two separate frames: a fixed window at the lower third and a casement on the upper two thirds. The size of the window was (nominally) 610-mm wide by 1220-mm high (2-ft. by 4 ft.).

Figures A6-2 and A6-3 show the wall-window detailing for the “B-side” half of the test Specimen, whereas Figures A6-4 and A6-5 provide the wall-window detailing for the “V-side” half of the test Specimen.

The difference between the two details consists of a different way of draining the wall/window interface subsill. In the B-side, the window was installed on 19 mm furring strips while in the V-side small pieces of folded membranes were placed at regular interval between the sheathing board and the window flange, creating an air space of 2-3 mm.

Figures A6.6 to A6-25 provide photographic records of the construction of the Specimen.

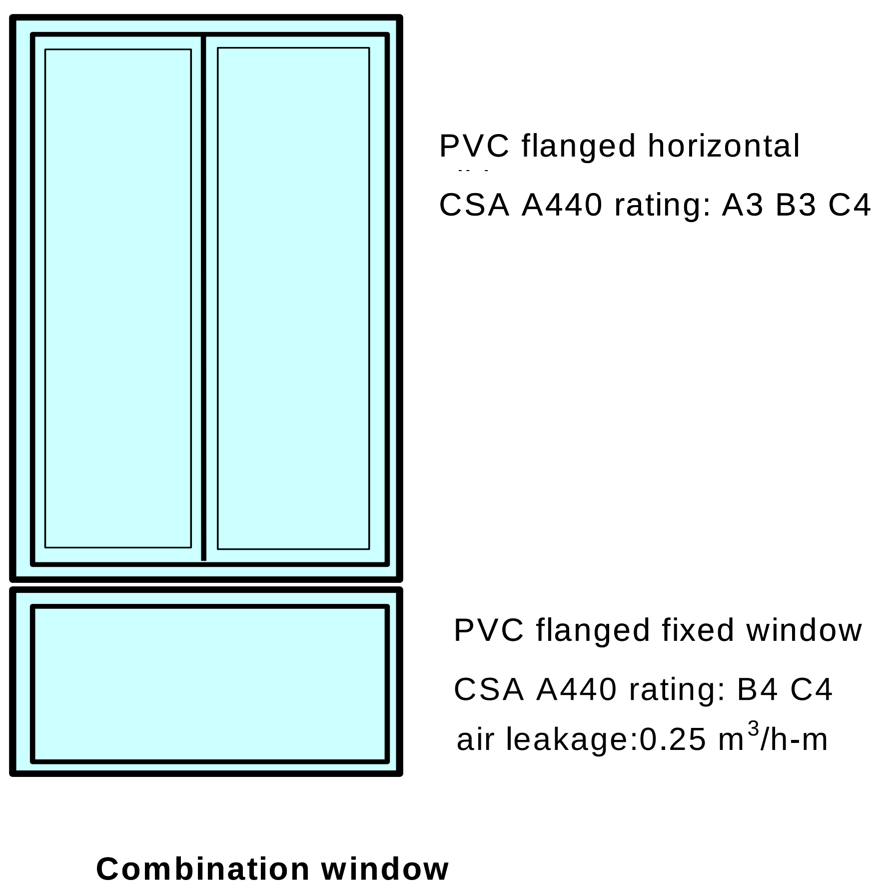


Figure A6-1: Diagram of the combination PVC flanged window (elevation view)

SPECIMEN W3

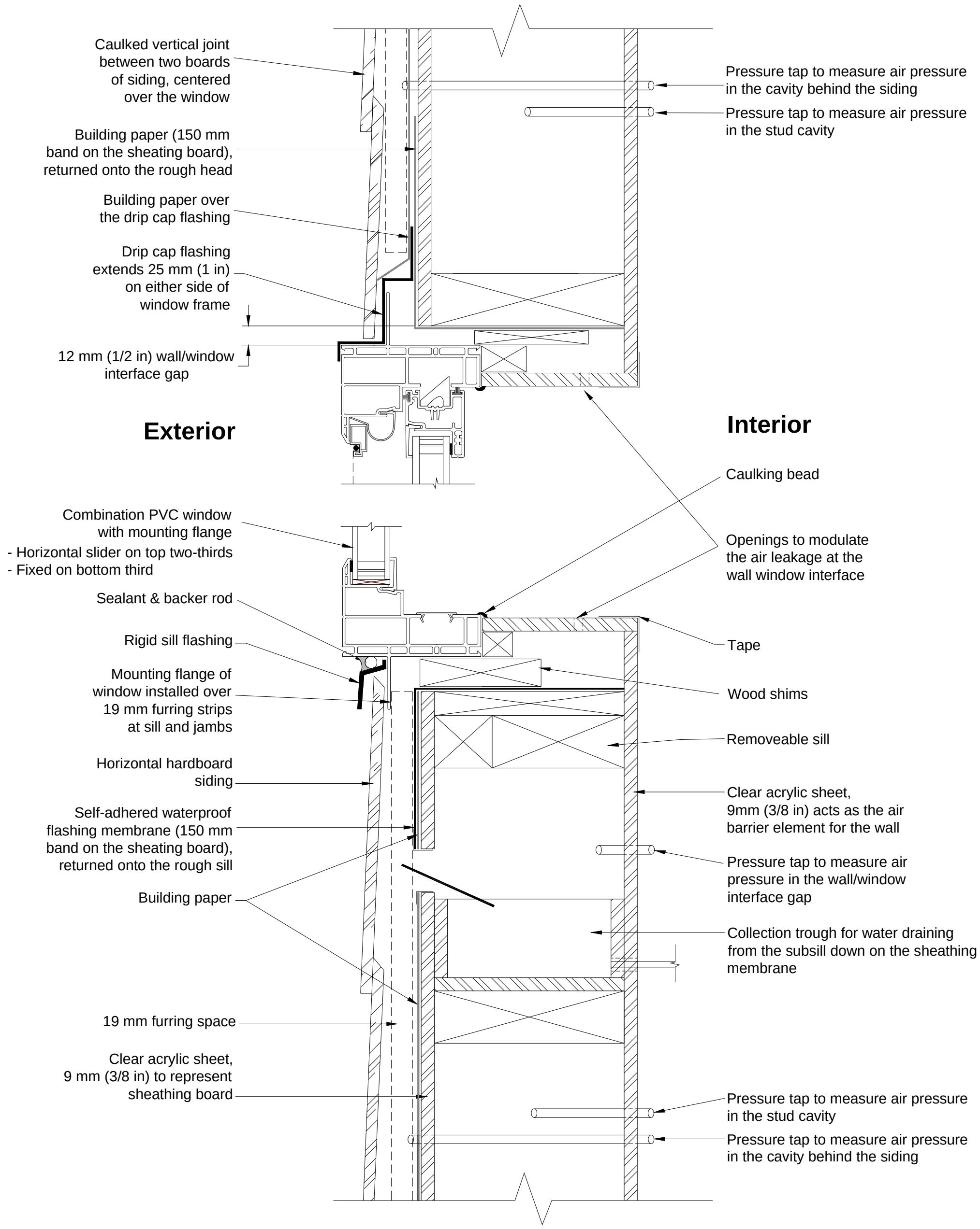


Figure A6-2: Specimen W3 B side (vertical section)

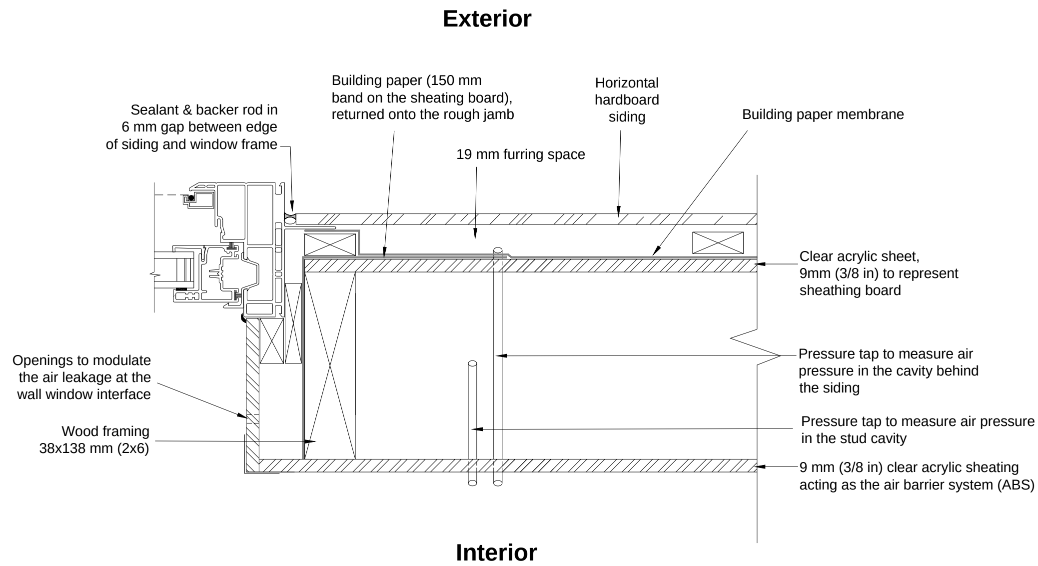


Figure A6-3: Specimen W3 B side (horizontal section)

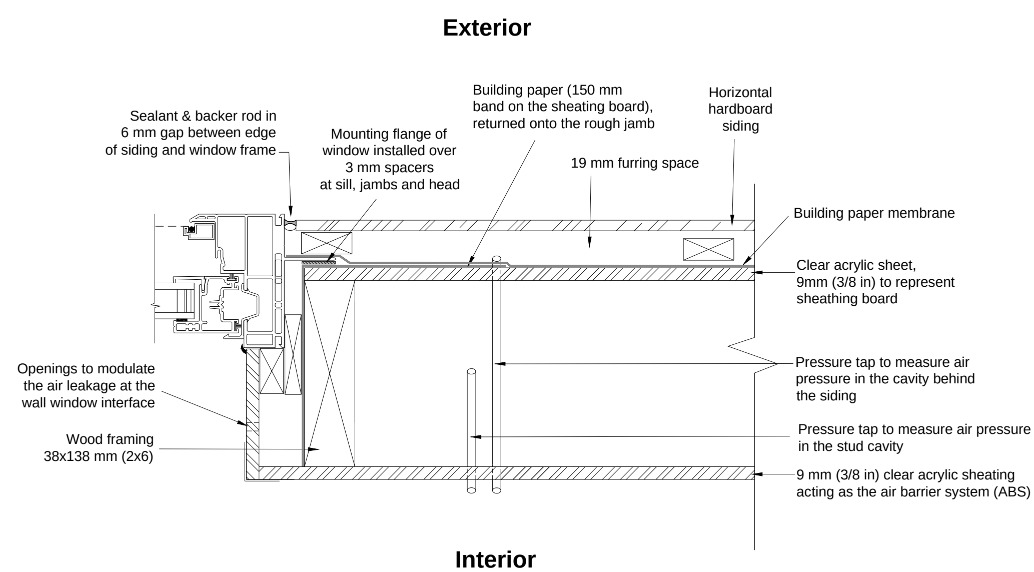


Figure A6-4: Specimen W3 V side (horizontal section)

SPECIMEN W3

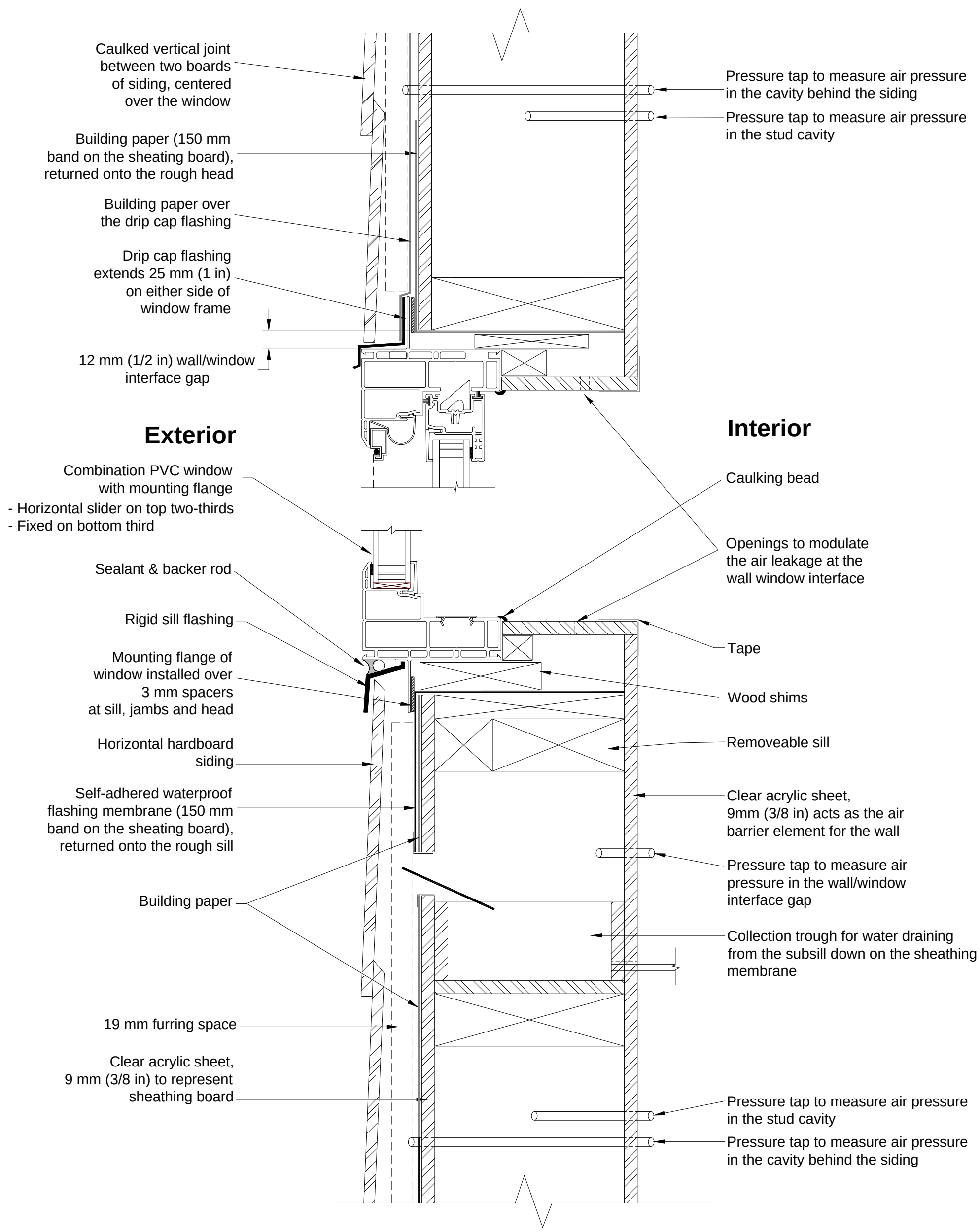


Figure A6-5: Specimen W3 B side (vertical section)

Figure A6-6: Framing for the left hand side of the wall Specimen is completed. Right side is in progress

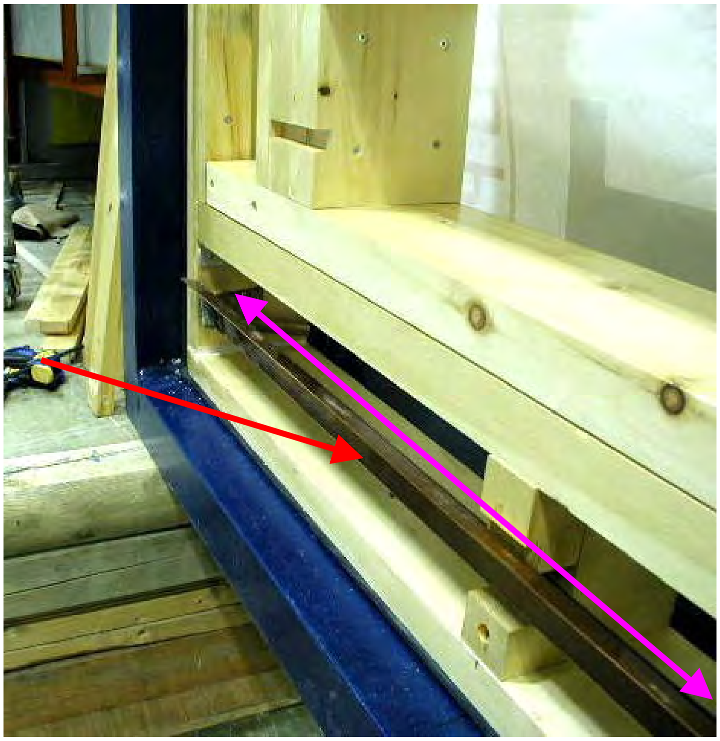


Figure A6-7: Installation of a metal trough to collect accidental water on the exterior face of the water resistive barrier, across the half-Specimen. Same trough system was installed independently on the other half of the Specimen.

SPECIMEN W3

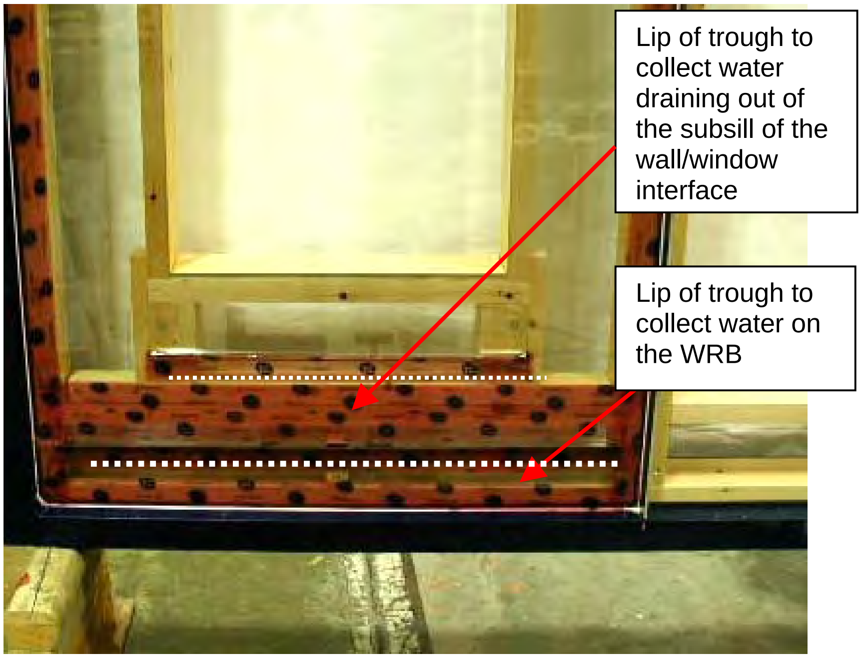


Figure A6-8: Installation of the clear acrylic sheet acting as a sheathing board, and sealing of the troughs to the acrylic sheathing

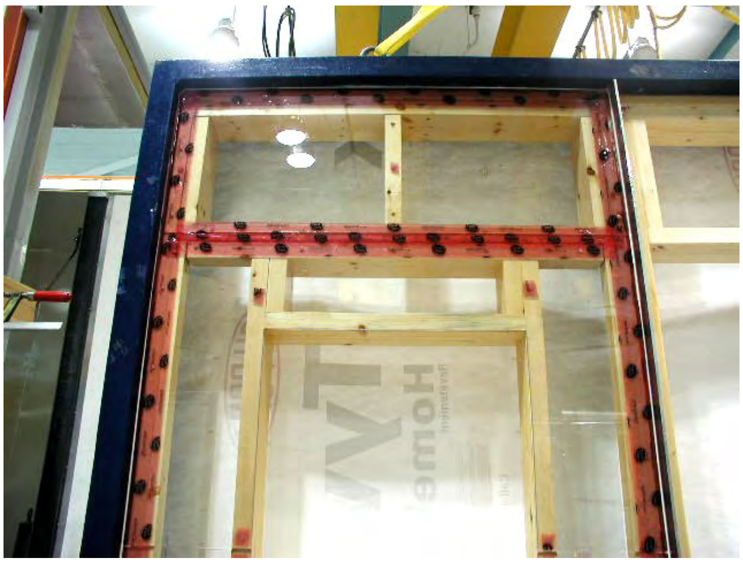


Figure A6-9: Installation and sealing of the clear acrylic sheet in upper part of the Specimen

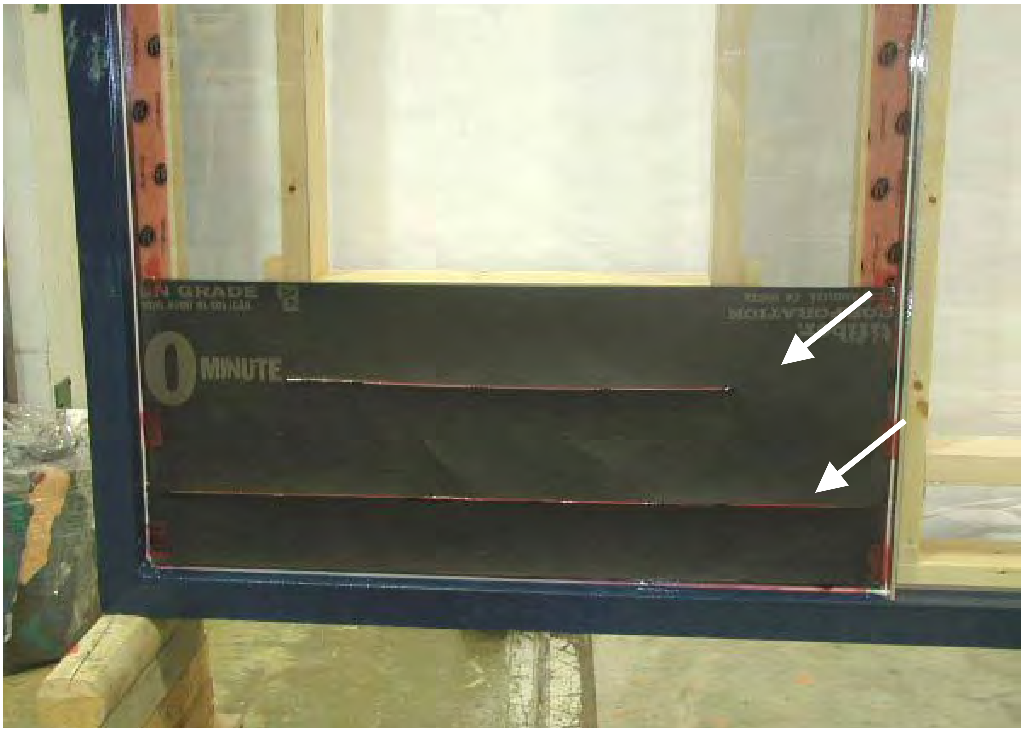


Figure A6-10: B-side – Installation of lower course of water resistive paper (60-minute building paper). Slots were made to allow for capture of water by projecting lip of two trough systems

Figure A6-11: Specimen W3 B-side – Installation of the waterproof membrane onto the subsill, over the sheathing board below and up rough jambs (150-mm). Corner piece of waterproofing membrane also applied.

SPECIMEN W3

Figure A6-12: Specimen W3 B-side – Waterproof membrane installed, lapping down over the first course of building paper by 150-mm

Figure A6-13: Specimen W3 B-side – Strip of waterproof membrane installed at jamb (150-mm high), lapping over the sill membrane

Figure A6-14: Specimen W3 B-side – Installation of strips of building paper at rough jambs

Figure A6-15: Specimen W3 B-side – Installation of strips of 60 minute building paper at rough head

SPECIMEN W3

Figure A6-16: Specimen W3 B-side – Installation of the furring strips prior to window installation (Left side of Specimen only)

Figure A6-17: Stepped drip cap flashing accommodates window recessed from the back up wall (Specimen W3 B side)

Figure A6-18: Installation of the drip cap flashing and WRB building paper over it (Specimen W3 B side only)

SPECIMEN W3

Figure A6-19: Specimen W3 B side: installation of furring strips (19 mm) and shims (12 mm)

Figure A6-20: Window flange with spacers, designed to create a drainage space at the rough sill (Specimen W3 V side only)

Figure A6-21: Siding installation. 10 mm gap left at the jambs and sill for a backer rod and sealant

Figure A6-22: Installation of siding on Left and Right sides of Specimen. Siding back-primed and painted (one coat).

SPECIMEN W3

Figure A6-23: Saw cut (3mm thick by 150 mm long) in the hardboard siding, acting as a deficiency potentially allowing water ingress above the window

Figure A6-24: Completed Specimen; view from exterior side

Figure A6-25: Completed Specimen – View of the interior side

SPECIMEN W4 (MODIFIED)

7. SPECIMEN W4

SPECIMEN W4 was built twice. In light of the results obtained on the first series of test, the Specimen was modified and retested. Figure A7-2 to A7.15 show the steps of construction of the original Specimen. Figure A7-16 shows the construction of the modified W4.

Figure A7-1 shows the combination window inserted into the rough opening. The window combines two separate frames: a fixed window at the lower third and a horizontal slider on the upper two thirds. The nominal size of the window is 610 mm wide by 1220 mm high (2-ft. by 4-ft.). The window combination is identical to what was used on Specimen W3.

Figures A7-2 and A7-3 show the wall-window detailing for the B-side of the test Specimen, whereas Figures A7-4 and A7-5 provide the wall-window detailing for the V-side half of the test Specimen. The difference between the two detailing consists of a different way of connecting the water resistive barrier (WRB) to the window frame. In both cases the WRB was installed after the window. However on the V-side, the WRB was sealed to the window frame using strips of self-adhesive elastomeric membrane while on the V-side the WRB was butt against the window frame without additional sealing measures.

Figures A7-5 to A7-15 provide photographic records of the construction of the Specimen.

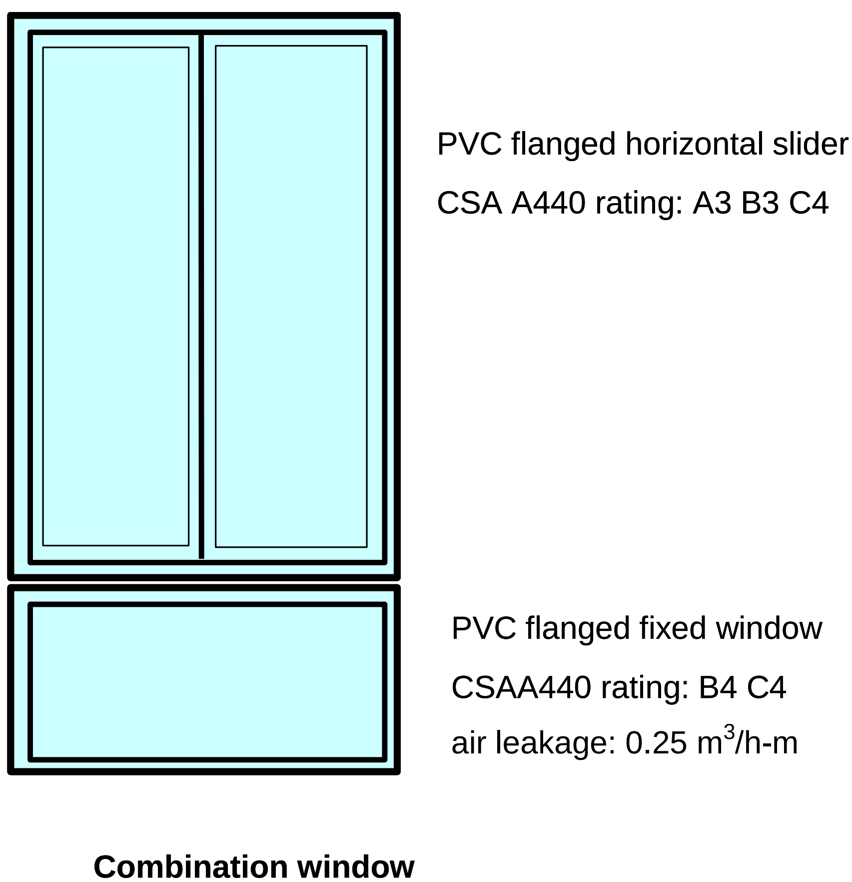
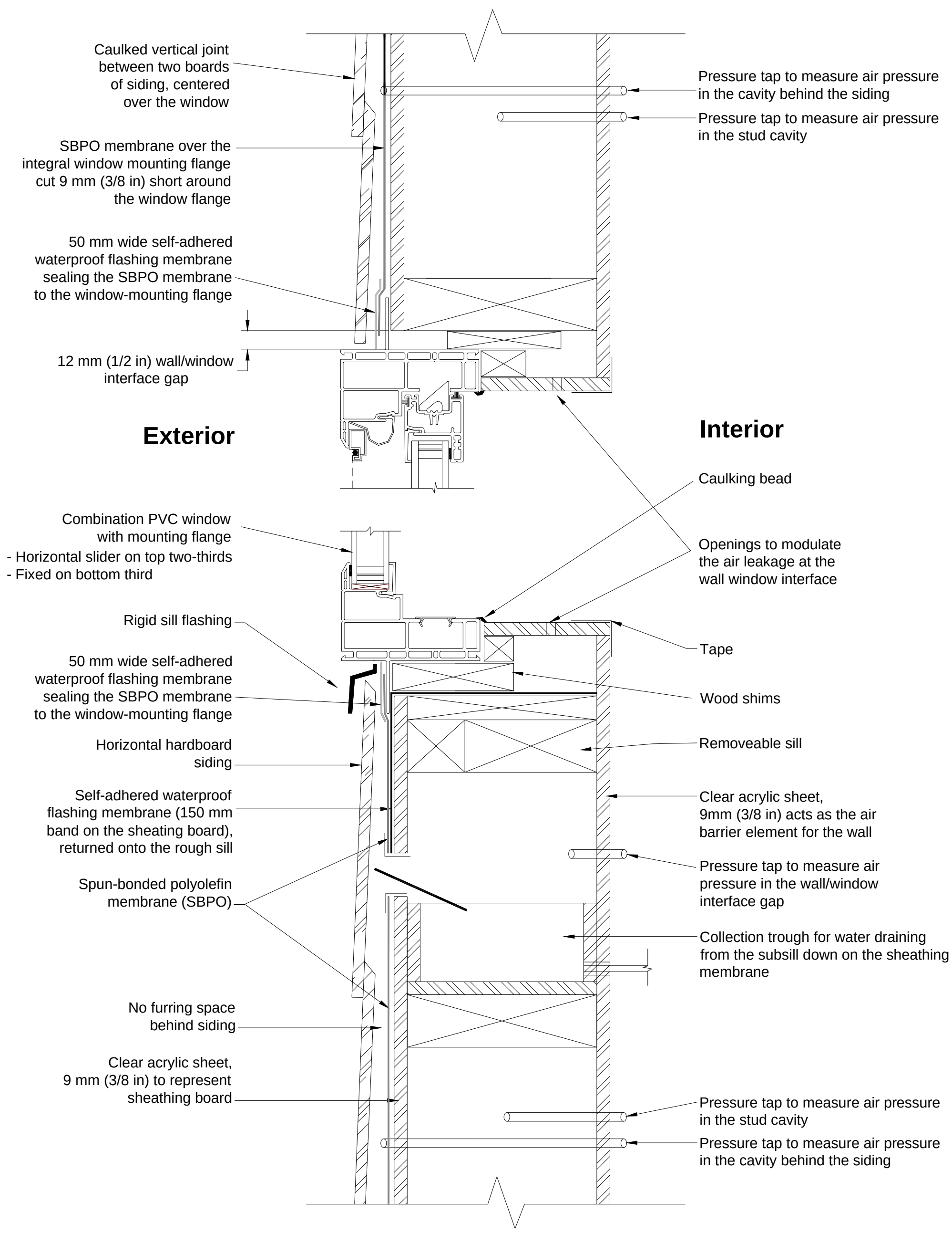


Figure A7-1: Elevation view of the PVC combination window in Specimen W3



Vertical Wall Section
CMHC W4 Specimen - Left Half
Original Test July 2004

Figure A7-2: Specimen W4 B-side (vertical section)

SPECIMEN W4 (MODIFIED)

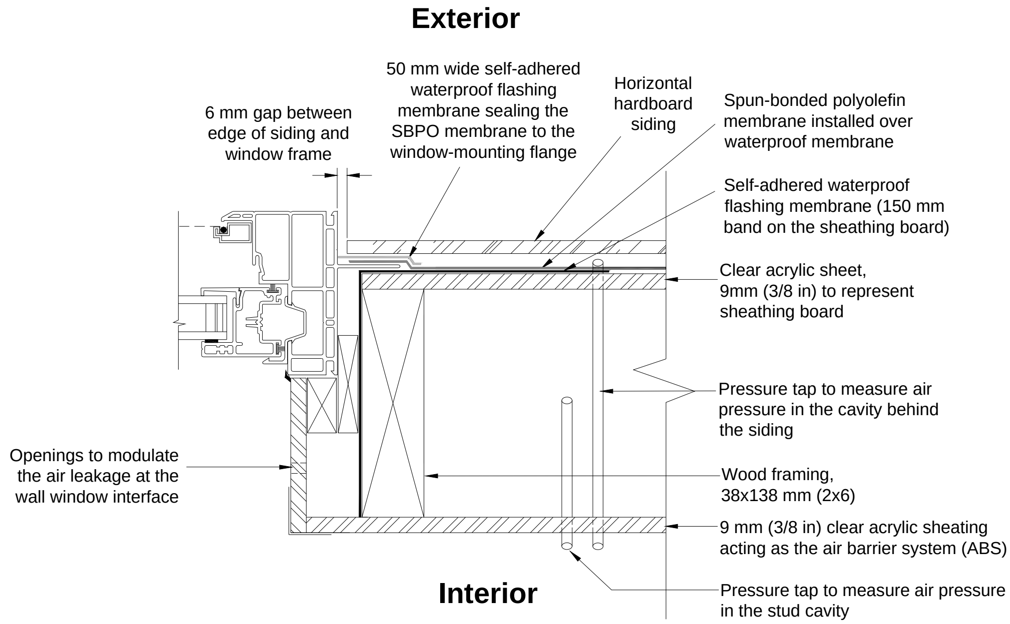


Figure A7-3: Specimen W4 B-side (horizontal section)

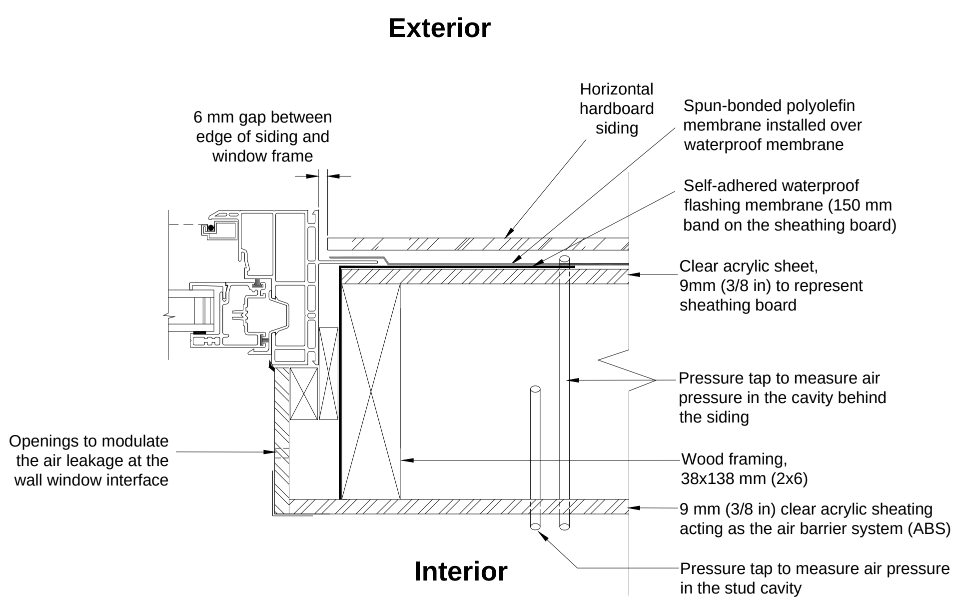


Figure A7-4: Specimen W4 V-side (horizontal section)

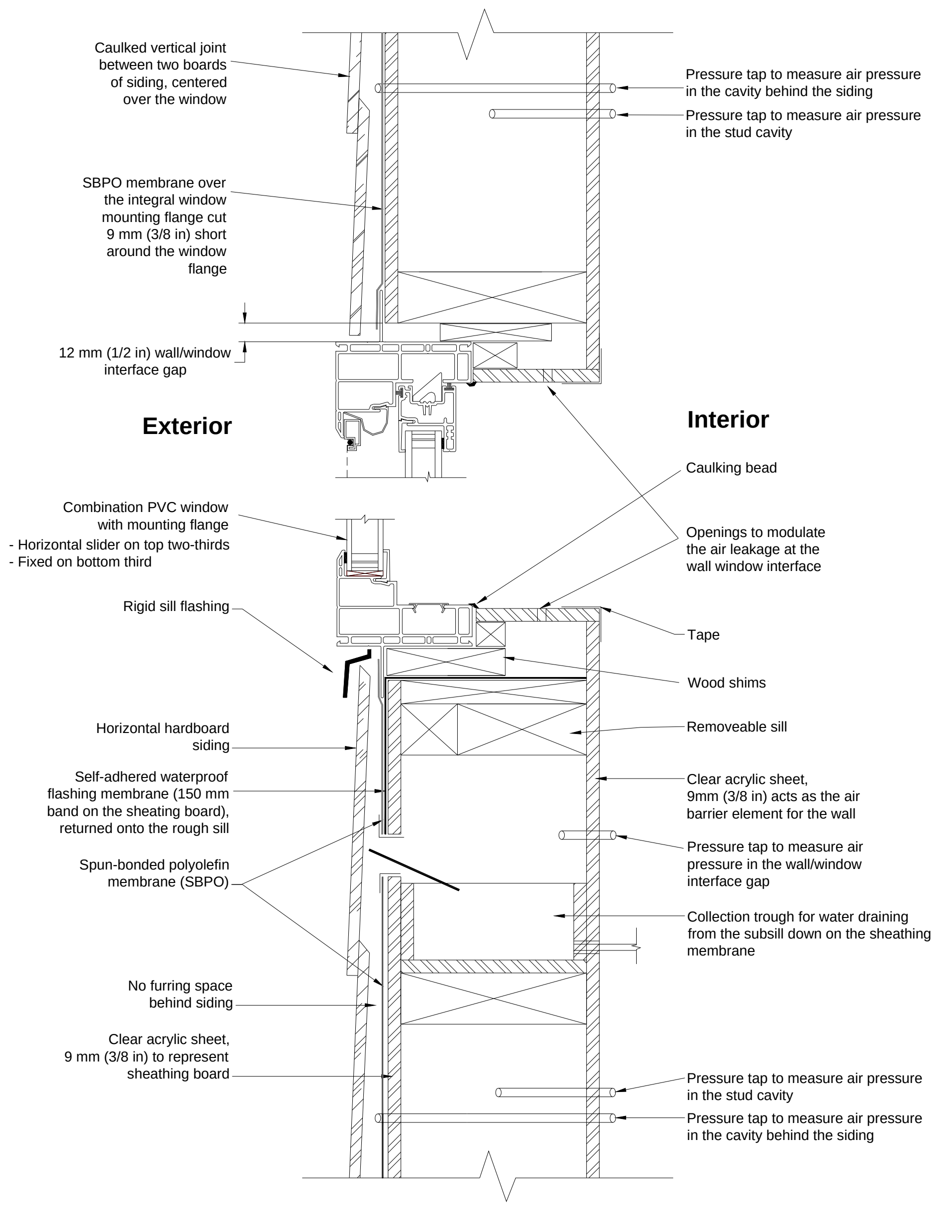


Figure A7-5: Specimen W4 V-side (vertical section)

SPECIMEN W4 (MODIFIED)

Figure A7-6: Framing is no different than what was done for the other three Specimens

Figure A7-7: Water collection trough under the rough sill in place

Figure A7-8: Installation of waterproof membrane at the rough sill

Figure A7-9: Installation of waterproof membrane at the jambs, lapping over the sill membrane

SPECIMEN W4 (MODIFIED)

Figure A7-10: Window installation

Figure A7-11: Installation of WRB membrane on the right side of Specimen

Figure A7-12: Specimen W4 WRB installation

Figure A7-13: Specimen W4 B-side only: Installation of a strip (50-mm) of waterproof membrane sealing the WRB to the window flange

SPECIMEN W4 (MODIFIED)

Figure A7-14: Specimen W4 B-side only – Self-adhered membrane installation at sill, and at jambs

Figure A7-15: Specimen W4 B-side – Self-adhered membrane installed at the perimeter of window frame and WRB junction

Figure A7-16: Specimen W4 At jambs and head siding was installed 5-mm away from frame of window and spaced 10-mm away from metal drip edge

Figure A7-17: Specimen W4 Completed Specimen; view of exterior (V-side on right, B-side on left)

SPECIMEN W4 (MODIFIED)

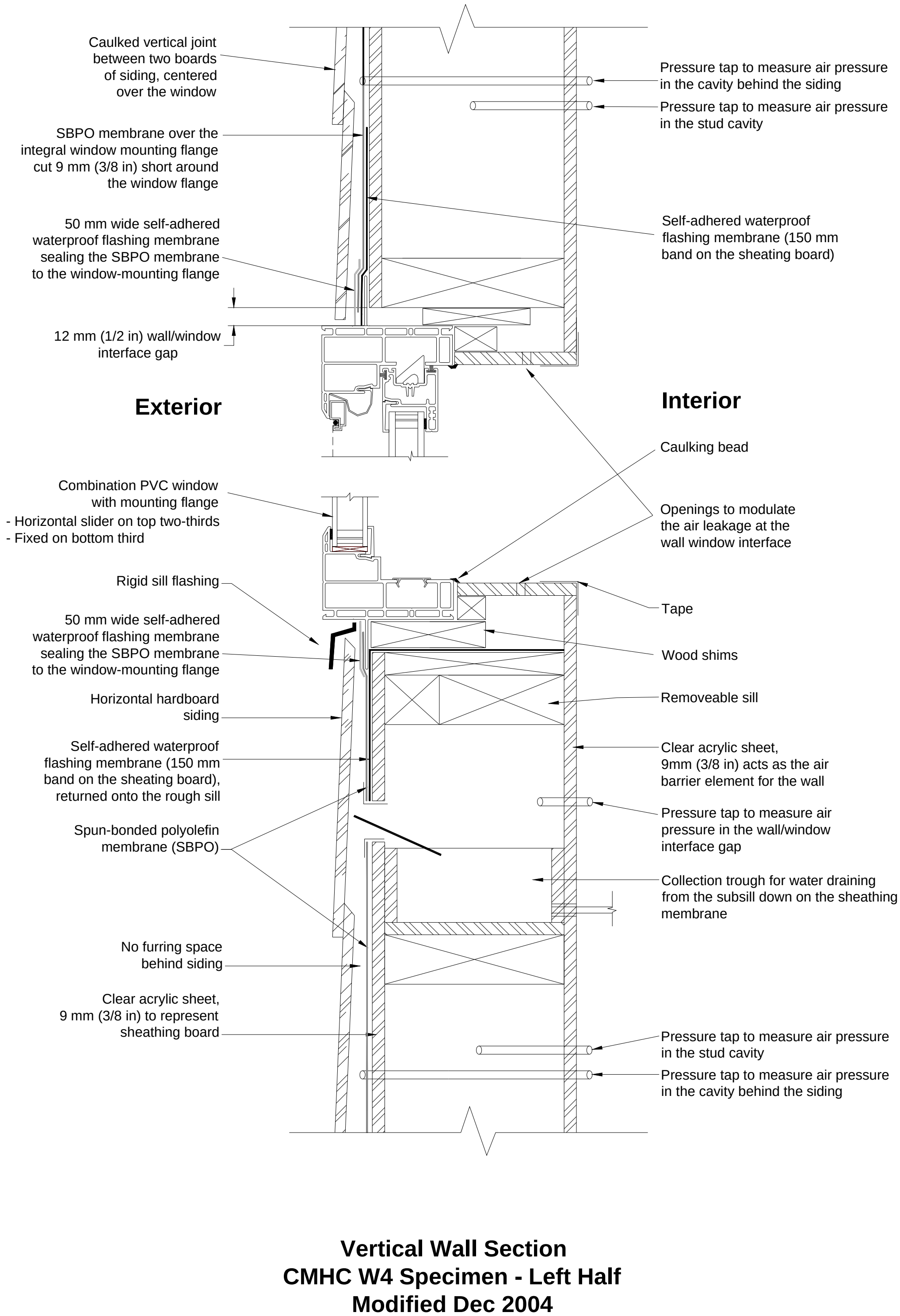


Figure A7-18: Modified Specimen W4 – B-side

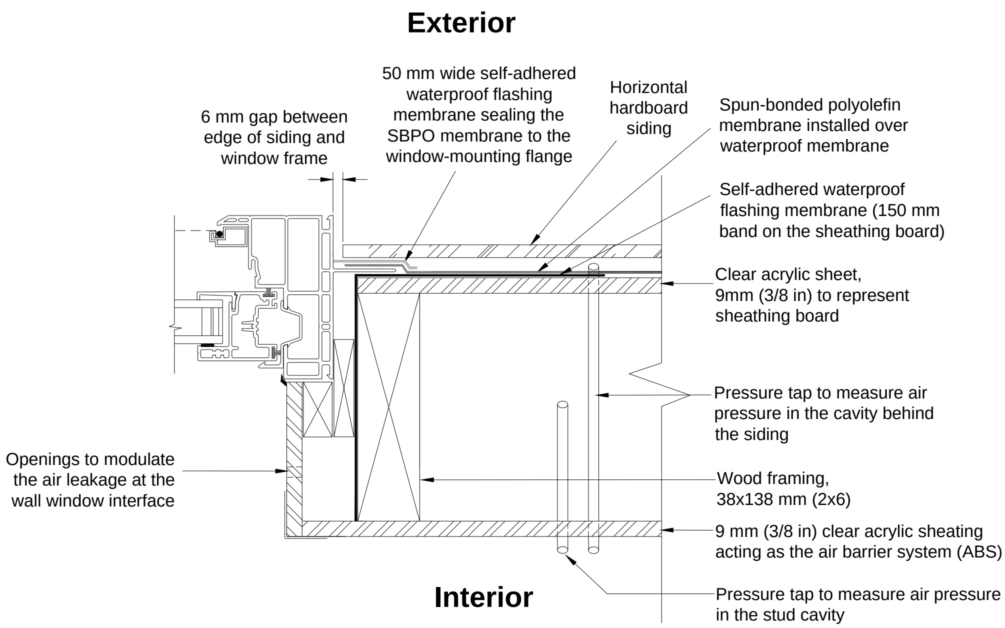


Figure A7-19: Modified Specimen – B-side (identical to original horizontal section)

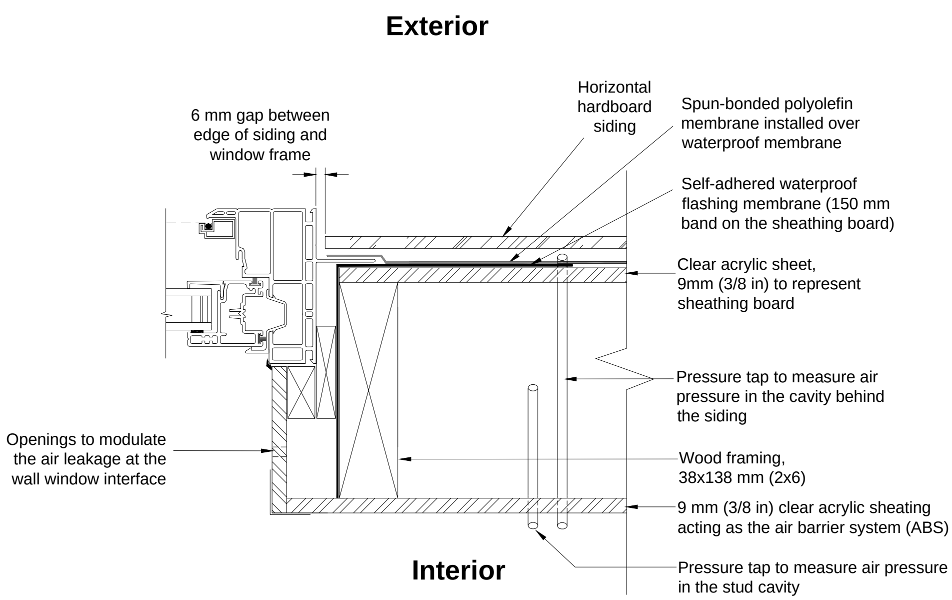


Figure A7-20: Modified Specimen W4 – V-side (identical to original horizontal section)

SPECIMEN W4 (MODIFIED)

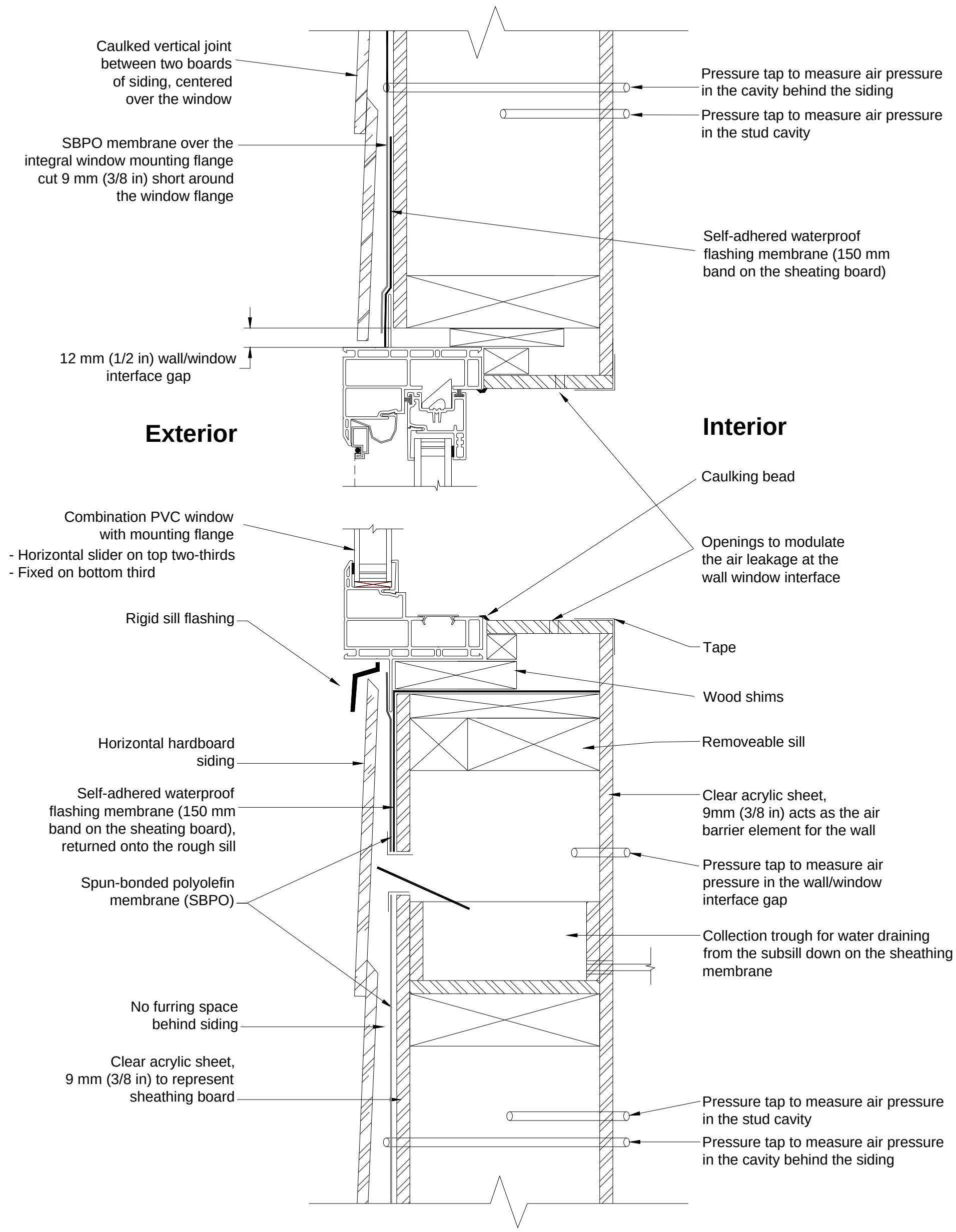


Figure A7-21: Modified Specimen W4 – V-side

Figure A7-22: Modified Specimen W4 – Installation of the self-adhered membrane on both sides of Specimen

Figure A7-23: Modified Specimen W4 – Installation of self-adhered membrane at the window head over the window flange (the original Specimen did not have that membrane at that location)

SPECIMEN W4 (MODIFIED)

Figure A7-24: Modified Specimen W4 V-side – Installation of WRB membrane

Figure A7-25: Modified Specimen W4 V-side – WRB membrane cut 6 mm short of window frame

Figure A7-26: Modified Specimen W4 B-side – Self-adhered flashing membrane at sill

Figure A7-27: Modified Specimen W4 – B-side. Gap left between WRB membrane and window flange, to be covered later by a 50 mm wide strip of flashing membrane

SPECIMEN W4 (MODIFIED)

Figure A7-28: Modified Specimen W4 – B-side self-adhered membrane installed at the perimeter of the joint between the WRB membrane and the window flange

Figure A7-29: Modified Specimen W4. Siding installation (b-side on the left and V-side on the right)

Figure A7-30: Modified Specimen W4 Siding installation completed

Figure A7-31: Modified Specimen W4. Detail at the window head: no drip cap flashing and gap left open