ABTG

Research Report

Installation and Performance of Flanged Fenestration Units Mounted on Walls with Foam Plastic Insulating Sheathing

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Applied Building Technology Group (ABTG) is committed to using sound science and generally accepted engineering practice to develop research supporting the reliable design and installation of foam sheathing. ABTG's work with respect to foam sheathing is supported by the Foam Sheathing Committee (FSC) of the American Chemistry Council. Foam sheathing research reports, code compliance documents, educational programs, and best practices can be found at www.continuousinsulation.org.

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INTRODUCTION

This report assesses construction practices, codes, standards, and performance test data related to the installation of flanged fenestration units on walls with foam plastic insulating sheathing (FPIS) serving as continuous insulation (ci). A key objective is to determine appropriate limitations to the historically accepted practice of installing flanged fenestration units directly over FPIS ci (i.e., mounting flanges bearing on and fastened through foam sheathing). Understanding the historically accepted practice and knowing its limitations based on actual performance also will serve to better delineate where enhanced installation procedures may become advisable or necessary.

Based on the findings reported herein, a standard installation practice is recommended in Appendix A to achieve the above-described objective. The proposed standard practice includes performance-based (e.g., testing) and prescriptive installation requirements. The performance-based approach offers the greatest flexibility to qualify acceptable installation methods. The prescriptive installation requirements represent a refined and limited application of historically accepted installation practice.

The use of FPIS ci on building walls dates back to at least the 1970s and includes the installation of fenestration on such walls. As shown in Figure 1, this application has evolved over time based on necessity as well as other factors such as material innovations, market influences, and building code changes. Figure 1 establishes the context for this report.

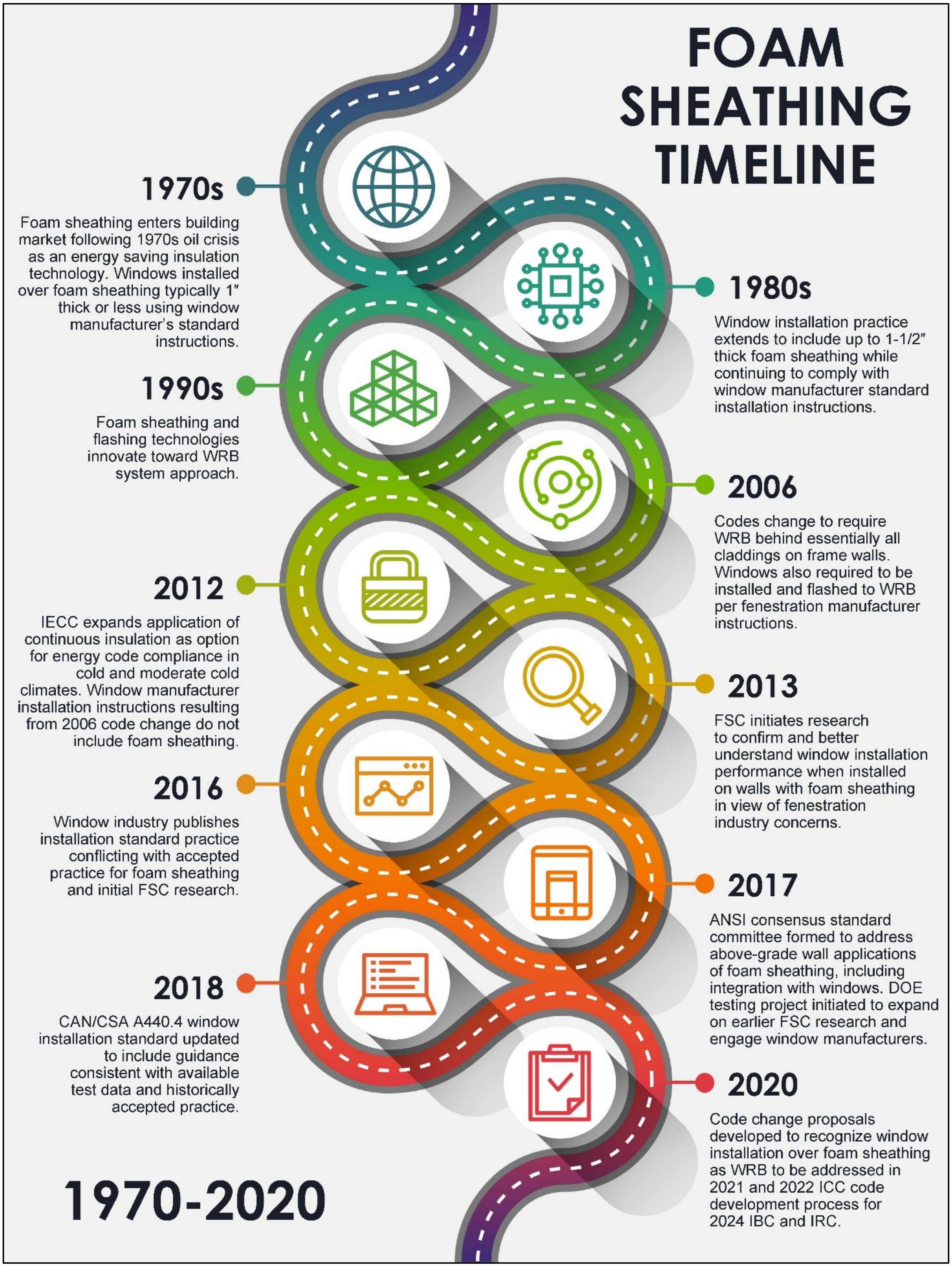

Figure 1. Sequence of events influencing the installation of windows on walls with foam sheathing.

REVIEW OF INSTALLATION PRACTICE

Historically Accepted Practice

In the 1970s, the practice of installing windows on walls with FPIS ci naturally started with the use of the window manufacturer's product-specific installation instructions and included some obvious adjustments, such as use of longer flange fasteners to accommodate the FPIS thickness. For special conditions, such as large window units, thresholds for doors, and FPIS thickness greater than 1½", the installation instructions were further modified or enhanced by use of blocking or other devices (such as a window buck) for support and anchorage. Because such practices developed from "lived experience" in the building industry, the primary sources for their documentation are those who applied them in the field.

In one example, the development of the historically accepted installation practice is described as follows:[1]

> "Back then, we weren't using OSB or plywood sheathing — just XPS foam sheathing, usually Dow blue board, with diagonal metal strapping for bracing," Lstiburek told me recently. "At first, we would run a horizontal 1"- thick board under the bottom flange of the window, to help support the weight of the window. Under the other three flanges, there was nothing but foam. We attached the windows to the studs with screws through the foam. We built thousands of houses this way, using foam up to 1½-inch thick. We never experienced any problems."
>
> …
>
> Eventually, Lstiburek realized he didn't need to install any wood under the lower flange. "In the late 1980s, I took that practice with me to the U.S.," said Lstiburek. "Then we stopped installing the horizontal board underneath — except for wide windows. If the window was wider than 4', we'd still install a board under the bottom flange. But most of the windows we installed were basically hung from the flange fasteners."
>
> I asked Lstiburek how he attaches flanged windows on walls with very thick foam. "I don't have enough of a track record with 2" foam, so when we go above 1½"-thick foam, I recommend using side straps," Lstiburek told me. (Side straps are also called masonry clips.)

In another example, a professional builder describes his successful experience with installation of windows on walls with FPIS as follows:[2]

> "As I have discussed with many of you, we have been installing vinyl double pane windows over 1½" XPS foam with no OSB for over six years and before that over 1" foam for almost 30 years and have seen no issues with window movement."

Documentation of actual construction projects also serves as a basis for defining accepted practice. For example, Figure 2 shows a typical example of flanged window installation over FPIS where, in this 2014 construction project, the FPIS served as continuous insulation and the water-resistive barrier (WRB) system. The window and door installations followed the manufacturer's installation instructions with the following modifications:

- window flanges were installed over and flashed directly to the FPIS WRB surface,
- longer flange fasteners were used to maintain required embedment in wood framing, and
- wood blocking was used to provide full support of door thresholds (inswing exterior doors were used such that door frame or hinge anchor screws could be securely driven into the rough opening framing without added jamb blocking).

[1] Martin Holladay, "Nailing Window Flanges through Foam", GreenBuilding Advisor, May 20, 2011, www.greenbuildingadvisor.com/article/nailing-window-flanges-through-foam
[2] Communication with Arn McIntyre (McIntyre Builders Inc.) by e-mail dated 4/5/2019

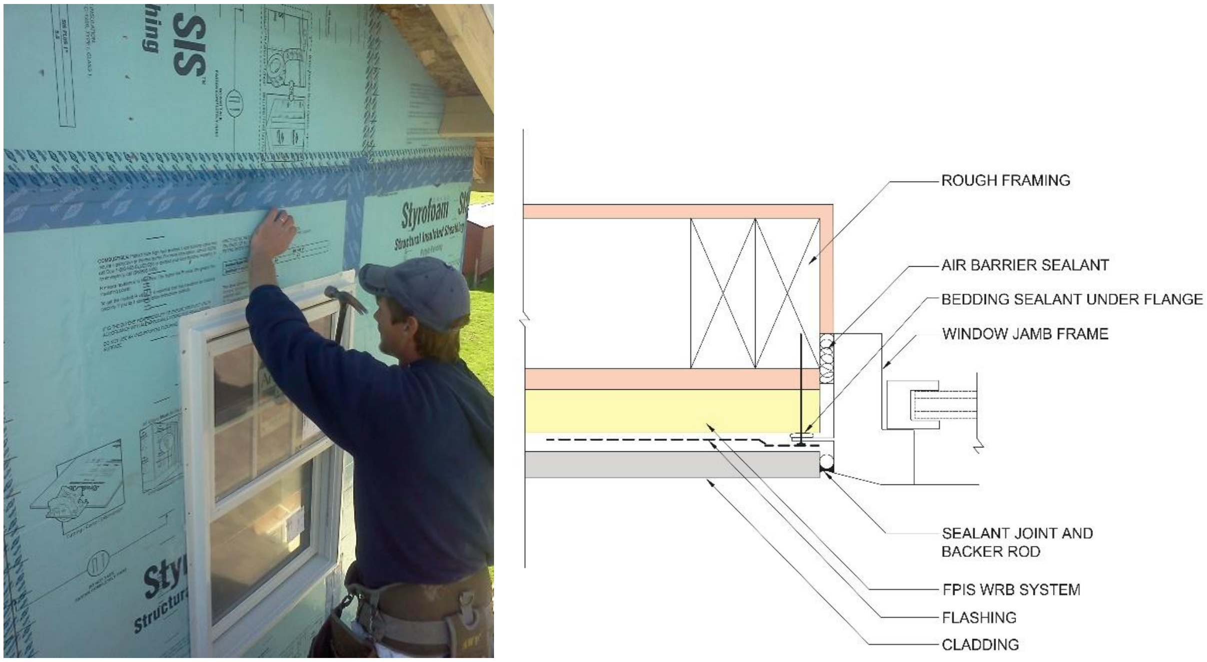

Figure 2. Typical installation of a flanged window directly over FPIS on a wood frame home.

In parallel with development of the accepted installation practice for structural support and anchorage, joint tape and adhered flashing materials saw major advancements and market acceptance through the 1990s.[3] These flashing and joint-sealing technologies were applied to various applications, including FPIS products.

As shown in Figure 3, adhered flashing and joint sealing tapes allow FPIS WRB systems to be flashed seamlessly and simply directly to window flanges for continuity of the water resistance plain (i.e., drainage plain) of the entire wall assembly. Consequently, this flashing practice grew to become part of the historically accepted practice for installation of fenestration on walls with FPIS ci by the early 2000s. These products have continued to evolve and innovate for increasing functionality and durability. Eventually, these flashing practices became necessary for building code compliance when WRB installations and window flashing to the WRB became a requirement in Section R703 of the 2006 edition of the International Residential Code (IRC).[4]

Before the 2006 IRC code change, so-called “self-flashing” flanged fenestration units were commonly mounted directly to wall sheathing materials (e.g., fiberboard, plywood, OSB, and FPIS) without the presence of any type of WRB. Instead, bedding sealant applied under the fenestration flange was the sole defense against water intrusion at the fenestration perimeter. This practice of building walls without a continuous WRB, flashing, and a means of drainage was found to be unreliable based on experience gained in the 1990s.[5]

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[3] Lstiburek, J. (2013). “Stuck on You,” Building Science Insight-067 (originally published in ASHRAE Journal), Building Science Corporation, www.buildingscience.com/documents/insights/bsi-067-stuck-on-you

[4] International Residential Code, 2006 Edition, International Code Council, Inc., www.iccsafe.org/

[5] Crandell, J.H. and Smart, J. (2004), Lessons from EIFS: Past, Present, and Future Challenges for Exterior Envelope Design and Construction, Proceedings of Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, NV, October 4-6, 2004, Forest Products Society, Madison, WI

Figure 3. Adhered flashing and joint tapes used for FPIS WRB systems and window flashing for houses completed in 2014 and 2019.

Finally, an installation detail for a net zero energy house with 4"-thick FPIS ci is shown in Figure 4. This house, designed by Building Science Corporation, was completed in 2013. A ½"-thick plywood window buck was used to support fenestration placed in alignment with the exterior FPIS ci. Anchor straps commonly used for block frame windows were used to anchor the fenestration unit. This detail is an example of the historically accepted practice of providing additional support where the FPIS thickness exceeds 1½".

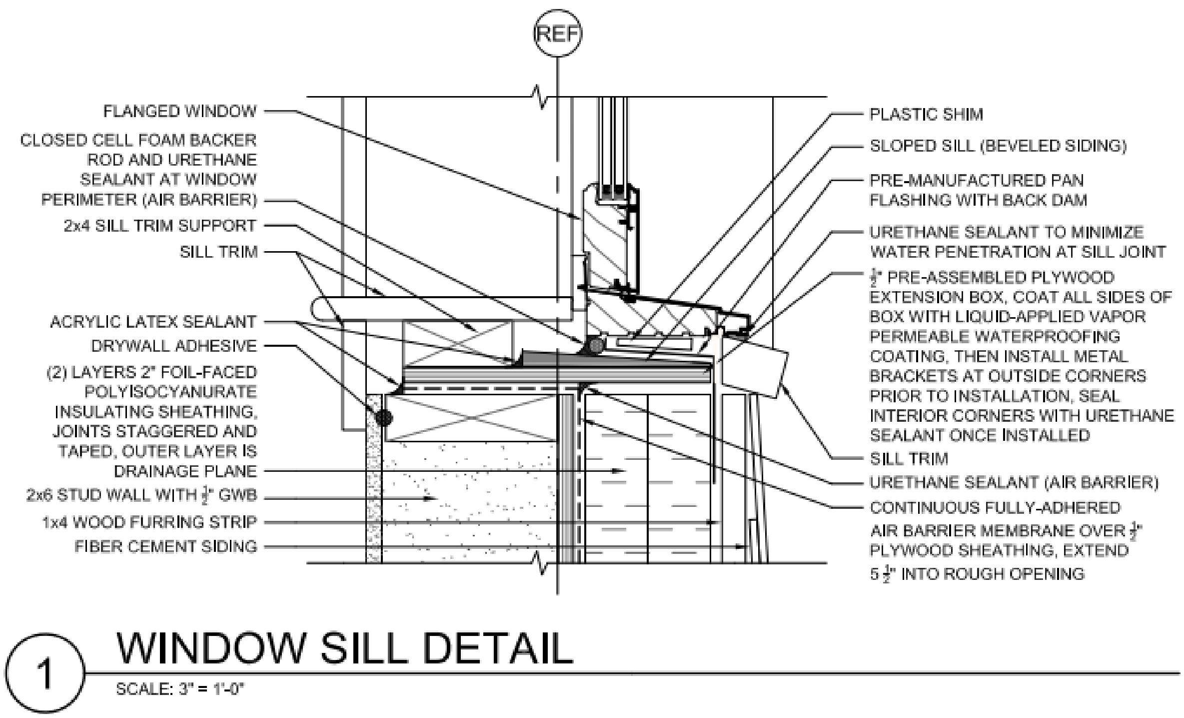


Figure 4. Plywood window buck detail for fenestration installation in alignment with 4"-thick FPIS. (Source: www.nist.gov/system/files/nzertf-architectural-plans3-june2011.pdf)

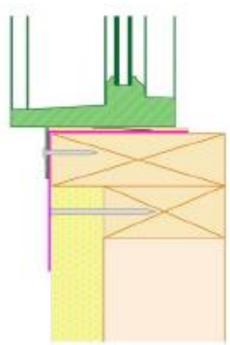
In summary, the documentation of historically accepted practice across independent sources is reasonably consistent. It represents a timeframe spanning more than four decades and, presumably, many thousands of successful fenestration installations on walls with FPIS ci. However, the development and use of this historically accepted practice concentrates mainly in northern U.S. and Canada where FPIS usage has been common for energy conservation reasons. Thus, much of the U.S. building industry may remain completely unfamiliar with this historically accepted practice. This observation speaks to the need for the standard practice proposed in Appendix A.

Fenestration Installation Instructions, Standards, and Guides

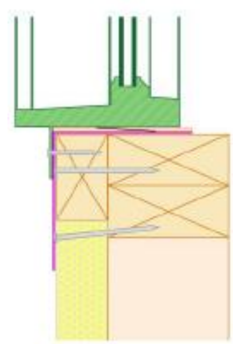
Historically, fenestration manufacturer installation instructions and associated code requirements have focused on structural support and anchorage. However, in the 2006 IRC, fenestration manufacturers' responsibility was expanded to include the provision of flashing instructions as, at least in part, a reaction to the mentioned water intrusion problems of the 1990s. However, it was impractical to expect that all code-compliant wall assembly substrate conditions and installation nuances could be addressed by each individual window manufacturer in their installation instructions for each product line. Consequently, manufacturer installation instructions tended to focus only on one common or popular wall assembly condition (usually excluding details for other code-compliant wall materials and assemblies, such as walls with exterior FPIS ci).[6] This unintended consequence of the 2006 IRC code change has persisted to the present 2021 edition of the IRC.[7]

Similarly, standard installation guides for fenestration tend to exclude FPIS from the scope of application (e.g., ASTM E2112[8], AAMA 2400[9], and FMA/AAMA 100[10]). These installation guides were initially developed in the 2001 to 2007 timeframe.[11] They tend to lack important structural support and anchorage details relevant to the unique characteristics of a specific window type and product line or brand. Such unique characteristics are necessarily addressed by the window manufacturer to achieve or bolster the product's rated and labeled performance. Consequently, industry guidance documents are ultimately dependent on and often defer to the fenestration manufacturer's product-specific installation instructions for anchorage and support, even though a generic anchorage and support specification may be provided.

In 2016, FMA/AAMA/WDMA 500[12] was published to address fenestration installations on walls with FPIS. However, given a lack of clarity on the range of acceptable parameters for installation of windows directly on walls with FPIS (e.g., window size and weight, window type, anticipated structural response, and fastening requirements), the use of a rough opening extension support element (ROESE), such as a window buck, for all fenestration installations in walls with FPIS is specified by default. A couple examples of a ROESE are shown in Figure 5. While the historically accepted practice included these variants of a ROESE for walls with thick FPIS (i.e., greater than 1½"), such installation enhancements were not typically used for all FPIS installations irrespective of its thickness or other installation factors.



Rough opening "window buck"



Rough opening "picture frame" blocking

Figure 5. Illustration of two common ROESE applications.

[6] There are some recent exceptions to this trend. For example, Pella Corporation's 2019 installation instructions specifically allow use of their "standard" installation practice (consistent with historically accepted practice described earlier) for the installation of windows in walls with up to 1"-thick FPIS. Refer to: New Construction Installation with Nail Fin Over 1½"-2" Thick Continuous Exterior Insulation Using Rough Opening Support Brackets (Patent Pending), https://www.pella.com/professionals/installation-instructions/windows/new-construction/

[7] International Residential Code, 2021 edition, International Code Council, Inc., www.iccsafe.org

[8] ASTM 2112 – 18, Standard Practice for Installation of Exterior Windows, Doors and Skylights, www.astm.org

[9] AAMA 2400-10, Standard Practice for Installation of Windows with a Mounting Flange in Open Stud Frame Construction for Low Wind/Water Exposure, www.aamanet.org

[10] FMA/AAMA 100-12: Standard Practice for the Installation of Windows with Flanges or Mounting Fins in Wood Frame Construction for Extreme Wind/Water Conditions, www.aamanet.org

[11] Katsaros, J.D. (2013). Development of Industry Guidelines for Standard Practice of Fenestration Product Installation, Buildings XII International Conference, ASHRAE, web.ornl.gov/sci/buildings/conf-archive/2013%20B12%20papers/066-Katsaros.pdf

[12] FMA/AAMA/WDMA 500 – 16, Standard Practice for the Installation of Mounting Flange Windows into Walls Utilizing Foam Plastic Insulating Sheathing with a Separate Water-Resistive Barrier (WRB), www.aamanet.org

Requiring the use of a ROESE in all applications with FPIS posed a number of problems that did not previously exist in the market. First, the ROESE creates a thermal bridge around the perimeter of every window or door opening, partially eroding the primary function of FPIS as continuous insulation. FMA/AAMA/WDMA 500 also addresses only the case where a separate membrane-type WRB is used. Thus, it failed to recognize the functional capability of the FPIS ci to serve as a code-compliant WRB system with relatively simple window-to-wall flashing details. While FMA/AAMA/WDMA 500 provides useful guidance for enhanced window installation practices for walls with FPIS (and flashing details only for cases where the FPIS is not used as the WRB system), it may deter appropriate use of historically accepted installation practices.[13,14] For this reason, independent studies were launched to evaluate the historically accepted practice and provide improved guidance where required. Data from those studies are addressed later.

Building Code Installation Requirements

Section 9.7.6.1 of the 2020 National Building Code (NBC) of Canada references CAN/CSA-A440.4, "Window, Door, and Skylight Installation."[15] This standard is a Canadian-only extension of the North American Fenestration Standard (NAFS).[16] NAFS also is referenced in U.S. model codes (without the CAN/CSA-A440.4 installation standard). NAFS establishes performance rating requirements for fenestration units themselves, not their installation as addressed in CAN/CSA-A440.4.

The preface to CAN/CSA-A440.4 makes the following statement regarding installation of fenestration on walls with "insulating sheathing" (i.e., FPIS):

> e) Insulating sheathing: Since the second edition of this Standard, the effect of heat loss (thermal bridging) through wood frame components (such as studs, top plates, sill plates, rim joists, etc.), has become more important in order to meet energy performance targets. This edition includes adjustments to shimming and anchoring techniques to accommodate the installation of insulating sheathing which often requires a window or door to be set partly or wholly outside the wood stud frame.

Relevant structural and flashing installation provisions of CAN/CSA-A440.4 are excerpted in Appendix B. In general, they are consistent with the historically accepted practice described earlier, but lack definitive limits of use with regard to structural anchorage and support. Instead, guidance is provided to support informed judgment.

In the U.S., fenestration installation requirements are found in Section R609 of the 2021 IRC. Unlike Canada, fenestration installation requirements are not standardized and instructions are required to be provided by the fenestration manufacturer as the basis for a code-compliant installation. The relevant provisions are as follows:

> **R609.1 General.** This section prescribes performance and construction requirements for exterior windows and doors installed in walls. Windows and doors shall be installed in accordance with the fenestration manufacturer's written instructions. Window and door openings shall be flashed in accordance with Section R703.4. Written installation instructions shall be provided by the fenestration manufacturer for each window or door.

The 2021 IRC (as with previous editions) does allow alternative methods of anchorage:

> **R609.7.1 Anchoring requirements.** Window and glass door assemblies shall be anchored in accordance with the published manufacturer's recommendations to achieve the design pressure specified. Substitute anchoring systems used for substrates not specified by the fenestration manufacturer shall provide equal or greater anchoring performance as demonstrated by accepted engineering practice.

Also, the 2021 IRC does permit use of flashing instructions provided by others, but in a very limited sense as described below. The ability to use the WRB manufacturer's installation and flashing instructions is not specifically recognized.

> **R703.4.1 Flashing installation at exterior window and door openings.** Flashing at exterior window and door openings shall extend to the surface of the exterior wall finish or to the water-resistive barrier complying with

[13] Listiburek, J.W., "The Star-Crossed Lovers of Building Science, Flanged Windows and Foam Plastic Insulating Sheathing", ASHRAE Journal, November 2016, pp. 68-76, www.ashrae.org
[14] Lstiburek, J.W., "Punched Openings", ASHRAE Journal, March 2018, www.ashrae.org
[15] CAN/CSA-A440.4-18, Window, Door, and Skylight Installation, Standards Council of Canada, www.csagroup.org/store/
[16] NAFS-2017, North American Fenestration Standard (AAMA/WDMA/CSA 101/I.S.2/A440)

Section 703.2 for subsequent drainage. Mechanically attached flexible flashings shall comply with AAMA 712. Flashing at exterior window and door openings shall be installed in accordance with one or more of the following:

1. The fenestration manufacturer's installation and flashing instructions, or for applications not addressed in the fenestration manufacturer's instructions, in accordance with the flashing manufacturer's instructions. Where flashing instructions or details are not provided, pan flashing shall be installed at the sill of exterior window and door openings. Pan flashing shall be sealed or sloped in such a manner as to direct water to the surface of the exterior wall finish or to the water resistive barrier for subsequent drainage. Openings using pan flashing shall incorporate flashing or protection at the head and sides.

2. In accordance with the flashing design or method of a registered design professional.

3. In accordance with other *approved* methods.

The option to use alternative structural or flashing installation practices requires the discretionary approval of each local code authority as an "approved" method (see Item 3 above). Alternative means and methods for any code-compliance matter are administered in accordance with Section R104.11 of the IRC. Typically, the process is facilitated by way of a code evaluation report prepared by an approved agency (i.e., a code evaluation service, test lab, or engineering firm also approved by the local code authority) on behalf of a building product manufacturer. For example, FPIS WRB systems are typically qualified for approval as a code-compliant WRB system in accordance with material and assembly testing requirements and criteria of ICC-ES AC71.[17] In addition to other evaluation requirements, AC71 requires that water penetration resistance is evaluated using ASTM E331 at a pressure differential of 6.24 psf for a 2-hour duration. This level of performance exceeds that applied to other WRB materials and systems.[18] More importantly, the evaluation is commonly done with the inclusion of windows and a flashing detail using the FPIS WRB system manufacturer's specifications. An example is shown in Figure 6.[19] However, AC71 does not address structural performance of the window installation.

Figure 6. Example of an ASTM E 331 test being conducted on an FPIS WRB system including window flashing for code-compliance evaluation in accordance with AC71.

[17] ICC-ES, AC71, Acceptance Criteria for Foam Plastic Sheathing Panels Used as Weather-resistive Barriers, www.icc-es.org
[18] ABTG (2015), Water-Resistive Barriers: Assuring Consistent Assembly Water-Penetration Resistance, ABTG Research Report No. 1504-03, www.appliedbuildingtech.com
[19] RADCO Test Report No. RAD-4242, Tests per AC71 on ThermalStar Joint Tape, January 10, 2008.

Building Code Fenestration Requirements

As a fundamental requirement for performance of exterior windows and doors, Section R609.2 of the 2021 IRC (excerpted in part below) requires that fenestration products be "capable of resisting the design wind loads" specified in the code, just as any other exterior wall component. Design wind loads specified by the IRC for exterior wall components in most of the U.S. (in non-hurricane prone regions) are typically about +15 psf (positive design pressure) and -20 psf (negative design pressure). However, for the most extreme exposures and hurricane prone regions, these values can exceed +60 psf and -80 psf.

> **R609.2 Performance.** Exterior windows and doors shall be capable of resisting the design wind loads specified in Table R301.2(2) adjusted for height and exposure in accordance with Table R301.2(3) or determined in accordance with ASCE 7 using the allowable stress design load combinations of ASCE 7. For exterior windows and doors tested in accordance with Sections R609.3 and R609.5, required design wind pressures determined from ASCE 7 using the ultimate strength design (USD) are permitted to be multiplied by 0.6.

As a means to regulate and define fenestration product performance, Section R609.3 of the 2021 IRC as shown below requires that fenestration products comply with NAFS (also known as the "AAMA/WDMA/CSA 101/I.S.2/A440" standard).

> **R609.3 Testing and labeling.** Exterior windows and sliding doors shall be tested by an approved independent laboratory, and bear a label identifying manufacturer, performance characteristics and approved inspection agency to indicate compliance with AAMA/WDMA/CSA 101/I.S.2/A440. Exterior side-hinged doors shall be tested and labeled as conforming to AAMA/WDMA/CSA 101/I.S.2/A440 or AMD 100, or comply with Section R609.5.

For other window and door products not included within the scope of NAFS, Section R609.5 of the 2021 IRC requires that they "shall be tested in accordance with ASTM E330" for wind pressure resistance. Section 1709.5.2 of the 2021 International Building Code (IBC)[20] is similar and it adds performance criteria for ASTM E330 testing consistent with NAFS (i.e., "each assembly shall be tested for 10 seconds at a load equal to 1.5 times the design pressure").

The NAFS standard addresses various performance considerations including durability, operability, air-leakage resistance, water-resistance, and structural wind pressure resistance. It considers the performance of the fenestration unit itself and not its interface with any particular wall assembly. For example, water resistance performance is evaluated only for the fenestration unit itself. The means of interfacing (flashing) with any type of wall system is not part of the fenestration product evaluation for water resistance in accordance with NAFS.

For design wind pressure rating in accordance with NAFS, a "gateway" sized fenestration unit is typically installed into a test buck. The test buck provides a reference substrate, typically wood. The "gateway" size is typically the largest fenestration unit used as a reference window for an entire product line of smaller sized windows. Thus, structural wind pressure ratings per NAFS are essentially "indices" of fenestration performance that relate only to a specific window size and test boundary conditions. They do not account for actual installed performance as it may be influenced by installation quality, aging effects, variable substrate properties, size of fenestration, variation in rough opening gap, and other factors associated with actual conditions of use.

Regarding the effect of fenestration size, Section 1709.5 of the 2021 IBC references AAMA 2502 and Section R609.3.1 of the 2021 IRC similarly references use of "accepted engineering analysis" or WDMA I.S. 11 as a means to evaluate higher wind pressure ratings for fenestration products smaller in size than the NAFS "gateway" size representing a given fenestration product line.[21,22] These code provisions are excerpted below.

> **[2021 IBC] Exception [to Section 1709.5]:** Structural wind load design pressures for window units smaller than the size tested in accordance with Section 1709.5.1 or 1709.5.2 shall be permitted to be different than the design value of the tested unit provided such pressures are determined by accepted engineering analysis or validated by an additional test of the window or door assembly to the alternative allowable design pressure in accordance with Section 1709.5.2. Components of the alternate size assembly shall be the same as the tested or labeled assembly. Where engineering analysis is used, it shall be performed in accordance with the analysis procedures of AAMA 2502.

[20] International Building Code, 2021 edition, International Code Council, Inc., www.iccsafe.org
[21] AAMA 2502-19, Comparative Analysis Procedure for Window and Door Products
[22] WDMA I.S. 11-18, Industry Standard for Analytical Method for Design Pressure (DP) Ratings of Fenestration Products

[2021 IRC]R609.3.1 Comparative analysis. Structural wind load design pressures for window and door units different than the size tested in accordance with Section R609.3 shall be permitted to be different than the design value of the tested unit where determined in accordance with one of the following comparative analysis methods:

1. Structural wind load design pressures for window and door units smaller than the size tested in accordance with Section R609.3 shall be permitted to be higher than the design value of the tested unit provided such higher pressures are determined by accepted engineering analysis. Components of the smaller unit shall be the same as those of the tested unit. Where such calculated design pressures are used, they shall be validated by an additional test of the window or door unit having the highest allowable design pressure.

2. In accordance with WDMA I.S.11.

AAMA 2502 states that "The purpose of this procedure is to allow higher design pressures on a tested window or door product line by decreasing the size of the unit or lower design pressure by increasing the size of the unit compared to the size of the test specimen." It also references the AAMA 2501 standard that "establishes minimum requirements to confirm that a fenestration anchorage system for a product included in the North American Fenestration Standard (NAFS) provides a load resistance with an appropriate safety factor that is equal to or greater than the project specific design pressure requirements and supports the product in a manner equivalent to that tested."[23]

AAMA 2502 (and similarly WDMA I.S. 11) outline engineering principles to allow increased fenestration design pressure ratings based on the proportionate effect of decreasing window size on governing forces, stresses, and deflection associated with the tested failure mode of a larger or NAFS "gateway" sized fenestration unit representing the product line. Important to the purpose of this report, the same principles can be used to evaluate differences in installation conditions for typical (smaller than gateway sized fenestration units) while maintaining at least equivalent performance to that required by the building code, NAFS, and the fenestration manufacturer's installation instructions. The magnitude and significance of this size effect as it relates to installed performance is demonstrated later in the review of performance test data.

REVIEW OF PERFORMANCE TEST DATA

Test data relevant to installation of windows on walls with FPIS ci is summarized in Table 1. This data addresses water penetration resistance of the window-wall interface (i.e., flashing details) and the structural wind pressure resistance associated with anchorage and support provided by the installation. Additional tests addressing sustained dead load and applied shear load resistance are addressed later in this section. Tests demonstrating the effect of fenestration size on installed performance also are discussed later in this section.

Tests represented in Table 1 cover four types of windows (single hung, double hung, casement, and horizontal slider), two window frame types (vinyl and wood), two window configurations (single and mulled 2-unit), rough opening sizes up to 6' wide, and several wall configurations with and without FPIS of three material types (XPS, EPS, and polyiso) of up to 2" thick and two compressive resistances (15 psi and 25 psi). Where included, the FPIS was detailed to serve as the WRB system, including joint tapes and various types of flexible adhered flashings at the window-wall interface. For walls without FPIS, a building wrap or No. 15 felt was used as the WRB and similarly flashed to the window flange using adhered flashings.

In general and with some variation in test sequence or focus of testing, the test data represented in Table 1 employed test methods consistent with those included in AAMA-TIR-504.[24] While also aligning with the evaluation of fenestration units themselves in accordance with NAFS, AAMA-TIR-504 is specifically "intended to examine the performance and durability of the integration of a fenestration product with the building envelope."

The sequence of testing for evaluation in accordance with AAMA TIR-504-20 is as follows:

1. Initial air leakage resistance per ASTM E283[25]
2. Initial water penetration resistance per ASTM E331[26]

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[23] AAMA 2501-20 - Fenestration Anchorage Design by Engineering Analysis
[24] AAMA TIR-504-20, Voluntary Laboratory Test Method to Qualify Vertical Fenestration Installation Procedures, www.aamanet.org
[25] ASTM E 283 / E283M-19, Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Skylights, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen, www.astm.org
[26] ASTM E 331-00(2016), Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference, www.astm.org

3. Thermal (temperature) cycling per ASTM E2264 Method A (level 1) [27]
4. Repeat air and water testing (steps 1 and 2)
5. Design pressure (DP) load test per ASTM E330[28]
6. Repeat water penetration resistance test (step 2)
7. Structural test pressure (STP) load test per ASTM E330

AAMA TIR-504-20 applies the following performance criteria:

- Air leakage resistance tests (steps 1 and 4) – report values;
- Water resistance tests (steps 1, 4, and 6) – No water penetration around the fenestration unit beyond the defined drainage path;
- Design pressure (DP) load test (step 5) – No damage to fenestration unit that prevents normal operation;
- Structural test pressure (STP) load test (step 7) – No damage to fenestration unit or installation method that results in failure to sustain the specified structural test pressure load (e.g., 1.5 x DP) such as a breach resulting in depressurization; any damage or operability impact is to be reported but not considered as a basis for failure where the structural test pressure was sustained.

These criteria are applied to the water-resistance and structural test data reported in Table 1.

In accordance with AAMA-TIR-504, the test pressure used during the ASTM E331 water resistance test is based on 15 percent of the allowable stress wind design pressure applicable to the building site, which is consistent with NAFS requirements for fenestration water resistance rating. The duration of test is specified as 15 minutes. For Canadian applications, the ASTM E331 test pressure should be based on the site's driving rain wind pressure (DRWP) as specified in CSA A440S1.[29] Also in accordance with AAMA-TIR-504, the design pressure (DP) and structural test pressure (STP) is to be sustained for 10 seconds as required by reference to ASTM E330, Procedure A. Furthermore, the STP should be 150 percent of the components and cladding structural design wind pressure. The 150 percent of design load (i.e., a safety factor of 1.5) is consistent with NAFS and model building code requirements for fenestration products as discussed earlier.

AAMA-TIR-504 permits the structural tests (steps 5 and 7) and the water- and air-resistance tests (steps 1-6) to be evaluated separately. This allows testing of a particular installation variation that may affect only structural performance considerations or water/air/durability performance considerations. Air leakage testing is only required to be "reported" because the issue of air leakage at the window-to-wall interface: (1) is a matter of whole building air leakage (beyond the scope of the air leakage requirements of the window product itself per NAFS), (2) is difficult to isolate from air leakage occurring through other paths in an assembly, and (3) is tested at a greater pressure differential during water-resistance testing using ASTM E331, which can serve as an adequate proxy for air tightness. In addition, the final operability check after completion of structural testing requires only "reporting" any operability impact. Operability is considered adequately addressed at the DP test level (i.e., a 1-in-50 to 1-in-100 year wind loading). At the STP load level, the ability to sustain the load (i.e., approximately 1-in-300 year wind load) without failure is the primary concern. This criteria for serviceability (i.e., operability) and structural safety (e.g., ability to sustain an extreme load) is consistent with long-standing engineering design conventions in building codes and standards.

[27] ASTM E 2264-05(2013), Standard Practice for Determining the Effects of Temperature Cycling on Fenestration Products, www.astm.org
[28] ASTM E 330-14, Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference, www.astm.org
[29] CSA A440S1-17, Canadian Supplement to AAMA/WDMA/CSA 101/I.S.2/A440-11, NAFS – North American Fenestration Standard / Specification for windows, doors, and skylights, CSA America, Inc., webstore.ansi.org/standards/csa/csaa440s12017

Table 1: Summary of Test Specimens, Installation Conditions, and Results for Water Resistance and Structural Performance

ID#	FPIS		WRB	Window Specimen Description (Type, DP rating, Size, and Weight)	R.O. Gap	Window Flange Substrate	Window Flange Fastener	Variances from Window Manufacturer Instructions		RESULTS		
	Type (comp. strength)	Thick						Flashing	Structural Support & Anchorage NOTE 1	Water Resistance of Interface	Design Pressure (DP) Test	Structural Test Pressure (STP) or Load at Failure
A	None	N/A	n/a	Single Hung Vinyl Frame DP = +/- 25 psf (H-R25) Size = 29.5″ x 41.5″ DP rating gateway size 42″ x 66″ Weight = 27.2 lbs Flange/Frame Mounting Depth = 1-5/8″	3/8″	OSB	Roofing Nail 0.120″ x 1.75″ (every hole, 10 at jambs, 7 at sill/head)	n/a	Specimens A & B used a “non-DP rated” install with roofing nails in every flange hole as required, but omitted all required shims; also omitted flange bedding sealant, used nails instead of screws, and used 3/8″ r.o. gap in lieu of ¼″ max – all required for “DPR” install	n/a	No damage at +25 psf (operability not evaluated)	Failure at **+151 psf (6.0 x DP)** Movable sash dislodged at check rail
B	15 psi	2″				FPIS only (no OSB)	Roofing Nail 0.120″ x 3.5″ (every hole, 10 at jambs, 7 at sill/head)				No damage at +25psf (operability not evaluated)	Failure at **+118 psf (4.7 x DP)** Movable sash dislodged at check rail
1	None	N/A	Wrap	Double Hung Vinyl Frame DP = +/- 25 psf (LC-PG25) Size = 48" x 64" DP rating gateway size 48" x 72" Weight = 64 lbs Flange/Frame Mounting Depth = 2½"	1/4″	OSB	1.25" roof nail (generally every other nail hole)	Wrap manuf. flashing instructions used	Specimens #1-#11 omitted about one-half of required flange fasteners in jamb flange at location of sash horizontal check rails (e.g., flange fastener group not provided at mid-height of jamb); sometimes skipped two nail holes instead of every other; where used, flange screws omitted required 1" fender washer or used 5/8" washer instead; omitted spray foam air sealant used in window DP certification test; no flange bedding sealant used.	No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
2	None	N/A	Felt		1/4″	OSB	1.25" roof nail (generally every other nail hole)	Code minimum (2" lap) with adhesive flashing felt-to-flanges		No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
3	15 psi	1"	Wrap		1/4"	ROESE (2x)	2.5" roof nail (generally every other nail hole)	Wrap manuf. flashing Instructions used		No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
4	15 psi	1"	FPIS		1/4"	FPIS over OSB	2.5" roof nail (generally every other nail hole)	FPIS WRB manuf. flashing instructions used – applies to all specimens 4-15 and R1, R2, R3a, and R3b.		No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
5	25 psi	1"	FPIS		1/4”	FPIS over OSB	2.5" roof nail (generally every other nail hole)			No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
6	15 psi	1"	FPIS		1/4"	FPIS only (no OSB)	2.5" roof nail (generally every other nail hole)			No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
7	15 psi	1"	FPIS		1/4"	FPIS over OSB	2.5" roof nail (generally every other nail hole)			No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2

ID#	FPIS		WRB	Window Specimen Description (Type, DP rating, Size, and Weight)	R.O. Gap	Window Flange Substrate	Window Flange Fastener	Variances from Window Manufacturer Instructions		RESULTS		
	Type (comp. strength)	Thick						Flashing	Structural Support & Anchorage NOTE 1	Water Resistance of Interface	Design Pressure (DP) Test	Structural Test Pressure (STP) or Load at Failure
8	16 psi	1"	FPIS		1/4"	FPIS over OSB	2.5" roof nail (generally every other nail hole)	FPIS WRB manuf. flashing instructions used – applies to all specimens 4-15 and R1, R2, R3a, and R3b.		No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
10	15 psi	2"	FPIS		1/4"	FPIS over OSB	#8 x 3.5" bugle head screw with 5/8" washer (7 at head/sill and 9 every other nail hole at jambs)			No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
11	15 psi	2"	FPIS		1/4"	FPIS over OSB	#8 x 3.5" GRK cabinet screw (generally every other nail hole)			No leakage at +5.43psf	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure at +/- 39.5 psf (~1.58 x DP) NOTE 2
R1	15 psi	1"	FPIS		1/4"	FPIS over OSB	2.5" nail		No installation variances (manufacturer permits standard install over 1" FPIS)	n/a (not re-evaluated)	No damage or operability impact at -27 psf (~1.08 x DP)	No structural failure or operability impact at -39.5 psf (~1.58 x DP)
13	15 psi	2"	FPIS	Double Hung Vinyl Frame 2-wide, mulled DP = +/- 35 psf (PG 35) Size = 96" x 64" Weight = 128 lbs Flange/Frame Mounting Depth = not reported	1/4"	FPIS over OSB	#8 x 3-1/8" GRK cabinet screw		Need manufacturer install data to assess (Specimen #13 installation followed a practice similar to Specimens #1-#11)	No leakage at +5.43psf	No damage at +/- 37 psf (~1.06 x DP) (operability not evaluated)	No structural failure at +/-54.5 psf (~1.58 x DP) NOTE 2
14	15 psi	2"	FPIS	Double Hung Vinyl Frame, 2-wide, mulled with IR glazing DP = +/- 35 psf (PG 35) Size: 96" x 64" Weight = 384 lbs Flange/Frame Mounting Depth = not reported	1/4"	FPIS over OSB	#8 x 3-1/8" GRK cabinet screw		Need manufacturer install data to assess (Specimen #14 installation followed a practice similar to Specimens #1-#11)	No leakage at +5.43psf	No damage at +/- 37 psf (~1.06 x DP) (operability not evaluated)	No structural failure at +/- 54.5 psf (~1.58 x DP) NOTE 2
12	15 psi	2"	FPIS	Casement Vinyl Frame 2-wide, mulled DP = +/- 25 psf (PG25) Size 72" x 72" Weight = 108 lbs Flange/Frame Mounting Depth = not reported	1/4"	FPIS over OSB	#8 x 3-1/8" GRK cabinet screw (every other nail hole, approx. 12"oc or 6 per side)		Need manufacturer install test data for labeled PG rating to assess; DP rating of 15 and 25 are both reported. Closest match on manufacture website is 20 DP product. AAMA 2400 referenced for installation.	No leakage at +5.43psf (also no water driven up into sill pan)	No damage at +/- 27 psf (~1.08 x DP) (operability not evaluated)	No structural failure or operability impact at +/- 39.5 psf (~1.58 x DP)

ID#	FPIS		WRB	Window Specimen Description (Type, DP rating, Size, and Weight)	R.O. Gap	Window Flange Substrate	Window Flange Fastener	Variances from Window Manufacturer Instructions		RESULTS		
	Type (comp. strength)	Thick						Flashing	Structural Support & Anchorage NOTE 1	Water Resistance of Interface	Design Pressure (DP) Test	Structural Test Pressure (STP) or Load at Failure
15	15 psi	2"	FPIS	Horiz.l Slider Vinyl Frame DP = +35/-40 psf (LC-PG35) Size = 72" x 72" (DP gateway size) Weight = 108 lbs Flange/Frame Mounting Depth = 1-15/16"	1/4"	FPIS over OSB	#8 x 3-1/8" GRK cabinet screw	FPIS WRB Manuf. flashing instructions used – applies to all specimens 4-15 and R1, R2, R3a, and R3b.	No shims at head frame, reduced number of fasteners along head flange, and not continuous bearing at sill per install instructions and DP rating certification test	No leakage at +5.43 psf (window sash/seal leakage)	Head frame rotated causing sash to dislodged; glass broken +32.5 psf (0.93 x DP)	Structural pressure test not conducted due to failure during ramp to DP
R2	15 psi	1"	FPIS		1/4" (no gap at sill)	FPIS over OSB	3-1/8" GRK cabinet screw		No installation variances except flange bedding sealant omitted	n/a (not re-evaluated)	No structural damage at +37 psf (1.06 x DP); However, sliding sash locking latch screws withdrawn	Structural test pressure not conducted due to latch connection failure during DP test
9	15 psi	1"	FPIS	Double Hung Vinyl Clad Wood Frame DP = +/- 30 psf (R-PG30) Size = 39.5" x 56.5" DP rating gateway size 39.5" x 71.5" Weight = 60 lbs Flange/Frame Mounting Depth = 2¼"	1/4"	FPIS over OSB	2.5" nail		No variances from window manufacturer installation instructions, except flange bedding sealant omitted	No leakage at +5.43 psf (initial test only)	Structural failure at +23 psf (0.77 x DP) during service loading to 0.8xDP; wood sash failure	DP and STP evaluation not conducted (see R3a and R3b specimens)
R3 a	None	n/a	Wrap		1/4"	OSB	#8 x 1.5" GRK cabinet screw			n/a (not re-evaluated)	No damage or operability impact at +/- 32 psf (~1.07 x DP)	No structural failure or operability impact at +/- 47 psf (~1.58 x DP)
R3 b	15 psi	1"	FPIS		1/4"	FPIS over OSB	#8 x 2.5" GRK cabinet screw			n/a (not re-evaluated)	No damage or operability impact at +/- 32 psf (~1.07 x DP)	No structural failure or operability impact at +/- 47 psf (~1.58 x DP)

NOTE 1. Variances from window manufacturer's installation instructions were based on comparison of reported installation details for test specimens to the associated window manufacturer's installation instructions for each specific window type and brand including, in some cases, the installation description included in the fenestration product's rating test report noted on the product label.

NOTE 2. For the double-hung vinyl frame windows (Specimens 4-11, 13, and 14) with noted installation variances, a repairable operability impact was reported following the final structural test pressure (STP) loading of ~1.58xDP in the negative pressure direction; refer to discussion in report. This operability condition was not observed for Specimens 1-3, 12, and 15.

Test Data Sources:

ID# A and B: Wind Pressure Resistance of Windows Installed over Foam Sheathing Panels and OSB, Qualtim, Inc., Madison, WI, 2013.

ID#1-14: Performance of Windows in Walls with Continuous Insulation, draft interim project report dated January 2020, prepared by Home Innovation Research Labs for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office, Washington, DC (Contract Award # DE-EE0007574).

ID#R1, R2, R3a and R3b: Evaluation of Windows Installed with Continuous Insulation, Prepared by Home Innovation Research Labs for the American Chemistry Council, Washington, DC, December 2020.

Water Penetration Resistance Performance

Based on water penetration test results shown in Table 1, none of the ASTM E331 tested fenestration installations experienced water intrusion at the flashed fenestration-to-wall interface. This finding held for walls with building wrap and walls with FPIS WRB systems (see Figure 7). It also held for various window types, FPIS types, thicknesses, and compressive strengths (EPS, XPS, and PIC of 1" and 2" thickness and 15 to 25 psi compressive strength), and various flexible adhered flashing materials used in accordance with the WRB system (FPIS or wrap) manufacturer's flashing instructions and flashing material specifications. In addition, this finding held for water penetration resistance tests that were repeated after exposure to thermal cycling (ASTM E2264) and service level wind pressure loading.

Figure 7. Adhered flashing as installed at window perimeters in test specimens with a building wrap WRB (left) and with FPIS WRB system (right).

In all cases, window flange bedding sealant was not used so that any observed water penetration could be directly associated with the adhered flashing approach commonly used with FPIS WRB systems. Bedding sealant, as commonly required by fenestration manufacturer installation instructions, would have provided a redundant water resistance measure.

With rare exceptions, water was typically driven up behind the unsealed bottom flange and onto the rough opening sill pan used for all tested specimens, with or without FPIS ci. This occurrence was expected because the specified ASTM E331 water spray test pressure differential (5.43 psf) was sufficient to drive water up approximately an inch and onto the sill pan. Sill pan installations are particularly vulnerable to this phenomenon where the rough opening gap is not pressure equalized (i.e., no spray foam air sealant was applied to the interior side of the rough opening gap in the test specimens to allow for observation). Consequently, for the purposes of these tests, water-intrusion onto the sill pan through the unsealed bottom flange was not considered a failure of the window-WRB perimeter flashing system.

Structural Wind Load Performance

The ASTM E330 test apparatuses used to generate structural results summarized in Table 1 are shown in Figure 8. Unless noted otherwise in Table 1, both positive and negative pressure tests were conducted on the same specimen with positive pressure testing completed first. With two exceptions, all tests were conducted in a sequence of targeted pressure levels: 0.5xDP (pre-load), 1.0xDP (design pressure), 0.75xDP, and finally 1.5xDP (structural test pressure or STP). For each targeted pressure level, the load was held for 10 seconds, released for a pause, and then the next pressure level was applied. For two test specimens (ID# A and B), the test pressure was ramped to failure to determine the ultimate capacity and failure mode (i.e., ASTM E330 Procedure B was used with a monotonically increasing load until failure).

Figure 8. ASTM E330 test apparatuses used to evaluate positive and negative pressure resistance.
(LEFT – Specimens A and B; RIGHT – Specimens 1-15 and R1-R3)

In general, the installation and test conditions resulted in a more stringent evaluation than used to rate and label the fenestration units themselves in accordance with NAFS. Contrary to the historically accepted installation practice discussed earlier, many installations had significant weakening variances from the window manufacturer's structural anchorage and support installation requirements as noted in Table 1. Flange bedding sealant was intentionally omitted to avoid any structural "bonding" of the fenestration flange to the wall sheathing or WRB material that could have improved structural performance. In addition, most of the specimens (ID#1-15 and R1-R3) were tested to a STP load of 1.58 times the labeled DP load rating of the fenestration product (instead of 1.5 times the labeled DP rating) due to a 2 to 3 psf conservative bias in operation of the test apparatus.

Based on the results and observations summarized in Table 1, none of the fenestration specimens experienced structural failures directly associated with installation over foam sheathing. In the two cases where a structural failure did occur prior to reaching the STP load level, it was related to a premature failure of a fenestration component (e.g., wood cross rail splitting in Specimen ID#9) or significant installation variances from the fenestration manufacturer's installation instructions leading to a premature failure (e.g., no shims and reduced fastening located at the window head resulting in unrestrained window frame rotation in Specimen ID#15). For these two "exceptional" cases, follow-up tests (Specimens ID# R2 and R3) were conducted. For Specimen ID# R2 (follow-up test to Specimen ID#9), the installation variances were eliminated by following the manufacturer's installation instructions and the installation description in the window product's labeled certification test report. However, the final structural test was not completed because of a premature failure of the window's hardware (latch) discovered during the operability check conducted after the DP test level. For Specimen R3a and R3b (follow-up tests to Specimen ID#15), no structural failure or operability impact occurred.[30]

Operability Performance

Operability checks were conducted as part of the ASTM E330 structural testing. Of the various types of windows represented in Table 1, there were two window types that experienced operability incidents. One was a horizontal slider window as mentioned above (Specimen ID# R2), which experienced a premature window hardware failure. The security latch self-tapping screw fasteners withdrew from the metal reinforcing bar inside the vertical rail of the vinyl sash. By observation, the latch failure appeared to be associated with inadequate thread embedment and possible over-torqueing of the latch screws during fabrication.

The other operability incident was observed only after completing the STP test level (with the mentioned overload bias), which is not considered an operability failure in accordance with AAMA-TIR-504. This operability observation occurred consistently with double-hung windows installed over foam sheathing of 1" and 2" thickness (see Note 2 in Table 1 for Specimen ID#4-8, 10-11, 13-14). The operability impact consisted of a metal sash pin becoming dislodged from the balance/braking mechanism such that the upper sash would slide down under its own weight when unlocked after completing the final STP test level without structural failure. This operability impact was easily repaired by re-inserting the sash pin into the receiver of the balance/braking mechanism.

To better understand the cause for the above-described operability occurrence (even though not considered a failure in accordance with FGIA/AAMA-TIR-504), it was necessary to conduct a follow-up test (Specimen ID#R1) to eliminate the weakening installation variances noted in Table 1 for the double-hung window test specimens. The installation variances corrected were:

1. Providing the manufacturer's required flange nail group at mid-height of the jambs (where the sash pins and brake/balance mechanism were located during testing with the window closed and locked). This is a location where concentrated forces are passed from the sashes to the window frame and then into the flange and flange connection to the wall substrate.

2. Providing a low-expansion spray foam air sealant 1" deep from the interior side of the rough opening gap, which was included in the installation description in the window product's labeled DP rating test report; its application followed the manufacturer's air sealing instructions.

With the above two installation corrections applied to Specimen R1 (and still not applying flange bedding sealant required by the instructions for reasons stated earlier), no operability impact was observed after completing the DP and STP test levels without failure or damage.

[30] Test specimens R3a and R3b used the same window specimen. Test R3a was conducted without foam sheathing as a "proof test" of the window specimen to confirm that the specimen met the required DP rating consistent with its labeling and NAFS certification. Test R3b was then conducted using the same window specimen re-installed over foam sheathing. This was done to minimize the possibility of a premature window component failure (as occurred in Test 15 and obscured the intended evaluation of installation over foam sheathing). It is noted that the window unit retested in Specimen R3b was subjected to additional pressure cycles and load duration effects from prior testing of Specimen R3a and also additional test pressure cycles during testing of Specimen R3b due to air leakage problems with the test apparatus that required restarting the test twice, once at the DP load level and again for the STP load level. Thus, cumulative load duration and load cycling of Specimen R3b was more stringent than that used to certify windows in accordance with NAFS.

Sustained Dead Load Performance

In addition to structural wind pressure testing and water-resistance testing documented in Table 1, tests were conducted on Specimens A, B, 4, 5, 6, 10, 11, 12, 13, and 14 to evaluate the movement of the fenestration unit when subject to a period of sustained dead load (i.e., window self-weight). An example test set-up is shown in Figure 9. Maximum downward (negative) movements of -0.000" to -0.032" were recorded for monitoring durations of 20-days (Specimens A and B) and 6-months (all other specimens noted above) for installations including up to 2" of FPIS and window weights ranging from 27 lbs to 384 lbs. There were no obvious trends relative to weight, size, or type of window, or foam thickness and compressive resistance. In some cases positive (upward movement) occurred, which indicates that some portion of the measured positive and negative movements may be associated with normal response of wall and window materials to temperature, humidity, and moisture content changes. It should be noted that these sustained dead load tests were conducted with the same window installation weakening variances as noted in Table 1 and discussed previously.

Figure 9. Sustained dead load tests for creep and stability (Qualtim, Inc., 2013).[31]

Flange Fastener Shear Performance

In additional structural tests, installed single-hung vinyl frame windows (identical to Specimens A and B of Table 1 discussed previously) were subjected to an applied downward load at the head of the window to study the shear capacity and stiffness of flange fasteners installed through 1" and 2" thick FPIS of 15 psi compressive resistance.[32] Again, the windows were installed with no shims such that the resistance to the applied load was transferred entirely through the flange and the flange fasteners penetrating through the FPIS. These tests were used to evaluate the ability to predict the flange fastener shear behavior by an engineering method developed for evaluating fastener shear capacity of connections with an intervening layer of FPIS. It also served as the technical basis for cladding and furring connections through FPIS in U.S. model building codes.[33]

The test set-up is shown in Figure 10 with a wood blocking use at the head of the window to distribute the downward applied load uniformly into the window frame. Load and deflection of the window units were monitored as the flange

[31] Qualtim, Inc. (2013), Creep of Fasteners Installed into Windows over Foam Sheathing Panels and OSB, Qualtim, Inc., Madison, WI
[32] Qualtim, Inc. (2013), Resistance of Fasteners Installed into Windows over Foam Sheathing Panels and OSB, Qualtim, Inc., Madison, WI
[33] Attachment of Exterior Wall Coverings Through Foam Plastic Insulating Sheathing (FPIS) to Wood or Steel Wall Framing, ABTG Research Report No. 1503-02, Applied Building Technology Group, LLC, Madison, WI, 2015, www.appliedbuildingtech.com

fasteners and flange material responded in reaction to the downward shear load. The results of these tests (load-deflection plots) are shown in Figure 11. It is clear that the ultimate shear capacity, ranging from 3,300 to 3,600 lbs, of the flange connection is relatively unaffected by the presence of FPIS up to 2" thick. However, the stiffness response became predictably more ductile with increasing FPIS thickness as expected. With proper design, this improved ductility can result resilient support allowing building and window frame differential movement to be accommodated without damaging or warping fenestration components while, at the same time, providing adequate support and stability to the fenestration unit.

Figure 10. Window installation shear load test set-up.

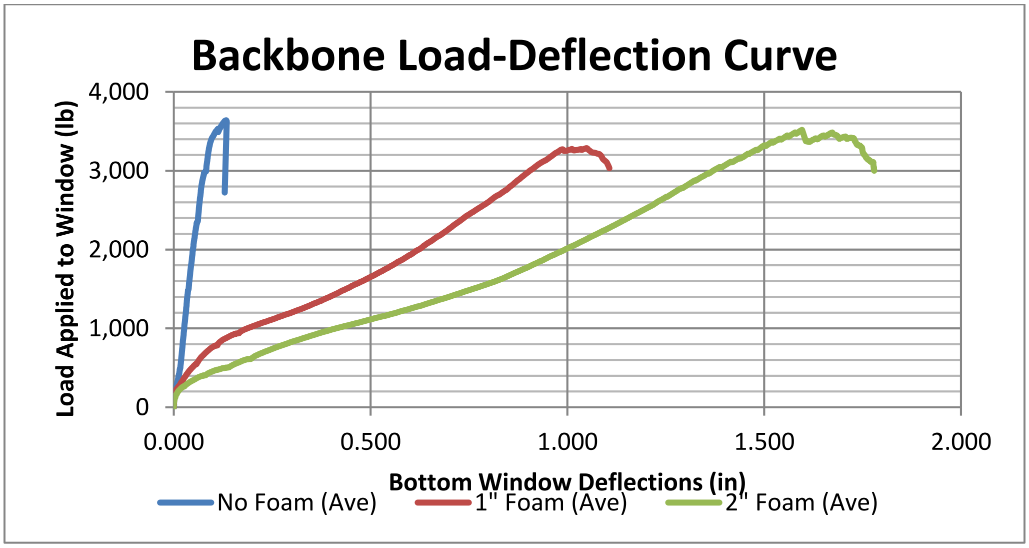


Figure 11. Load-deflection plots for window installations over wood, 1" FPIS, and 2" FPIS substrates. (Qualtim, Inc., 2013)

As mentioned, these test results were compared to an engineering methodology used to design cladding, furring, and structural component connections through FPIS to wood and steel framing. The performance target for the design method limits fastener design shear capacity to that which produces no more than about 0.015" deflection. Consequently, the small deflection portion of the load-deflection plots in Figure 11 are shown in Figure 12 for comparison to the design methodology on a per fastener load and deflection basis. The comparison is shown in Table 2 and it confirms that the design methodology can be conservatively applied to design flange connections to support fenestration dead loads and even additional applied shear load while restraining fenestration movement to not more than about 0.015".

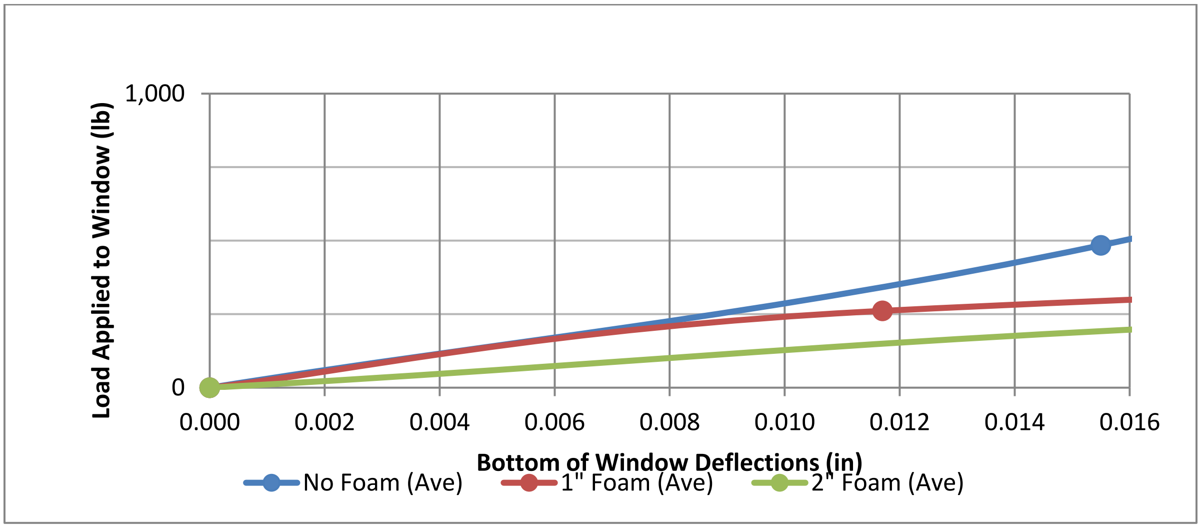


Figure 12. Lower left quadrant of chart in Figure 11 showing load deflection behavior at small deflections.

Table 2. Comparison of test data to design predictions for flange fastener shear behavior.

Foam Thickness	Applied Load (lbs) in addition to self-weight of window	Load per Fastener (lbs) at 0.015" deflection	Design Load Prediction (lbs) per ABTG Method[33]
2"	158	6	5
1"	280	10.7	9

Fenestration Size Effect on Installed Performance

The size effect on fenestration performance was discussed earlier in review of fenestration performance standards (e.g., AAMA 2502) referenced in U.S. model building codes. Referring again to test specimens A and B in Table 1, these windows were purposefully selected from a large retail store as a typical sized window. The size was 30" x 42" (width x height). The NAFS gateway size unit serving as the basis for the product line's DP rating was 42" x 66" as noted in Table 1. As mentioned, the windows were installed without shims, which are required by the fenestration manufacturer's installation instruction. Shims were omitted so that the structural support and anchorage relied exclusively on the flange fasteners installed through a layer of 2"-thick FPIS (Specimen B). Specimen A was a "baseline" condition without FPIS and was installed in the same manner (without shims) as a comparative. The purpose of the Specimen B test was to evaluate a "worst-case" installation condition for a "typical" size window (smaller than NAFS "gateway" size) installed over a practical upper limit for FPIS thickness used as a window flange substrate. Other installation variances included: (1) no use of bedding sealant (which the manufacturer's instructions noted as being necessary to "maintain DP rating") and (2) use of a maximum permitted rough-opening gap of 3/8" in accordance with the manufacturer's "non-DP-rated" instructions (separate "DP-rated" installation instructions limited the rough opening gap to a maximum of ¼").

As shown in Table 1, the test results for Specimens A and B show that they were able to resist an ultimate structural test pressure of 4.7 to 6.0 times the labeled 25 psf DP rating of the fenestration unit. The STP target load resistance of 1.5 x DP was exceeded by 300 to 400 percent. The failure mode was associated with the sash check rail dislodging from the window frame for the positive pressure loading direction. These results indicate that typical sized windows installed on walls with and without FPIS (and even with significant weakening installation variances) can resist structural test pressures well above the labeled DP rating as determined in accordance with NAFS for the gateway size window representing the largest size window unit in a given window product line. These tests also demonstrate that size effects are a significant factor in determining the actual performance of an installed fenestration unit and not just the fenestration unit itself. In fact, this size effect may at least partly explain the success of actual fenestration installations in general as well as the success of the historically accepted installation practice for fenestration installed on walls with FPIS ci discussed earlier.

More work should be conducted to explore and confirm use of the engineering analysis approach of AAMA 2502 as a pathway for evaluating installation conditions, window size effects, and a combination of these two important factors influencing the appropriate structural integration of windows with wall systems. Such an approach would permit limited structural testing (e.g., ASTM E 330) to be efficiently leveraged by engineering analysis, as needed, to properly assess and qualify many application variations based on window size and installation conditions for a wide range of wall substrate conditions, including those with FPIS.

SUMMARY & CONCLUSIONS

The findings of this report are consistent with the historically accepted practice for fenestration installation on walls with FPIS and provide a means for further refinement and improvement as represented by the proposed standard practice of Appendix A.

The key findings and conclusions are as follows:

1. The historically accepted practice for installing windows and doors on walls with FPIS developed over the course of several decades from successful field experience in the U.S. and Canada, as well as influence by product advancements and building code changes.
2. For structural installation details, the historically accepted practice relies on the fenestration manufacturer's product-specific installation instructions with the following additional features and limitations:
    a. For FPIS thicknesses up to 1½", longer flange fasteners are used to accommodate the FPIS thickness and maintain the fastener embedment and withdrawal strength; for windows greater than 4' wide as well as for doors, sill or threshold blocking (equal to the FPIS thickness) is provided for support.
    b. For FPIS thicknesses greater than 1½", the accepted practice uses various types of rough opening extension support elements, such as a window buck made of dimension lumber for direct support and attachment of flanges or a plywood buck with window frame anchor straps to secure the fenestration unit without relying on a flange attachment.
    c. In all cases, shims are used to support the fenestration in accordance with the manufacturer's requirements.
3. For flashing details, the historically accepted practice addresses two different applications of FPIS:
    a. Where a separate WRB material layer is used (e.g., building wrap), flashing to that layer typically follows the fenestration manufacturer's flashing instructions or that of the WRB manufacturer.
    b. Where the FPIS is used as the WRB system, the flashing material specifications and details typically follow the FPIS WRB system manufacturer's flashing instructions.
4. The CAN/CSA A440.4 standard for fenestration installation recognizes many features of the historically accepted practice for fenestration installation on walls with FPIS. In general, codes, standards, and industry guides in the U.S. have not yet followed suit, although at least one U.S. fenestration manufacturer has recently included a limited application of the historically accepted practice in their installation instructions.
5. The AAMA TIR-504-20 standard provides an effective means to evaluate the performance of fenestration installation conditions for water-resistance (flashing), structural performance (anchorage and support), or both as a particular installation variation may require.
6. For water penetration resistance (flashing), all reviewed test data for walls with and without FPIS up to 2" (including several different types of FPIS and adhered flashing materials) satisfied the performance criteria of AAMA TIR-504.20. No water penetration occurred through the window-wall interface at an ASTM E331 test pressure differential of up to 5.47 psf (maximum tested), matching or exceeding the water resistance ratings of each window product as installed in the various wall test specimens.

7. Structural Wind Pressure Performance:
    a. Structural uniform pressure tests per ASTM E330 included several flanged window product types (single-hung, double-hung, casement, and slider), brands, and configurations (1-wide and 2-wide mulled) in rough openings up to 6' wide installed on walls with and without various FPIS material types (EPS, XPS, and Polyiso) having compressive resistances of 15 psi and 25 psi and thicknesses up to 2". Window products tested had labeled design pressure ratings of up to +/-35 psf.
    b. When installed in accordance with the historically accepted practice (using as a basis each fenestration manufacturer's product-specific installation instructions), none of the ASTM E330 tests resulted in a structural failure or operability failure associated with installation over foam sheathing as judged by application of the performance criteria of AAMA TIR-504-20.
    c. For some window installations over FPIS that included significant weakening installation variances (e.g., double hung windows missing a fastener group in the flange at sash check rails where forces are concentrated), the installations exhibited a repairable operability impact observed after sustaining the higher STP loading level without structural failure. This is a reportable observation in accordance with AAMA TIR-504-20. It also demonstrates that, even with significant weakening installation variances, the impact of FPIS appears minimal. A subsequent test correcting the weakening installation variances eliminated this operability impact.
    d. One window test was considered inconclusive because a premature hardware failure (latch fastener withdrawal apparently due to inadequate penetration or over-torqueing of screws) occurred at the DP loading level, which was considered unrelated to the installation over foam sheathing.
    e. Two window installation tests failed at low load levels (below DP rating) due in one case to a significant weakening installation variation (e.g., missing shims at a high stress location and inadequate number of flange fasteners in the same location). The other case was related to a wood component failure and was resolved by follow-up tests using a "proof tested" fenestration unit to minimize the potential for wood material variability from obscuring the intended evaluation of installation on an FPIS substrate.
8. For all window installations evaluated for sustained dead load resistance (creep/stability) and installed over FPIS up to 2" thick, the measured movement was less than 30/1000ths of an inch and commonly less than approximately 20/1000ths of an inch over for monitoring periods up to six months. In some cases, movement occurred in the upward direction (against gravity) indicating that some of the movement may be caused by normal expansion/contraction response of the materials to environmental conditions. Overall, the movement was considered negligible and followed no identifiable trend with fenestration weight, size, configuration, or FPIS thickness.
9. Shear tests of fenestration flange fastener connections through FPIS up to 2" thick indicate that the shear-deflection behavior is predictable and consistent with engineering procedures previously developed to evaluate and design similar connections through FPIS for cladding, furring, and other types of building components as recognized in U.S. model building codes.
10. Two typical sized windows (smaller than the large gateway size window used to rate and label a fenestration product line) were tested for positive pressure resistance using ASTM E330. Even with the intentional absence of all required shims (to evaluate only the flange connection through FPIS), the installed performance over 2"-thick, 15 psi FPIS was 300 percent above the required structural test pressure based on the product's labeled design pressure rating. The installation had an effective safety factor of almost 5 whereas the safety factor required for fenestration product performance is 1.5.

RECOMMENDATIONS

The following recommendations are based on the findings and conclusions of this report:

1. The standard practice of Appendix A should be implemented to provide consistent guidance for the installation of fenestration on walls with FPIS ci, including performance-based and prescriptive solutions with defined and enforceable limitations.
2. AAMA-TIR-504 should be implemented (as done in Appendix A) as a means to effectively evaluate fenestration installation for conditions that may not be addressed in the fenestration manufacturer instructions or the limited prescriptive solutions included in Appendix A.
3. While the prescriptive installation requirements in Appendix A are limited to FPIS thicknesses of 1½" or less, data in this report suggest that they may be applicable for FPIS thicknesses up to 2". Additional tests of window installations on walls with 2"-thick FPIS should be conducted to confirm and identify appropriate limitations and guidance.
4. Additional tests should be considered to expand application of the prescriptive installation requirements of Appendix A to include fenestration products and design conditions where the allowable stress design wind pressure exceeds +/- 35 psf.
5. A testing and analysis study should be conducted to evaluate the use of engineering procedures in AAMA 2502 as a means to predict and account for size effects on the installed structural performance of fenestration to allow limited test data to be extended to different fenestration sizes and wall system or substrate variations.

APPENDIX A

Standard Practice for Fenestration Installations in Walls with Foam Plastic Insulating Sheathing (FPIS)

A.1 General. Fenestration specification and installation in above-grade exterior walls with FPIS continuous insulation shall comply with the locally applicable building code and the requirements of this standard practice. Sections A.2 and A.3 shall apply to the installation of any fenestration type. Section A.4 shall apply to the installation of integrally-flanged fenestration units. An installation shall be permitted to comply with any combination of anchorage and support (Section A.3 or A.4.2) and flashing (Sections A.2 or A.4.1).

A.2 Flashing. Flashing of a fenestration installation shall comply with one of the following:

1. The fenestration manufacturer's installation instructions.
2. For FPIS water-resistive barrier (WRB) systems, comply with either of the following:
    a. The FPIS WRB system manufacturer's installation instructions provided fenestration flashing materials and methods were included as part of the FPIS WRB system's ASTM E 331 qualification testing. The ASTM E 331 test pressure differential shall be at least equivalent to the specified fenestration product's rated water test pressure differential.
    b. The prescriptive flashing method of FMA/AAMA/WDMA 500 where FPIS is used with a separate membrane WRB material.
3. The flashing manufacturer's installation instructions.
4. The design of a registered design professional.
5. Testing in accordance with the water penetration resistance test requirements of AAMA TIR 504.

A.3 Anchorage and Support. Fenestration shall be anchored and supported in accordance with the fenestration manufacturer's installation instructions. For anchorage and support conditions not addressed in the fenestration manufacturer's installation instructions, the installation shall comply with one or more of the following as applicable:

1. The design of a registered design professional.
2. An analysis conducted in accordance with AAMA 2502.
3. An analysis of anchorage in accordance with AAMA 2501.
4. Testing in accordance with the ASTM E330 structural test requirements of AAMA TIR 504.

A.4 Prescriptive Installation. For walls with a FPIS WRB system, flashing of integrally-flanged fenestration units shall be permitted to be specified and installed in accordance with Section A.4.1. As an alternative to Section A.3 and only for the case where the installation anchorage and support condition is not addressed in the fenestration manufacturer's installation instructions, support and anchorage shall be permitted to be provided in accordance with the requirements and limitations of Section A.4.2.

A.4.1 Prescriptive Flashing. Flashing materials and sealants shall comply with the material specifications of the fenestration manufacturer or the FPIS WRB system manufacturer. The flashing material shall be applied in accordance with Figures A1 and A2. The flashing material and method shown in Figures A1 and A2 is not intended to reflect a minimum practice or to restrict the use of other flashing methods complying with Section A.2.

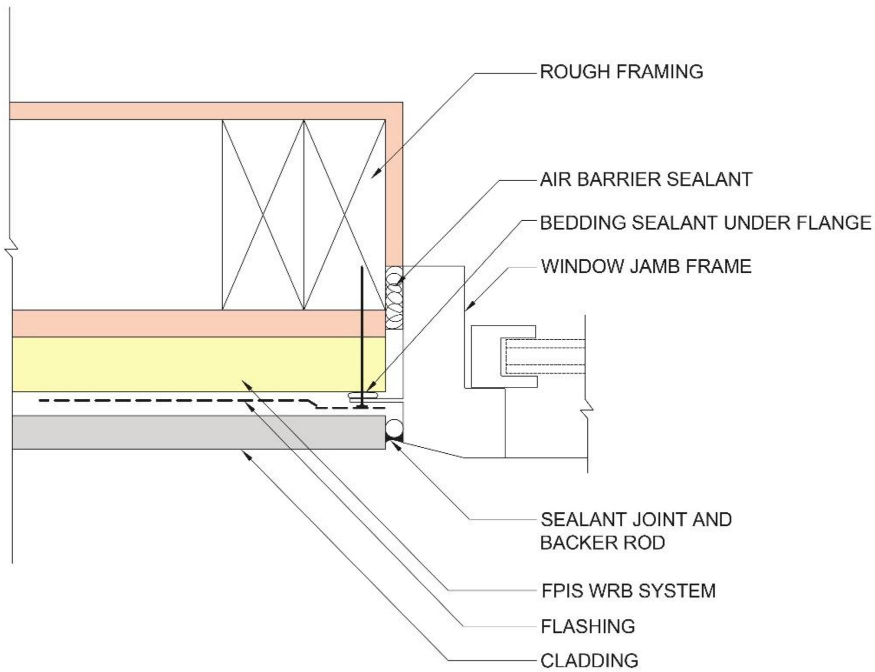


Figure A1. Interface of integral flange window with FPIS WRB system.

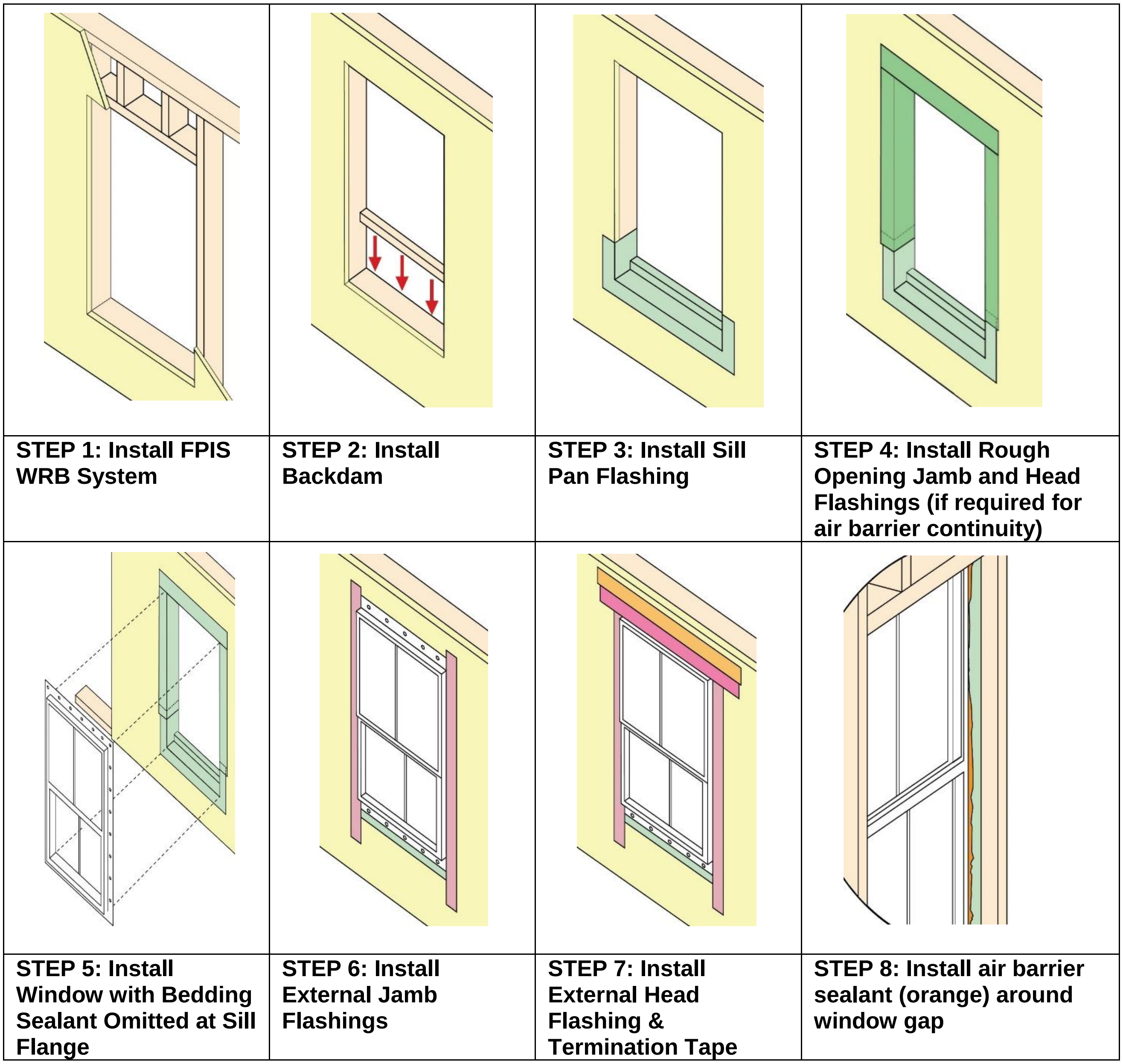


Figure A2. Fenestration flashing method for walls using an FPIS WRB system.

A.4.2 Prescriptive Anchorage and Support. Installation of integrally-flanged fenestration units with flanges bearing on and fastened through FPIS shall comply with the fenestration manufacturer's installation instructions for anchorage and support, including shim placement and fastening schedule. In addition, the following limitations and requirements shall apply:

1. Fenestration flange fasteners shall be increased in length equal to the thickness of the FPIS substrate to maintain required embedment in underlying framing materials.
2. Fenestration through-frame fasteners, where required, shall engage structural framing materials maintaining required penetration and edge distances.
3. The FPIS material shall comply with ASTM C578 or ASTM C1289 and have a minimum 15 psi compressive resistance.
4. The FPIS material thickness shall not exceed a nominal 1½"
5. The allowable stress design wind pressure for the building site and installed location on the building wall shall not exceed +/- 35 psf.
6. The width of single or mulled fenestration units shall not exceed 6'.

Where any of the above anchorage and support installation requirements and limitations are not satisfied, the fenestration shall be installed using a window buck or picture frame blocking secured to the wall framing as shown in Figure A3. The fenestration shall be supported and anchored in accordance with the fenestration manufacturer's installation instructions.

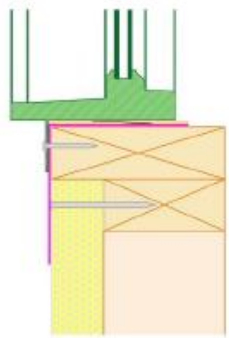
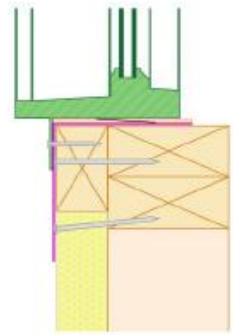
 Rough opening "window buck"	 Rough opening "picture frame" blocking

Figure A3. Illustration of a window buck and picture frame blocking for enhanced fenestration support.

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A.5 Reference Standards

FMA/AAMA/WDMA 500 – 16, Standard Practice for the Installation of Mounting Flange Windows into Walls Utilizing Foam Plastic Insulating Sheathing with a Separate Water-Resistive Barrier (WRB)

AAMA TIR-504-20, Voluntary Laboratory Test Method to Qualify Vertical Fenestration Installation Procedures

AAMA 2501-20, Voluntary Guideline for Engineering Analysis of Anchorage Systems for Fenestration Products Included in NAFS

AAMA 2502-19, Comparative Analysis Procedure for Window and Door Products

ASTM C578-19, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation

ASTM C1289-20, Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board

ASTM E 330-14, Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights, and Curtain Walls by Uniform Static Air Pressure Difference

ASTM E 331-00(2016), Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference

APPENDIX B

Excerpts from CAN/CSA-A440.4

Relevant structural installation provisions in CAN/CSA-A440.4 include the following:

6.5.2.3

In wood stud framed walls with insulating sheathing across the exterior face of the frame (either directly against the studs or against structural sheathing applied to the stud faces), windows or doors may be positioned within the depth of the insulating sheathing provided that

a) the window or door is installed into a wood sub-frame that projects through the thickness of the insulating sheathing to support the window or door. The sub-frame is anchored around the perimeter of the rough opening, and the window or door is anchored to the sub-frame, in the same manner as for steel stud framed walls (see Clause 6.5.3); or

b) the window or door frame includes a structural mounting flange in continuous contact with the insulating sheathing, fasteners through the mounting flange and insulating sheathing penetrate into the wood stud frame, and the insulating sheathing is extruded polystyrene or expanded polystyrene complying with CAN/ULC-S701 or polyisocyanurate complying with CAN/ULC-S704. The adequacy of the assembly to resist structural loads shall be assessed through structural strength tests in accordance with AAMA/WDMA/CSA 101/I.S.2/A440-11.

Notes:

1) *In steel stud framed walls, one of the functions of a wood sub-frame at the perimeter of a window or door opening is to provide a thermal break between the window or door frame and the steel stud frame. The wood sub-frame conducts heat at a slower rate than steel stud frame components. However, in a wood stud framed wall, a wood sub-frame conducts heat at a similar rate to the wood stud frame so the sub-frame, extending through insulating sheathing, acts as a thermal bridge. For this reason, when installing an integral mounting flange window with anchor fasteners through the flange, eliminating the wood sub-frame, and placing the flange directly against insulating sheathing with the fasteners extending into the wood frame, can provide better thermal performance.*

2) *For many typical applications, building industry experience and research by manufacturers of foam plastic insulating sheathing materials indicate that expanded polystyrene, extruded polystyrene, and polyisocyanurate board insulation materials are capable of providing a suitable flange substrate for long-term support of the self-weight of a window or door and transfer of applied loads to the wood stud frame using typical attachment and support practices. However, it is necessary to consider various potential limitations to this practice such as the thickness and compressive strength of the insulating sheathing, the length of fasteners necessary to accommodate a thickness of insulating sheathing, the size and weight of the fenestration unit, special anchorage or support conditions for mulled or combination assemblies, and support for door thresholds which must support foot traffic. Therefore, the fenestration product manufacturer or a design professional be should consulted on the need for a sub-frame for windows or doors.*

…

6.5.5 Windows and doors with structural mounting flanges

6.5.5.1

Fasteners shall penetrate at least 25 mm (1 in) into the wood stud frame at a location at least 10 mm (3/8 in) from the edge of the wood stud frame at the perimeter of the rough opening (e.g., jack stud, rough sill).

6.5.5.2

In wood stud framed walls with insulating sheathing across the exterior face of the frame (either directly against the studs (open stud frame) or against structural sheathing applied to the stud faces), see Clause 6.5.2.3 b).

6.5.5.3

Sufficient fasteners shall be installed through the nail flange to resist anticipated loads imposed upon them.

Note: *The window manufacturer should be consulted as to the number and location of fasteners in the nail flange. The number and location of fasteners should be confirmed during structural testing at appropriate NAFS product type, performance class, and grade gateway size.*

Relevant flashing guidance in CAN/CSA-A440.4 is included in Note 4 of Section 10.2.3 (an FPIS WRB system is considered a "sheathing-type WRB"):

4) *Extending the head flashing upward behind a membrane-type WRB or a sheathing-type WRB is an accepted solution described in Article 9.27.3.8 of the NBC. It follows the principle of shingled joints or sealed joints to shed water. For sheathing-type WRBs, however, sealed joints are an acceptable solution described in Article 9.27.3.4. Consequently, joints sealed with adhesive tape can be used to provide an effective and durable barrier to water penetration further into the wall assembly. Care must be taken to ensure the tape is applied without wrinkles extending to the upper edge ("fish mouths") that could allow water to penetrate joints. It is possible that head flashing could be turned up the exterior face of insulating sheathing with the upper edge similarly sealed with tape or self-adhered flashing to effectively shed water. The installer should confirm this method can be used with the local authority having jurisdiction (building department), insulating sheathing manufacturer, and tape or self-adhering flashing manufacturer.*