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Performance of Windows in Walls With Continuous Insulation

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Building America

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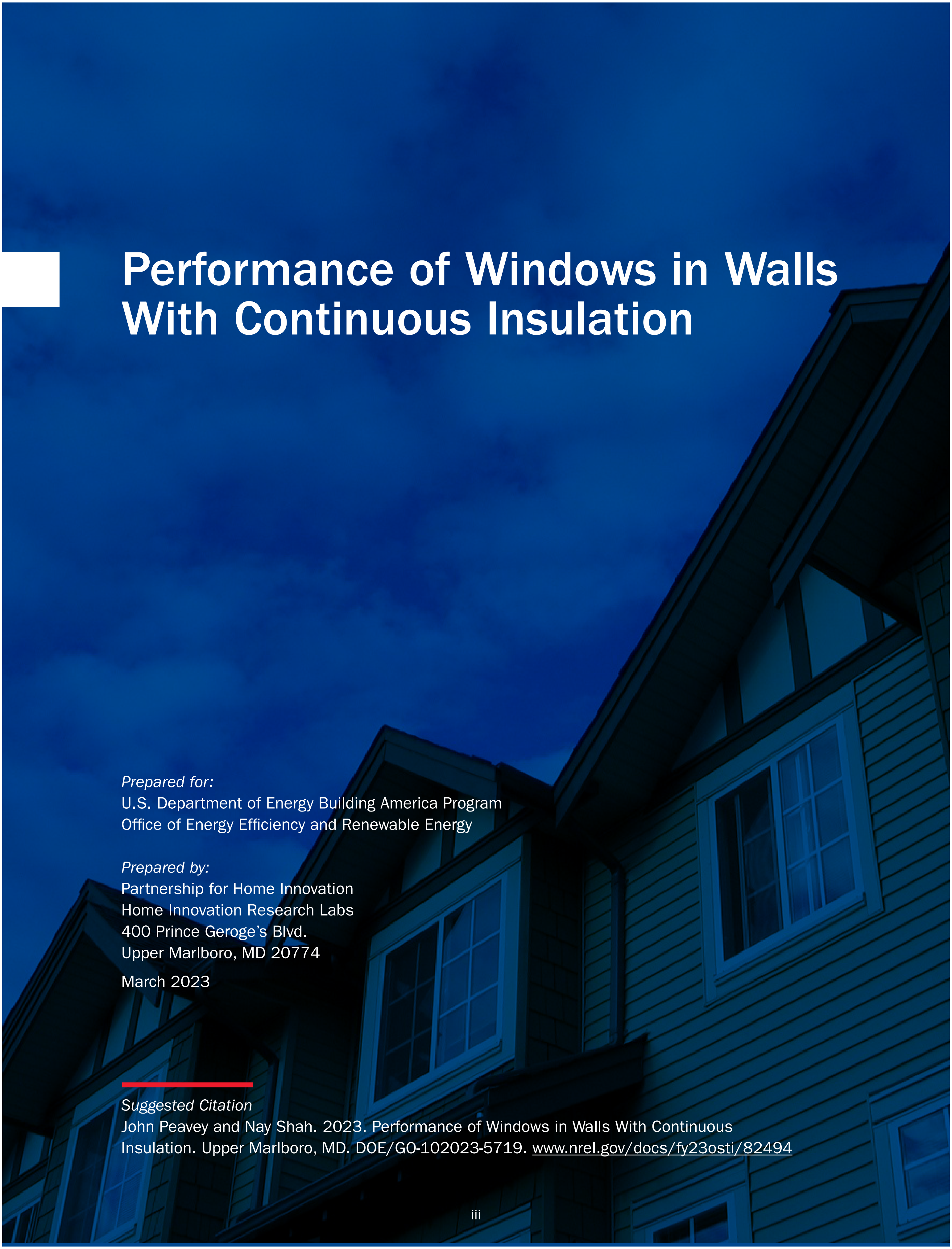

Performance of Windows in Walls With Continuous Insulation

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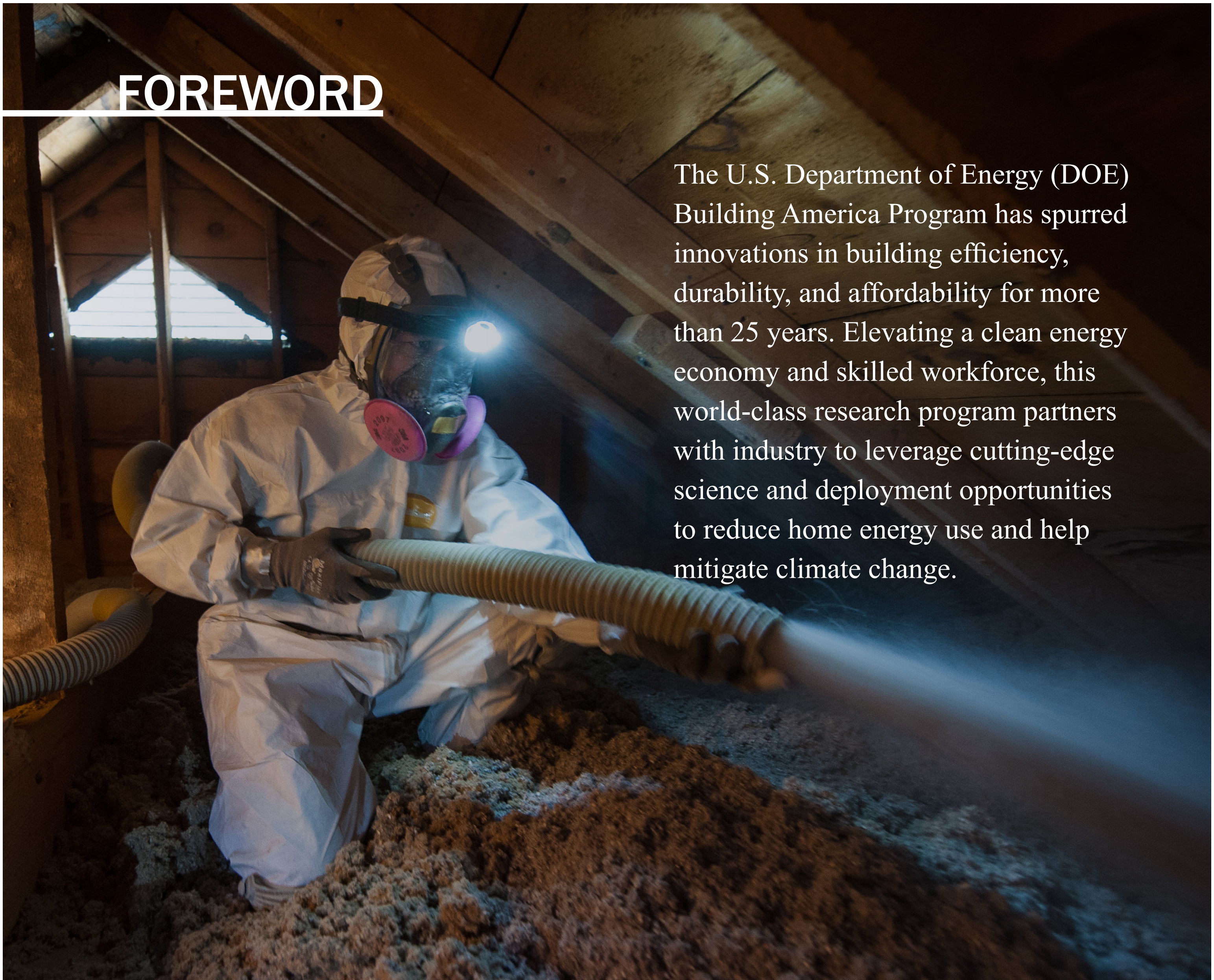
This material is based upon work supported by the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Building Technologies Office under Award Number EE0007574.

The work presented in this EERE Building America report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

FOREWORD



The U.S. Department of Energy (DOE) Building America Program has spurred innovations in building efficiency, durability, and affordability for more than 25 years. Elevating a clean energy economy and skilled workforce, this world-class research program partners with industry to leverage cutting-edge science and deployment opportunities to reduce home energy use and help mitigate climate change.

In cooperation with the Building America Program, the Partnership for Home Innovation team is one of many Building America teams working to drive innovations that address the challenges identified in the program's Research-to-Market Plan.

This report, *Performance of Windows in Walls With Continuous Insulation*, explores the common method for installing windows in walls with continuous insulation and presents acceptance criteria for evaluating the performance of windows installed in walls with and without continuous insulation.

As the technical monitor of the Building America research, the National Renewable Energy Laboratory encourages feedback and dialogue on the research findings in this report as well as others. Send any comments and questions to building.america@ee.doe.gov.

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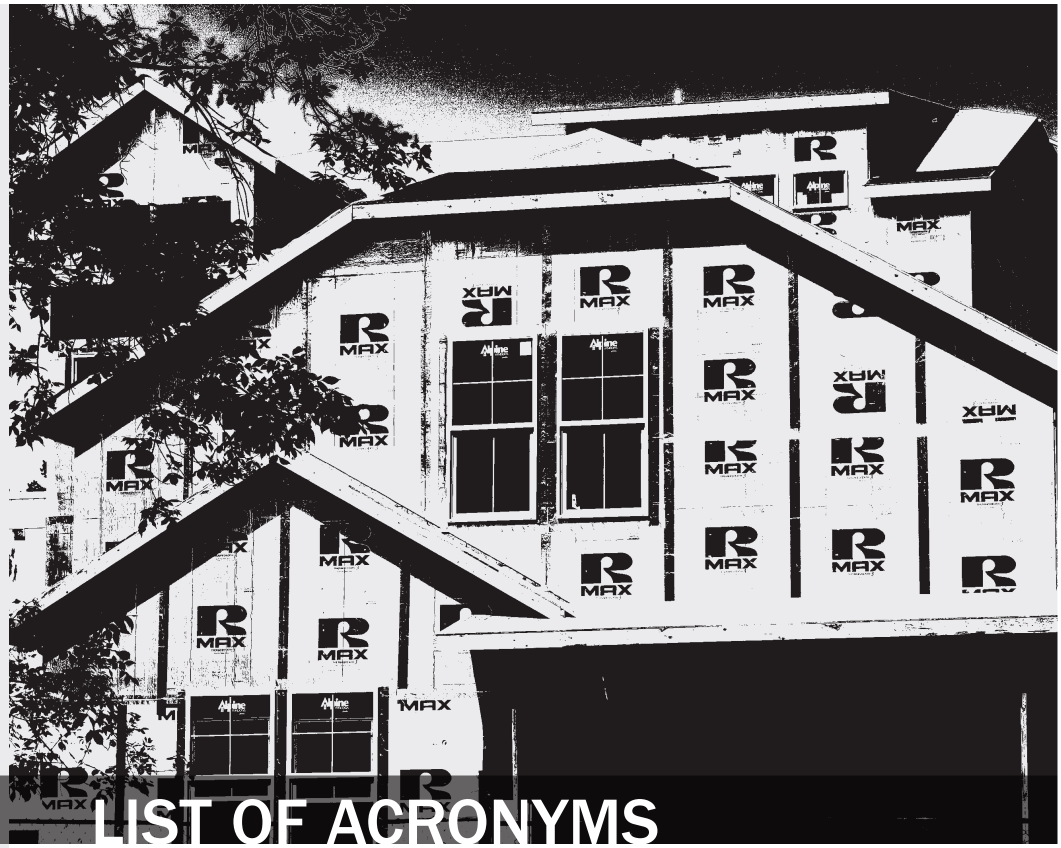

LIST OF ACRONYMS

AAMA	American Architectural Manufacturers Association
CI	continuous insulation
DH	double-hung
DP	design pressure
EPS	expanded polystyrene
ESR	Evaluation Service Report
FMA	Fenestration Manufacturers Association
FSC	Foam Sheathing Committee
IR	impact resistant
NAFS	North American Fenestration Standard
oc	on center
OOPS	out-of-plane stress
OSB	oriented strand board
PG	performance grade
PIR	polyisocyanurate, also referred to as polyiso
PLA	pressure load actuator
psf	pounds per square foot
psi	pounds per square inch
ROESE	rough opening extension support element
STP	structural test pressure
WDMA	Window and Door Manufacturers Association
WRB	water-resistive barrier
XPS	extruded polystyrene

EXECUTIVE SUMMARY

Window openings in walls are a significant contributor to poor thermal performance because of thermal bridging through the framing members (e.g., studs, joists, plates, bracing) and because windows lack the thermal properties of insulation.

Window installation guidance for walls with continuous insulation (CI) is critical for continued market growth of this energy efficiency technology. This research project offers window manufacturers a starting point and a potential path toward developing installation instructions for windows over CI.

The objectives of the research include evaluating the common method for installing windows in walls with CI, as well as establishing acceptance criteria for evaluating the performance of windows installed in walls with and without CI.

The research measures:

1. The performance characteristics (e.g., water management, structural integrity) of windows in walls without CI
2. The performance of different thicknesses and types of CI used in walls
3. The performance of different types of window assemblies (e.g., double-hung windows, mulled double-hung windows, mulled casement windows, and slider windows) installed over CI
4. The performance of window flange types (e.g., rigid mounting and less robust flanges) installed over CI
5. Installing windows over CI using baseline installation instructions versus window manufacturer installation instructions.

The project's sequential testing protocol includes the following:

- A water penetration resistance testing adapted from two ASTM standards: E331 (uniform static air pressure in four steps) and E547 (cyclic static air pressure)
- A temperature cycling adapted from ASTM E2264 Method B (convective hot air)

- A service condition wind loading test adapted from ASTM E330
- A six-month vertical displacement observation phase prior to the structural performance testing
- A final water penetration resistance test after vertical displacement observation
- A structural performance test adapted from ASTM E330.

Key Research Findings

- The criterion for passing a water penetration resistance test is that there is no water overflowing at the interior face of the studs. If there is any bubbling or slight pooling of water at the sill, then it must recede after the pressure is removed. Excessive leakage and/or water leaking to the interior face of the framing around the window constitutes a failure.
- All single double-hung windows installed directly to lumber or over oriented strand board passed all test protocols.
- For most wall specimens, the test results showed that the use of foam sheathing did not affect the performance of the window for water leakage.
- All wall specimens underwent temperature cycling. The results indicated that temperature cycling had little to no effect on windows installed over foam sheathing.

- For wall specimens that underwent six-month vertical displacement monitoring, the results showed that windows installed over foam sheathing do not sag over time.

- The single-hung and double-hung windows installed using window manufacturer installation instructions passed the structural performance test, compared to failures observed in windows that were installed using generic installation instructions. The generic and manufacturer installation methods differed on the following construction details: type of fasteners, fastening patterns on the flanges, and window shimming details.

- Additional testing is required to determine methods to improve structural pressure performance of slider windows. Potential solutions that would require additional testing may include fastener spacing, different types of fasteners, masonry window clips, construction adhesive, foam sealant, stronger window flange material, and/or straps.

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1 Introduction

1.1 Objective: Window Installation Over Continuous Insulation

Window openings in walls are a significant contributor to poor thermal performance because of thermal bridging through the framing members (e.g., studs, joists, plates, bracing) and because window frames lack the thermal properties of insulation. This research project addresses the thermal bridging that occurs between the framing members and window frames through the use of continuous insulation (CI).

CI is a continuous layer of insulative material that covers the building's structural members to eliminate thermal bridging except at the fasteners and service openings. CI is a practical and alternative method for increasing a wall's thermal performance by eliminating thermal bridging through the framing members. Rigid foam sheathing CI – e.g., expanded polystyrene (EPS), extruded polystyrene (XPS), or polyisocyanurate (PIR) – offers additional benefits such as increased wall temperatures for the prevention of condensation in the wall cavity; increased air tightness when installed properly; and improved resistance to rot, decay, and corrosion. Because of these benefits, rigid foam insulation earned recognition as a 2013 Building America Top Innovation and has achieved between 10% and 15% market penetration, depending on climate zone (Werling 2017). However, despite its practicality and popularity, there is an unresolved technical issue with using rigid foam sheathing that may hinder its continued growth within the home building industry – window installation in walls that use this technology.

During the early years of the research project, window manufacturers did not have any installation instructions related to installing windows over CI. The objectives of this research were: (1) evaluating the common method for installing windows in walls with CI; and (2) establishing acceptance criteria for evaluating the performance of windows installed in walls with and without CI. This research effort tested various window assembly configurations installed in wall specimens with rigid foam sheathing of various thicknesses. All the windows had one common characteristics – flanges. The testing provides an initial library of results on the performance of windows with flanges installed directly over rigid foam sheathing without additional structural support.

This research evaluated the following:

- The performance characteristics (water management, structural integrity) of windows in walls without CI
- The performance of characteristics (water management, structural integrity) of windows in walls with different thicknesses of CI
- The performance of different types of CI – XPS, EPS, PIR
- The performance of different types of window assemblies – double-hung (DH), mulled double-hung, mulled casement, and slider windows

- The performance of flange types – rigid ("structural") mounting flanges and less robust ("non-structural") flanges that are used only to position the window during installation
- Two potential installation methods: (1) a generic installation method applicable to any flanged window, and (2) the window manufacturer's instructions for a traditional OSB installation modified by increasing the length of the fasteners by 1".

1.2 Current Practices

The International Residential Code requires that window installation and flashing comply with window manufacturer instructions, yet window manufacturer literature has not addressed installation in walls with CI. As a result, windows have been installed in these walls following the same procedures typically used for walls with other types of sheathing.

In an effort to provide standard guidance for providing structural support and addressing water management details for windows installed in walls with CI, the fenestration industry developed the FMA/AAMA/WDMA 500-15 (*Standard Practice for Installation of Mounting Flange Windows into Walls Utilizing Foam Plastic Insulating Sheathing with a Separate Water-Resistive Barrier*). The installation procedures in Standard 500 include only two structural support methods: mounting the window on a rough opening extension support element (ROESE) or directly onto the structural sheathing. These methods allow the transfer of wind loads directly to the framing members.

Current installation methods that have been used (particularly with greater than 1" foam sheathing installations) include:

- The perimeter strapping method (ROESE) where 2x lumber is attached around the entire rough opening (i.e., "picture framing").
- Creating a window buck in the rough opening where lumber or plywood is installed horizontally and extends up to or past the foam exterior surface.
- Using mounting clips attached to the window frame to anchor the window to the framing member. The same method is used for non-flanged windows.

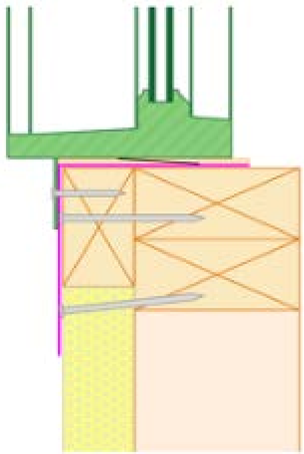

Figure 1. ROESE

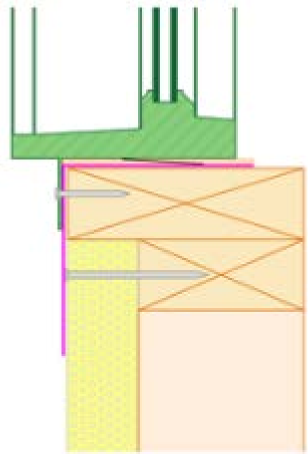

Figure 2. Window Buck

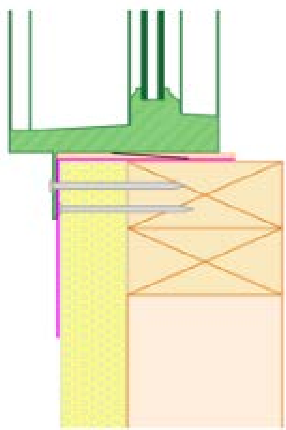

Figure 3. Flange Outboard CI

The ROESE and window buck methods have several disadvantages:

- They can complicate water-resistance detailing (flashing) depending on whether a separate water-resistive barrier (WRB) layer is used and whether it is located under or over the foam sheathing.
- Installing a ROESE at every window opening increases project costs (i.e., raw material and labor) and cycle time, therefore most builders do not use this method.
- The ROESE and window buck methods create an additional thermal bridge through the building envelope, negatively impacting the building envelope's thermal performance. The linear thermal bridging must be accounted for in either the window or wall U-factor used in energy modeling.

1.3 Relevance to Building America's Goals

Window installation guidance for walls with CI is critical for continued market growth of this energy-efficiency technology. Any such guidance must have reasonable limits (window type, CI thickness, flashing details, fastener schedule) that are validated by performance data to mollify concerns about the long-term structural integrity of these installations.

There are several existing Building America measure guidelines that could benefit from the library of performance data and installation specifications developed as a result of this research, including:

- Complete Window and Frame Replacement
- Continuous Rigid Insulation Sheathing/Siding
- Rigid Foam Insulation for Existing Exterior Walls
- Water Managed Existing Wall Penetrations

This research evaluated the common methods for installing windows in walls with CI. Neither the windows nor the rigid foam sheathing products are new to the building industry, therefore the study did not attempt to evaluate the cost of new or added energy measures. The key issue is avoiding unintended consequences of potential industry-wide or individual failures that can become a long-term barrier to continued adoption of CI as an energy efficiency measure. This project did not compare the energy performance, with regard to thermal bridging, of various installation methods.

2 Research Methodology

2.1 Overview

The research methodology, as well as the matrix of specimens, was developed with input from the project Advisory Group. The Advisory Group comprises window manufacturers (JELD-WEN, Milgard, Pella, Andersen), foam sheathing manufacturers (Atlas EPS, Dow, Owens Corning, Rmax), and other industry professionals (American Chemistry Council, Covestro, Department of Energy, Fenestration and Glazing Industry Alliance, Lennar, McIntyre Homes, National Association of Home Builders, National Renewable Energy Laboratory, Window & Door Manufacturers Association).

The testing and observation program for this research project consisted of seven discrete steps performed on each full-size wall specimen.

Table 1. Testing and Observation

Step	Test/Observation	Reference
1	Initial water penetration resistance test	Adapted from ASTM E331 and E547
2	Temperature cycling	ASTM E2264, Method B Level 1
3	Service-condition wind loading (15-year pressure)	Adapted from ASTM E330
4	Service-conditioned water penetration resistance test	Adapted from ASTM E331 and E547 (same as step 2)
5	Vertical displacement (gravity load) monitoring	Lab measurement
6	Final water penetration resistance test	Adapted from ASTM E331 and E547 (same as step 2)
7	Structural performance testing (wind loading, 1.5xDP)	ASTM E330

Referenced Standards:

1. ASTM E331-16, Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors and Curtain Walls by Uniform Static Air Pressure Difference
2. ASTM E547-16, Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors and Curtain Walls by Cyclic Static Air Pressure Difference
3. ASTM E2264-05, Standard Practice for Determining the Effects of Temperature Cycling on Fenestration Products
4. ASTM E330-14, Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference.

This program was adapted from the testing procedure contained in AAMA 504 (Voluntary Laboratory Test Method to Qualify Fenestration Installation Procedures) and ASTM E2264, which is used to evaluate installations that deviate from the window manufacturer's recommendations. Modifications and refinements to the evaluation protocol were made in an attempt to both address functional performance after realistic service preconditioning (representative of wind loading and temperature cycling expected during service) and evaluate structural integrity and operability after more extreme loads with a low probability of occurrence (e.g., greater than a 300 year return period).

The project's testing and observation program differed from the AAMA 504 procedures in the following ways:

- This program does not include air leakage testing per ASTM E283-04 because the windows will not be caulked given that caulking is not the focus of performance.
- The water penetration resistance testing is adapted from two ASTM standards: E331 (uniform static air pressure in four steps) and E547 (cyclic static air pressure). The uniform static air pressure test was selected to understand the windows performance at different pressure levels. The cyclic static air pressure test was to show the durability of the window.
- This program uses ASTM E2264 Method B (convective hot air) instead of Method A (infrared radiation) for temperature cycling. Method B was chosen because it is intended for research purposes, whereas Method A is intended for comparative product evaluations.
- This program adds a six-month vertical displacement observation phase prior to the structural performance testing.
- This program adds a final water penetration resistance test after vertical displacement observation and prior to structural performance testing.

2.2 Test Specimens

The testing program was conducted on 15 full-size wall specimens to evaluate the performance of various installed window assemblies/support/fastening/CI combinations. The 120x100 in. wall specimens consisted of 2x4 framing spaced 16 in. on center (o.c.) inside a 2x6 wood buck used to mount the test specimen onto the test equipment. Framing construction details can be found in Appendix C. Double-pane, non-impact resistant (non-IR) glazing was chosen for all wall specimens other than Wall 14 because this is the most common glazing.

No cladding, interior gypsum, and air sealants were installed on the wall specimens. The wall specimen did not have interior gypsum, back dam and any sealant in the sill area to observe the water penetration. Cladding and interior gypsum were not installed as they are non-structural components of the wall assembly and not considered primary water barriers. The ASTM methods for water and structural testing didn't require cladding and interior gypsum.

Table 2. Window Wall Specimen Details

Wall #	Insulation		WRB	Window					Support	Window Fastener
	Type	Thick		Type	Dimension (in)	Glazing	Est. Weight	PG Rating		
1	None	N/A	Wrap	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	OSB	1.25" nail
2	None	N/A	Felt	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	OSB	1.25" nail
3	15-psi XPS	1"	Wrap	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	ROESE	2.5" nail
4	15-psi XPS	1"	Foam	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	CI & Flange	2.5" nail
5	25-psi XPS	1"	Foam	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	CI & Flange	2.5" nail
6	15-psi XPS No OSB	1"	Foam	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	CI & Flange	2.5" nail
7	15-psi EPS	1"	Foam	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	CI & Flange	2.5" nail
8	16-psi PIR	1"	Foam	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	CI & Flange	2.5" nail
9	15-psi XPS	1"	Foam	Double Hung	39.5" x 56.5"	2-pane non-IR	60 lbs	PG 30	CI Only (Flimsy flange)	2.5" nail
10	15-psi XPS	2"	Foam	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	CI & Flange	3.5" screw
11	15-psi XPS	2"	Foam	Double Hung	48" x 64"	2-pane non-IR	64 lbs	PG 25	CI & Flange	3.5" cabinet screw
12	15-psi XPS	2"	Foam	Casement, mulled	72" x 72"	2-pane non-IR	108 lbs total	PG 25	CI & Flange	3-1/8" cabinet screw
13	15-psi XPS	2"	Foam	Double Hung, mulled	96" x 64"	2-pane non-IR	128 lbs	PG 35	CI & Flange	3-1/8" cabinet screw
14	15-psi XPS	2"	Foam	Double Hung, mulled	96" x 64"	2-pane Impact Resist	384 lbs	PG 35	CI & Flange	3-1/8" cabinet screw
15	15-psi XPS	2"	Foam	Slider	72" x 72"	2-pane non-IR	108 lbs	PG 35	CI & Flange	3-1/8" cabinet screw

* Performance grade (PG) means that the product was tested at the applicable design pressure for all performance requirements identified by NAFS. Minimum performance grade and design pressure and the corresponding uniform load structural test pressures and water penetration resistance test pressures for the four NAFS performance classes are indicated in the table.

Generic Installation Instructions

During the early years of the research project, window manufacturers did not have any installation instructions related to installing windows over CI. Home Innovation, in consultation with the Advisory Group, developed generic installation instructions that were applied to all the windows unless stated otherwise. These generic installation instructions specify how to flash the windows installed over CI; the types of tapes to use for flashing; the types of fasteners to use (i.e., length and type); and the fastening schedule to be used. See Appendix D for the generic installation procedures.

Control and Benchmark Specimens

Wall 1 served as a basis for comparison as it had no rigid foam sheathing. One double-hung PG25 window was installed in the rough openings directly onto housewrap and OSB sheathing. The vinyl frame window had an integral 1-5/8 in. rigid mounting ("structural") flange and double-pane, non-impact resistant glazing.

Wall 2 also served as a basis for comparison and its only difference from Wall 1 was the use of No. 15 felt. This wall served as a historic baseline as No. 15 felt paper has long been the code-referenced standard WRB material.

Wall 3 had a double-hung, vinyl frame window installed in an ROESE. The wall had 1 in. thick, 15 psi XPS foam sheathing outboard of the OSB structural sheathing. The WRB was the same building wrap used in Wall 1, and it was installed exterior to the foam sheathing and ROESE, but before the window was installed (see installation Method A in FMA/AAMA/WDMA Standard 500-16).

Wall 4 was similar to Wall 3 except that the window was installed directly over the 1 in. thick 15 psi XPS foam sheathing that was outboard of the OSB. The XPS sheathing served as the WRB. This configuration was considered representative of typical practice that demonstrated successful use of foam sheathing with windows.

Together, the above four wall configurations were used to evaluate appropriate performance criteria with which to assess results from subsequent tests.

Evaluating Compressive Strength

Wall 5 was the same as Wall 4 except its XPS foam sheathing had a compressive strength of 25 psi. With 15 psi as the baseline compressive strength for all foam sheathing used, this wall specimen was used to evaluate what effect, if any, the compressive strength of the foam sheathing had on the installed window's performance. The results for this wall would be useful if any of the subsequent 15 psi XPS walls failed due to increased foam thickness because they could be used to predict whether a higher compressive strength product would pass.

Evaluating Foam Sheathing Support

Wall 6 was the same as Wall 4 except it did not have OSB inboard of the foam sheathing; i.e., the foam served as the exterior sheathing as well as the WRB. This was useful to evaluate the applicability of the common installation method for walls without OSB providing long-term support to the foam sheathing.

Evaluating Foam Type

Wall 7 consisted of a double-hung window installed over 1 in. of 15 psi EPS foam. Wall 8 was similar to Wall 7 except its windows were installed over 1 in. of 16 psi, foil-faced PIR foam. The same type of windows installed in Walls 1, 2, and 4 (double-hung, vinyl frame, double-pane, non-impact resistant) were installed in Walls 7 and 8 with the flange outboard of the rigid foam.

This compared the performance of the windows installed over different types of foams to determine if there was an appreciable difference when the compressive strength remains constant.

Evaluating Flange Type

Wall 9 was similar to Wall 4 except that the window had a different flange. Instead of the more rigid mounting flange in the previous window products, the window in Wall 9 was equipped with less robust flanges that had a primary function of positioning the window during installation rather than providing structural support. The purpose of this specimen was to determine how the flange type affects performance by comparing it to the benchmark specimen.

Evaluating Foam Thickness

Wall 10 had the same type of window as Wall 4, installed over 2 in. of 15 psi XPS foam, with the flange outboard of the foam sheathing. The results for Wall 10 were to be compared to the results for the Control and Benchmark specimens.

Evaluating Fasteners

The type of fasteners used to attach the CI to the OSB, and those used to attach the window through the CI to the framing members, depended on foam thickness. Fasteners used to attach the rigid foam sheathing penetrated the studs a minimum of 3/4 in., while fasteners used to install the window assembly penetrated the studs a minimum of 1-1/4 in. [NOTE: these penetration depths included the 7/16 in. OSB, as it was a nail-base sheathing]. Spacing for foam sheathing attachment followed the manufacturer’s requirements, while spacing of window fasteners was based on the results of previous exploratory testing that was agreed upon by the Advisory Group. The window spacing was chosen based on the size and the weight of the windows. The table below provides generic spacing recommendations.

Table 3. Fastener Spacing

Foam Sheathing Thickness	Spacing (3lb/SF window)	Spacing (9 lb/SF window)
1”	11.5” o.c.	3.5” o.c.
1.5”	8” o.c.	2.5” o.c.
2”	7” o.c.	2” o.c.

Wall 10 and Wall 11 evaluated the fastener types between wood screws versus cabinet screws for installing 3.5 in. fasteners over 2 in. CI.

Table 4. Fasteners

CI Thickness	CI Fastener	Window Fastener
1"	2" cap nail	2.5" roofing nail
1.5"	2.5" cap nail	3" roofing nail
2"	3" cap nail	3.5" screw

Evaluating Mulled Assemblies

Walls 12-14 evaluated the performance of mulled assemblies in comparison to single-unit installations, as well as the effects of significant additional weight.

Walls 12 and 13 had mulled window assemblies installed over 15-psi foam sheathing at the greatest thickness that had demonstrated acceptable performance in earlier tested assemblies. The window assembly in Wall 12 consisted of two tall casement windows joined by combination mullion. In Wall 13, two double-hung windows were joined by combination mullion. Fastener spacing for window installation followed the window manufacturer instructions.

Wall 14 was similar to Wall 13 except the window units had IR glazing in order to maximize the installed assembly's weight (9 psf for double-pane, IR, compared to 3 psf for double-pane, non-IR).

Evaluating Slider Windows and Additional Sill Support

Wall 15 evaluated the performance of a single slider window unit with two vents. Slider windows were of interest because they tend to carry more weight outboard of the mounting flange. The Advisory Group identified the slider windows as less structurally resilient because they were more likely to lose a sash if the frame twisted during wind loading.

2.3 Test Procedures

Water Penetration Test (E331 and E547)

For the step portion of the water penetration resistance test (shown in Figure 2), the window assembly was covered with a 6-mil poly film to exclude the effects of water leakage through the fenestration product and the wall specimen was installed in Home Innovation's wind-blown rain infiltration test chamber. The water spray system was turned on and the exterior face of the specimen was sprayed for 15 minutes; any visible water penetration was documented. The chamber was then pressurized with pressure load actuators (PLAs) to provide a pressure differential of 2.92 psf between the interior and exterior of the specimen while water continued to be sprayed on the specimen. This "step" lasted 15 minutes and any visible water penetration was documented. The pressure difference was increased two more times, to 3.76 psf and finally 5.43 psf (roughly 15% of DP (design pressure) for a PG35 window product), each lasted

15 minutes; the specimen was sprayed with water the entire time without disruption and any visible water penetration was documented. This allowed investigators to evaluate an installation's water penetration resistance during four discrete pressure steps: 0 psf; 2.92 psf; 3.76 psf; and 5.43 psf. These corresponded to standard testing pressures to achieve PG15, PG25, and PG35 ratings, respectively.

For the cyclic pressure portion of the water penetration resistance test, the chamber was depressurized, and the poly was removed from the window assembly. The specimen was then continuously sprayed with water and subjected to four 5-minute pressure cycles at 5.43 psf separated by 1-minute periods with no pressure difference (0 psf). Any visible water penetration during the pressure cycling was documented.

Evaluating water penetration is of interest as it shows the performance of continuous insulation as a WRB and how the continuous insulation interacts with the windows. The wall specimen did not have interior gypsum, back dam and any sealant in the sill area to observe the water penetration. Therefore, all these specimens had water penetration because the rough opening gap was not sealed. The purpose of the water penetration testing was to observe the difference in the level of water penetration between baseline wall specimen (non-CI walls) versus wall specimen with CI. The failure criteria for water penetration test is when the water starts pooling and overflowing on the interior face of the wall. The observations for each wall were compared to the baseline specimens (Wall 1, 2, 3, and 4) to see if the water penetration was excessive (overflowing) or different.

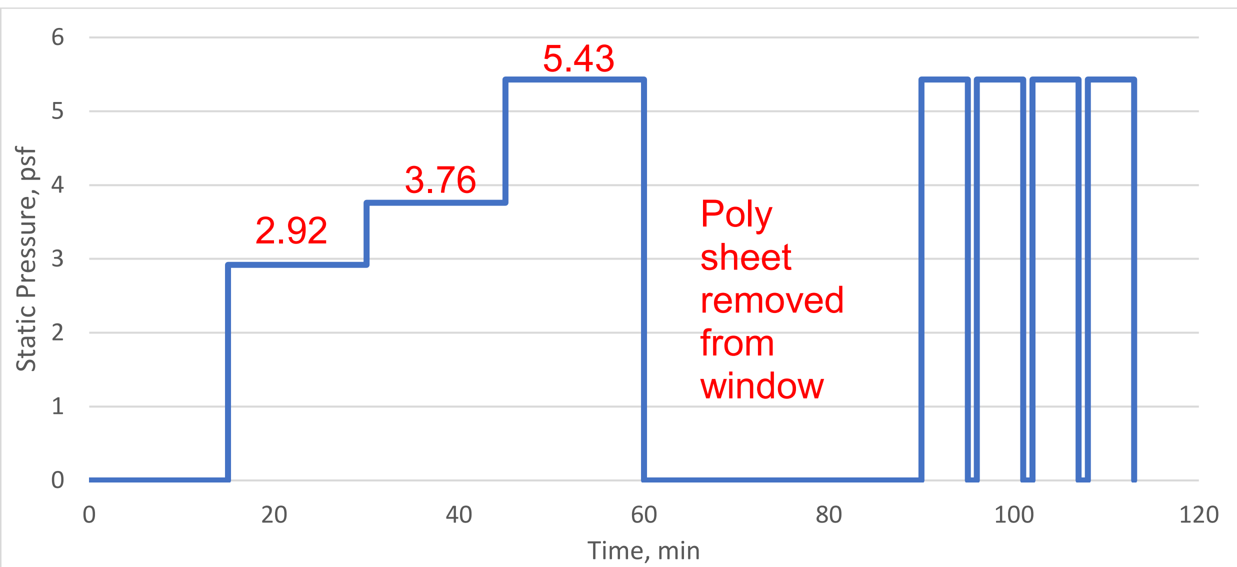

Figure 4. Water Penetration Resistance Protocol for PG25 and PG35 Rated Windows

Figure 5. Wind-Blown Rain/Air Infiltration Test Chamber for Air Leakage

Figure 6. Water Penetration Resistance Tests

Temperature Cycling (E2264, Method B, Level 1)

Wall specimens were installed in a heavily insulated Thermal Cycling Box and then subjected to 14 sixteen-hour durability (freeze-thaw) cycles. During the first half of a durability cycle, the temperature in the weather side of the box was lowered to 0°F. During the second half, the weather side was raised to 120°F. Note that AAMA 504 requires temperature cycling per ASTM E2264, Method A (infrared radiation), Level 1. This project used Method B (convective hot air) instead because Method A is intended for comparative product evaluations, while "Method B is intended for research and development purposes and not for comparative product evaluations" (ASTM E2264-05(2021)). In addition, the products of interest in this project (e.g., foam sheathing and interface with windows) were concealed in end use and in that condition would experience only temperature cycling. U/V resistance is primarily an issue for initial construction exposure, and this is addressed in U/V exposure pre-condition requirements for material tests, not assembly tests. The purpose of temperature cycling is to determine if this conditioning activity changes the outcome of the water penetration testing.

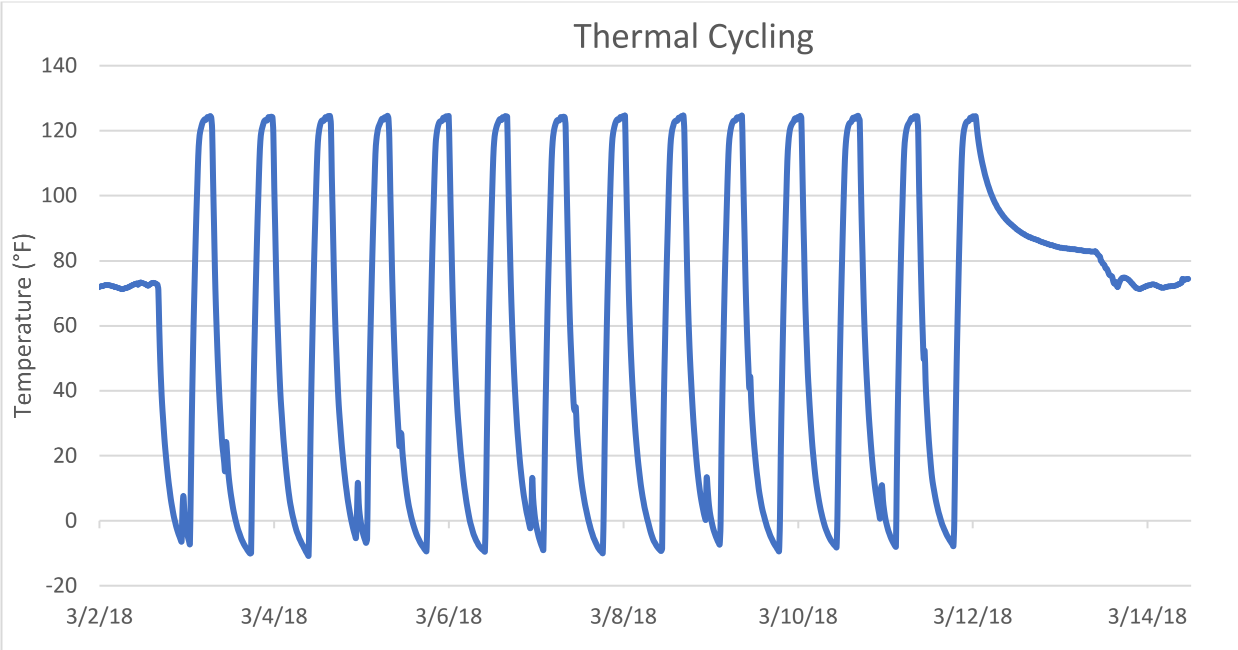

Figure 7. Freeze-Thaw Cycles, Approximately 16 Hours per Cycle

Vertical Displacement (Gravity Load) Monitoring

The wall specimens were left to stand in the laboratory for a period of six months. Dial gauges measured displacement at the bottom corners of the windows with respect to the base of each wall specimen over the course of the observation period.

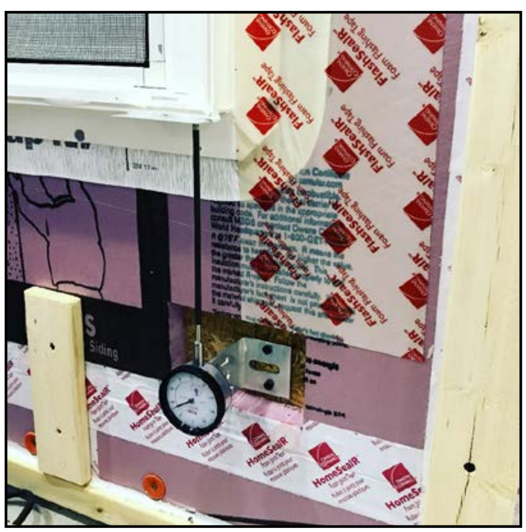

Figure 8. Measuring Vertical Displacement

Service-Condition Preloading

AAMA 504 has preloading before initial air leakage and water penetration resistance testing, but only requires that preloading be performed without stipulating a performance requirement. Wall specimens were mounted in an out-of-plane stress (OOPS) test frame. Pressure load actuators provided suction through hoses and diffusers for the wind pressure testing. The specimens were installed in the OOPS test frame with the rigid foam side facing away from the diffusers so that the negative pressure applied by the PLAs simulates positive pressure effects (i.e., inward force). Each specimen was subjected to 80% of design pressure.

Table 5. Load Tests

Load	Value	Magnitude		
		PG15 Window	PG25 Window	PG35 Window
Pre-Test Load	0.8 x DP	12 psf	20 psf	28 psf

Structural Performance Test (E330)

Wall specimens were mounted in an OOPS test frame. Pressure load actuators (PLAs) provided suction through hoses and diffusers for the wind pressure testing. The specimens were installed in the OOPS test frame with the rigid foam side facing away from the diffusers so that the negative pressure applied by the PLAs simulates positive pressure effects (i.e., inward force). Following the ASTM E330 procedure, each specimen was subjected to four distinct loads based on the North American Fenestration Standard (NAFS) structural test pressure (STP) for Class R windows. The structural performance test is to determine the operability of the window and any visible and structural changes to the wall itself.

Table 6. Load Tests

Load	Value	Magnitude		
		PG15 Window	PG25 Window	PG35 Window
Pre-Test Load	0.5 x DP	7.50 psf	12.50 psf	17.50 psf
Test Load (STP)	DP	15.00 psf	25.00 psf	35.00 psf
Pre-Proof Load	0.75 x DP	11.25 psf	18.75 psf	26.25 psf
Proof Load	STP = 1.5 x DP	22.50 psf	37.50 psf	52.50 psf

Figure 9. Structural Performance Test Frame

Figure 10. Pressure Load Actuators

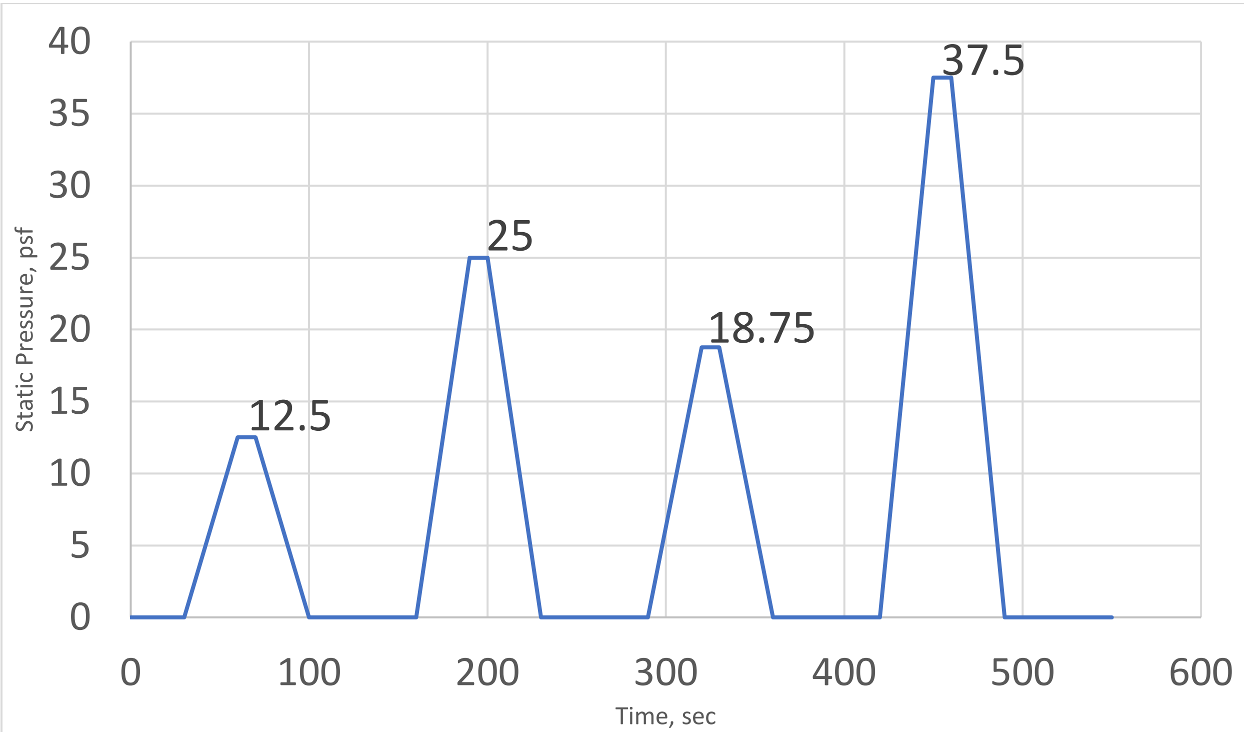

Figure 11. Structural Wind Loading Protocol

See Appendix D for the step-by-step laboratory procedures.

Performance Evaluation

Table 7 contains a summary of the performance requirements:

Table 7. Performance Evaluation

Test Protocols	Performance Evaluation
Initial water penetration resistance test	Report pressure and time if water penetration is observed.
Temperature cycling	Report observations.
Service-condition loading	Wind pressure loading at 80% DP. Report observations.
Service-conditioned water penetration resistance test	Report pressure and time if water penetration is observed.
Vertical displacement (gravity load) monitoring	Report maximum displacement.
Final water penetration resistance test	Report pressure and time if water penetration is observed.
Structural performance test	No damage to window assembly fastening system that prevents the window units from operating normally. Report observations.

Following the completion of laboratory testing and observation, this report served as a library of the specimen performance data. The analysis was used to develop and disseminate installation specifications and guidance that included performance-based limitations.

2.4 Measurements

The following measurements were taken:

- Water penetration: Only visual observation required.
- Vertical displacement: Dial gauges measured vertical displacement of the window frame relative to the test frame. Measurements were taken multiple times weekly over the course of six months.
- Structural Performance Test: After the structural testing, any permanent visual deformation of the window frames and sashes were noted, and sashes were opened and closed to check if a window was still operable.

2.5 Equipment

Table 8 lists all equipment used in the test and observation program.

Table 8. Equipment Used in the Test and Observation Program

Lab Test/Procedure	Equipment	Measurement
Water penetration	Wind-blown rain test chamber	
	Calibrated spray apparatus	
	Pressure load actuators	
	Computer system	Pressure regulation
Temperature cycling	Thermal Cycling Box	
	Thermocouples	Temperature at exterior and interior sides of specimen
	Relative humidity sensors	Relative humidity on interior side of specimen
	Computer system	Temperature regulation
Vertical displacement	Dial gauges	Vertical displacement at lower corners of window frames
Structural (wind) loads	Out-of-plane load test frame	
	Pressure load actuators	
	Computer system	Pressure regulation

3 Installation Method Changes for Phase II

Window manufacturers' instructions for installing directly on CI were not available when the project started. Manufacturers either recommended the ROESE method of installing windows with CI or did not include any instructions. So, the AG developed generic installation instructions for installing windows over CI. These generic installation instructions were used on all windows in Phase 1. (See Appendix D.) After testing 15 wall specimens (see Table 2), the team determined that the generic installation instructions for installing windows over CI were insufficient and lead to failure during the Structural Performance Test (ASTM E330). See Section 4 - Results for details.

Prior to starting the next phase of testing, Home Innovation and the American Chemistry Council (ACC) conducted exploratory testing to determine if installing windows on CI using a modification of manufacturer's installation instructions (described below) changed the results of the structural performance test. Based on the few tests that were carried out, the structural performance results for the windows showed improvement.

For Phase II, Home Innovation repeated Structural Performance Testing on wall samples with new installation methods. At this point in the project, Pella had added installation instructions on installing windows directly on CI. These instructions were used for the Pella windows.

For all other windows, the window manufacturer's instructions for a traditional OSB installation were modified by increasing the length of the fasteners by 1", to accommodate the CI while maintaining the fastener embedment length in the structural framing. Home Innovation installed all these windows directly on CI by following the window manufacturer's traditional OSB installation instructions in terms of fastener type, fastener spacing, and shimming details. The only modification to these installation instructions is that the fasteners will be one inch longer than what the manufacturer recommended for a traditional OSB installation. For example, if the manufacturer recommends using 1.5 in. roofing nails as fasteners, then 2.5 in. roofing nails were used.

A total of 10 windows were installed over 1-in. of CI for this next phase of testing. The same flashing details were used to install all these windows.

Table 9. CI and Flashing Details

Location	Details
Foam Joint Tape	Owens Corning HomeSealR (3" wide)
Sill Flashing	Dupont Flex Wrap (6" wide)
Jamb and Head Flashing	Owens Corning Foamular FlashSealR Tape (6" wide)
Furring Strips	3" nails

Three different types of windows were selected – single-hung, double-hung, and slider. The window sizes were selected to be large and, if possible, gateway sizes (size at which the window is qualified for its performance class). The PG rating for these windows ranged from PG20 to PG50. Five different manufacturers are represented in Phase II testing – Andersen, JELD-WEN, Pella, ReliaBilt, and United Window & Door.

Table 10. Window Specimens for Phase II Testing

#	Manufacturer	Series	1-in CI	Type	Dimension	PG Rating	Support	Fasteners
1	Andersen	100 Series	15-psi XPS	Single Hung	47.5" x 77.5"	PG50	CI & Flange	2.5" nail
2	Andersen	100 Series	15-psi XPS	Double Hung	42 5/8" x 72 3/8"	PG40	CI & Flange	2.5" nail
3	Andersen[1]	400 Series	15-psi XPS	Slider	71.5" x 59.5"	PG50	CI & Flange	2.5" nail
4	JELD-WEN	V-2500	15-psi XPS	Single Hung	47.5" x 71.5"	PG20	CI & Flange	3.5" cabinet screws
5	JELD-WEN	V-2500	15-psi XPS	Double Hung	47.5" x 77.5"	PG20	CI & Flange	3.5" cabinet screws
6	JELD-WEN	V-2500	15-psi XPS	Slider	71.5" x 59.5"	PG20	CI & Flange	3.5" cabinet screws
7	Pella	150 Series	15-psi XPS	Single Hung	39.5" x 71.5"	PG25	CI & Flange	3" nail
8	Pella	150 Series	15-psi XPS	Double Hung	47.5" x 77.5"	PG35	CI & Flange	3" nail
9	ReliaBilt	455	15-psi XPS	Double Hung	31.5" x 59.5"	PG20	CI & Flange	3" nail
10	United Windows & Door	5800	15-psi XPS	Slider	59.5" x 59.5"	PG20	CI & Flange	2.5" nail

[1]Note: This version of proposed wall type is not endorsed by the manufacturer given the number of variables involved to successfully install and have confidence in a properly performing product.

4 Results

The primary performance factors of interest in evaluating these wall specimens were (1) the observed water penetration at different points of the testing phase; and (2) the structural performance of windows over CI.

Evaluating water penetration was of interest as it shows the performance of CI as a WRB and how the CI interacts with the windows. The wall specimen did not have interior gypsum, back dam, or any sealant in the sill area to observe the water penetration. Therefore, all the specimens had water penetration because the rough opening gap was not sealed. The purpose of the water penetration testing was to observe the difference in the level of water penetration between the baseline wall specimen (non-CI walls) versus the wall specimen with CI. The failure criteria for the water penetration test is when water starts pooling and overflowing on the interior face of the wall. The observations for each wall were compared to the baseline specimens (Walls 1, 2, 3, and 4) to see if the water penetration was excessive (overflowing) or different.

The structural performance testing showed how the deflection due to wind loading at different points of the window DP (0.5 DP, 0.75 DP, 1.0 DP, and 1.5 DP) affected the structural components of the windows and their operability. See Appendix A for detailed observations of each test protocol for each wall assembly and their construction details.

Table 11. Results Matrix for Phase 1 Testing

#	Specimen	Water Penetration Test	Temperature Cycling Test	Service-Condition Loading Test	Vertical Displacement	Structural Performance Test
1	Housewrap and OSB – single DH (PG25)	✓	✓	✓	✓	✓
2	#15 felt and OSB – single DH (PG25)	✓	✓	✓	N/A	✓
3	ROESE w/ 1" XPS – single DH (PG25)	✓	✓	✓	N/A	✓
4	1" XPS (15 psi) – single DH (PG25)	✓	✓	✓	✓	×
5	1" XPS (25 psi) – single DH (PG25)	✓	✓	✓	✓	×
6	1" XPS (15 psi) w/o OSB – single DH (PG25)	✓	✓	✓	✓	×
7	1" EPS (15 psi) – single DH (PG25)	✓	✓	✓	N/A	×
8	1" PIR (16 psi) – single DH (PG25)	✓	✓	✓	N/A	×
9	1" XPS (15 psi) – single non-structural flange DH (PG 30)	✓	✓	✓	N/A	×
10	2" XPS (15 psi) – single DH (PG25)	✓	✓	✓	✓	×
11	2" XPS (15 mpsi) – single DH (PG25); cabinet screws as fasteners	✓	✓	✓	✓	×
12	2" XPS (15 psi) – mulled casement (PG15)	✓	✓	✓	✓	×
13	2" XPS (15 psi) – mulled DH (PG15)	✓	✓	✓	✓	×
14	2" XPS (15 psi) – mulled DH (PG35) - heavy	✓	✓	✓	✓	×
15	2" XPS (15 psi) – large slider (PG35)	×	✓	✓	N/A	×

4.1 Water Penetration Test Results

All specimens except for Wall 15 performed similarly in the water penetration resistance test. For these 14 specimens, the water bubbled when the pressure reached 3.76 psf or 5.43 psf during the step portions of the water test. In some specimens, slight pooling was observed at the sill region, however the water never overflowed from the sill to the interior face of the framing around the window. The water usually drained once the pressure dropped to 0 psf. For the cyclic portion of the water test, the water bubbled or slightly pooled at the sill when the pressure reached 5.43 psf. The water promptly receded as the pressure dropped back to zero. These observations were consistent for walls with and without CI. See Figure 12 and Figure 13 for detailed images of the observations.

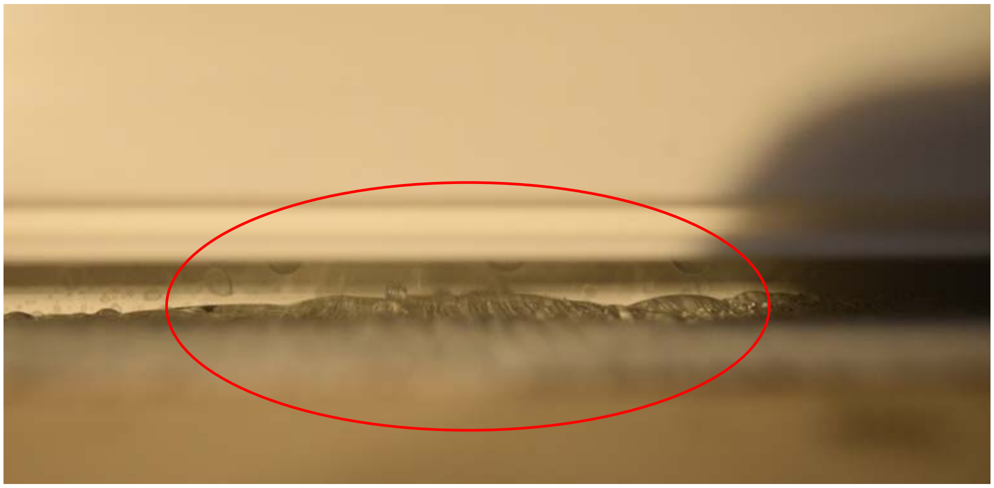

Figure 12. Slight Water Pooling at the Sill

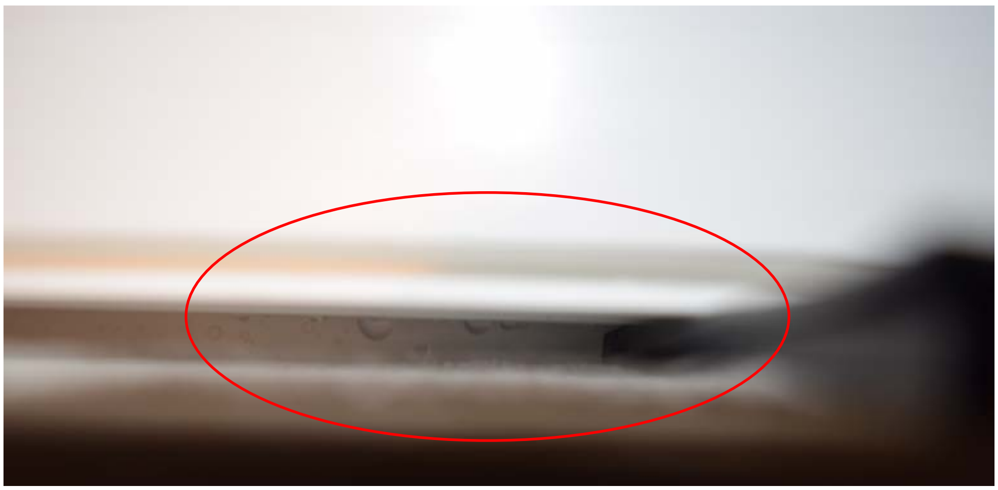

Figure 13. Water Bubbling at the Sill

For Wall 15, with the large slider window, there was a significant amount of water penetration at both the step and cyclic portion of the testing. The manufacturer provided a new window in case there was a factory defect, however the results were the same. See Figure 14 on the water leakage and pooling. The water pooled and overflowed from the slider rail region of the window assembly.

Figure 14. Water Pooling and Overflowing During the Water Test

4.2 Temperature Cycling Test Results

The results of the temperature cycling were consistent for all specimens. The results indicated that the temperature cycling had little to no effect on windows installed over foam sheathing. The water penetration tests were performed after temperature cycling showed no discernable trends.

4.3 Service-Condition Loading Test Results

The results of the service-condition loading were consistent for all the specimens except Wall 9 (non-structural flanged window installed over 1 in. XPS). The walls were loaded to 0.8 DP that is equivalent to 12 psf, 20 psf, 24 psf, 28 psf for windows with DP of 15 psf, 25 psf, 30 psf, and 35 psf, respectively. The water penetration tests were performed after the service-condition loading test and did not affect the walls' performance.

For Wall 9, the window experienced a structural failure when it was loaded to 24 psf in the positive direction. The window buckled at approximately 23 psf. The window sash had cracks and the sash was displaced from the window frame. Based on the 14 other walls tested, this failure is most likely unrelated to the foam sheathing. It could have been defect/damage caused during production or shipping.

Figure 15. Window Sash Damage

4.4 Vertical Displacement Results

During the six-month vertical displacement period, there was no visible degradation or deformation to the foam products, windows, flashing details, and fasteners used on the specimen. The maximum displacement observed was 0.032 in. for the mulled double-hung window installed over 2 in. of XPS. Based on the results of nine specimens, the vertical displacement period was not carried out for the remaining six specimens. Table 12 provides a summary of results per wall.

Table 12. Maximum Displacement During Six-Month Vertical Displacement Period

#	Specimen	Max. Displacement (in.)
1	Housewrap and OSB – single DH (PG25)	0.000"
2	#15 felt and OSB – single DH (PG25)	Not Applicable
3	ROESE w/ 1" XPS – single DH (PG25)	Not Applicable
4	1" XPS (15 psi) – single DH (PG25)	0.023"
5	1" XPS (25 psi) – single DH (PG25)	0.025"
6	1" XPS (15 psi) w/o OSB – single DH (PG25)	0.030"
7	1" EPS (15 psi) – single DH (PG25)	Not Applicable
8	1" PIR (16 psi) – single DH (PG25)	Not Applicable
9	1" XPS (15 psi) – single non-structural flange DH (PG30)	Not Applicable
10	2" XPS (15 psi) – single DH (PG25)	0.020"
11	2" XPS (15 psi) – single DH (PG25); cabinet screws as fasteners	0.025"
12	2" XPS (15 psi) – mulled casement (PG15)	0.022"
13	2" XPS (15 psi) – mulled DH (PG15)	0.032"
14	2" XPS (15 psi) – mulled DH (PG35) - heavy	0.016"
15	2" XPS (15 psi) – large slider (PG35)	Not Applicable

4.5 Structural Performance Test Results

For the initial 15 wall specimens, the results of the structural test presented a clear pattern between installing flanged double-hung windows directly over foam versus installing windows directly on wood sheathing or lumber.

Wall 1 (housewrap and OSB) and Wall 2 (#15 felt and OSB) had double-hung windows directly installed on the OSB sheathing. Both these windows functioned properly post-structural performance testing. There were no other structural failures. Similarly, Specimen 3 (ROESE with 1 in. of XPS) had a double-hung window installed on the 2x lumber. This window functioned properly post-structural performance testing.

However, there was a consistent operability failure for the double-hung windows that were installed directly on CI. During the negative pressure protocol portion of the structural test, where the foam was being pulled on, the sash of the window disengaged from the window's counterbalance mechanism. This disengagement caused the top sash of the window to slide down. Wall 8 (1 in. PIR) was slightly different as the bottom sash of the window disengaged from the counterbalance mechanism.

Figure 16. Normal Operation of Window Sash and Counterbalance Mechanism

Figure 17. Window Sash Popped Out from Counterbalance Mechanism

For the mulled double-hung windows (Wall 13 and Wall 14), the sash hook was slightly bent (see Figure 17), and it disengaged from the counterbalance mechanism. For Wall 14 (heavy window with 2 in. XPS), the counterbalance mechanism was disengaged in the mullion region as well.

Figure 18. Sash Hook Slightly Bent

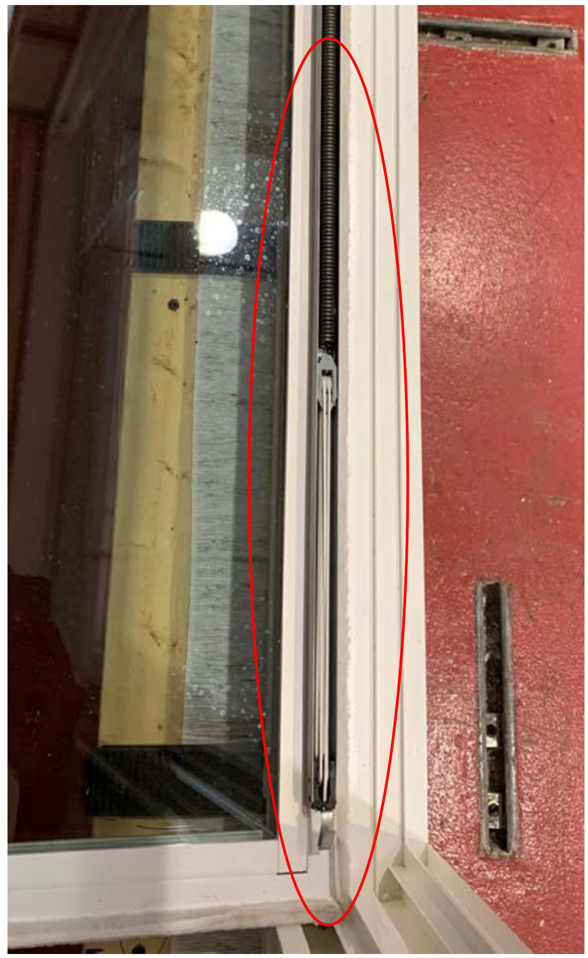

Figure 19. The Counterbalance Mechanism Fell When the Window Was Inspected.

For Wall 12 (casement window installed over 2 in. XPS), the window functioned properly post-structural performance testing. There were no other structural failures. This was the only casement window tested for this project.

For Wall 15 (large slider window installed over 2 in. XPS), the window experienced significant structural failure. The failure was observed at approximately 32.5 psf. See Figure 19 for photos of the structural damage. The slider window has two sashes – one stationary and one sliding. The glass broke from the stationary sash due to bending. The glass in the sliding sash did not break, but the sash popped out of the frame. During the final structural test, there was visible bending of the mullion (see Figure 19). This was the only slider window tested for this project.

Figure 20. Window Sash Popping Out of Frame

4.6 Structural Performance Test Results for Phase II

Nine of ten windows functioned properly post-structural performance testing.

Table 13. Results Matrix for Phase 2 Testing

ID-#	Specimen	Structural Performance Test
01	Andersen: 1" XPS (15 psi) – single DH (PG50)	✓
02	Andersen: 1" XPS – double DH (PG40)	✓
03	Andersen: 1" XPS – slider (PG50)	✓
04	JELD-WEN: 1" XPS – single DH (PG20)	✓
05	JELD-WEN: 1" XPS – double DH (PG20)	✓
06	JELD-WEN: 1" XPS – slider (PG20)	✓
07	Pella: 1" XPS – single DH (PG25)	✓
08	Pella: 1" XPS – double DH (PG35)	✓
09	ReliaBilt: 1" XPS – double DH (PG20)	✓
10	United Window & Door: 1" XPS – slider (PG20)	×

All single-hung and double-hung windows passed the structural performance test. For those windows, there were no failures related to the locking mechanism and counterbalance as previously evident in Phase I testing. The JELD-WEN slider (ID 06) and United Window slider

(ID 10) also passed the structural performance test. However, the Series 400 slider did not pass the structural performance test.

For the Andersen slider (ID 03) window, the sliding window unhinged from its sash and its locking mechanism during the positive pressure test. See Figure 20 for window damage. The window bowed-in significantly when the pressure was applied. The failure occurred around 60 psf as it was approaching the 75 psf (1.5 DP).

Figure 21. Window Being Pulled Off Its Sash

Given the Phase II results, it is evident that installing windows on CI while using window manufacturer installation instructions leads to less failure in structural performance tests, especially for the single-hung and double-hung windows. See Appendix D for generic installation instructions and Appendix A for details on construction and test results.

For all the slider windows, the deflection at the center of the window was more significant and noticeable than the for the other types of windows. This deflection may be caused by the lack of support for the center sashes of the slider windows. Potential solutions, which would require additional testing, may include fastener spacing reduction, different types of fasteners, masonry window clips, construction adhesive, foam sealant, stronger window flange material, or straps.

5 Discussion and Next Steps

This project was designed to evaluate the water penetration resistance, temperature cycling, and wind loading performance for windows installed in walls over CI. The research team collaborated with insulation and window manufacturers to assemble a test program, acquire the materials, and determine relevant construction details (e.g., flashing, fastener location, and spacing). The principal elements of the project were to use performance data to provide guidance, where possible, and to identify structural performance issues or limitations for installing windows over CI. The observations and conclusions below reflect the testing performed on a total of 25 windows. Phase I testing was conducted on 15 windows (see Table 2) and Phase II testing was conducted on 10 windows (see Table 8).

Phase I testing was conducted using generic installation instructions (see Appendix D) developed by the Advisory Group; however, Phase II testing was conducted by making a minor modification to the manufacturer's existing instructions (i.e., using longer fasteners to accommodate the thickness of the CI). Based on the improved test results in Phase II, we can reasonably conclude that modifying the specific manufacturer's instructions for a traditional OSB installation (by increasing the length of the fasteners by 1") is a better approach to integrating CI than developing a generic universal instruction for all window types.

As window manufacturers consider certifying their window installations over CI, the Phase II results illustrate a good starting point for testing; nonetheless, it must be noted that every existing window will not perform well as demonstrated by the Series 400 Slider window. In addition, window manufacturers understand the unique design features of their windows; as a result, they may prohibit the certain window types or series from being installed over walls with CI.

5.1 General Observations for Phase I

- All single double-hung windows installed directly onto lumber or over OSB passed all the test protocols.
- Based on the baseline walls (Walls 1, 2, 3, and 4), the criterion for passing the water penetration resistance test was bubbling or slight pooling of water at the sill that receded after the pressure was removed. Excessive leakage and/or water leaking to the interior face of the framing around the window constituted a failure.
- For most wall specimens, the test results showed that the use of foam sheathing did not affect the performance of the window for water leakage.
- All wall specimens underwent temperature cycling; the results indicated that the temperature cycling had little to no effect on the performance of windows installed over foam sheathing.
- For wall specimens that underwent six-month vertical displacement monitoring, the results showed that windows installed over foam sheathing did not sag over time.

- For the water penetration tests that were performed at various intervals of the test protocol, there were no trends showing that the water penetration test results were affected by either thermal cycling or service condition loading.
- The double-hung windows, rated at PG25, installed over foam sheathing passed all the test protocols except the final structural test under negative load only.
- The final structural test on double-hung windows, indicated that windows installed over foam sheathing did not experience obvious permanent deformation of the main frame, sash, sash member, leaf, or sill. However, testing revealed a specific and repeatable operability failure of the top sash of the double hung windows becoming dislodged from the counterbalance mechanism when subjected to 150% of the DP under negative load. These test results were consistent for the double-hung window installed over CI when tested for different attributes such as – foam sheathing types (XPS, EPS, PIR), thickness of foam (1 in. or 2 in.), compressibility of foam (15 psi, 16 psi, 25 psi), absence of OSB sheathing and using different types of screws.
- Testing of other brands of similar double-hung windows was not conducted to determine if the specific observed failure is common across other brands.
- For mulled double-hung windows installed over 2 in. of XPS and rated at PG35, the final structural test showed the same operability failure when the specimen was subject to 150% of the DP under negative load. The operability failure was consistent in the mullion region, as well.
- The mulled casement window installed over 2 in. of XPS passed all the test protocols. This was the only window rated at PG15.
- The large slider window installed over 2 in. of XPS did not pass any of the water penetration resistance tests or the final structural test. The window experienced structural failure when subjected to 150% of the DP under positive load. The moveable sash of the slider window popped out of the frame and the glass on the stationary sash broke.
- The single double-hung window with the non-structural flanges passed its initial water resistance test. This window experienced a structural failure when subjected to 80% of the DP under positive load during the service-condition loading protocol.
- These initial test results showed that the test protocols for Phase II could be condensed when testing windows installed directly over foam sheathing.

5.2 General Observations for Phase II

- All single-hung and double-hung windows passed the structural performance test when installed directly over CI by following the window manufacturer's installation instructions and increasing the fastener length by 1 in. to account for the 1 in. of CI. This is a significant improvement from the failures encountered in Phase I testing.
- For slider windows, two out of the three windows passed the structural performance test. All slider windows showed significant deflection (bowing) at the center of the window compared to single-hung or double-hung windows.

- The generic and manufacturer installation methods differed in the following construction details: type of fasteners, fastening patterns on the flanges, and window shimming details. The flashing details between the window and CI for the generic and manufacturer installation methods were similar and did not change the performance of the windows.

5.3 Next Steps

- Additional testing is required to determine methods to improve structural pressure performance of slider windows and mulled windows. Potential solutions, which would require additional testing, may include flange fastener spacing reduction, or using different types of fasteners, masonry window clips, construction adhesive, foam sealant, stronger window flange material, or straps.
- A potential series of tests focusing on the measurable deflection of the window frame and the sash could help better understand any operability issues and help identify how much deflection is required to cause the failure of the connection between the sash and counterbalance/sliding mechanism.

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Appendix A: Detailed Test Protocol Observations for Phase I

Specimen 1 – Housewrap and OSB – Single DH – PG25

Figure 22. Housewrap and OSB – Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
Continuous Insulation (CI): None
WRB and Fasteners: DuPont Tyvek HomeWrap with 1.5" cap nails
Sill Flashing: Vycor Flashing Tape
Head and Jamb Flashing: DuPont Flex Wrap NF
Window Fasteners: 1.25" nails
Furring Fasteners: 2" screws

Test Protocols	Observations
Initial water penetration resistance test	Leakage to interior face was observed at 3.76 psf for the step portion of the water penetration resistance test. The leakage was present at the sill region.
Temperature cycling	No leakage observed during the cyclic water test.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Leakage to interior face was observed at 3.76 psf for the step portion of the water penetration resistance test. The leakage was present at the sill region. No leakage observed during the cyclic water test.
Vertical displacement monitoring	No movement was observed. 0.0"
Final water penetration resistance test	No leakage observed during any of the water penetration resistance tests.
Structural performance test	Window opens and closes properly. No damage to window or WRB.

Specimen 2 – #15 Felt and OSB – Single DH – PG25

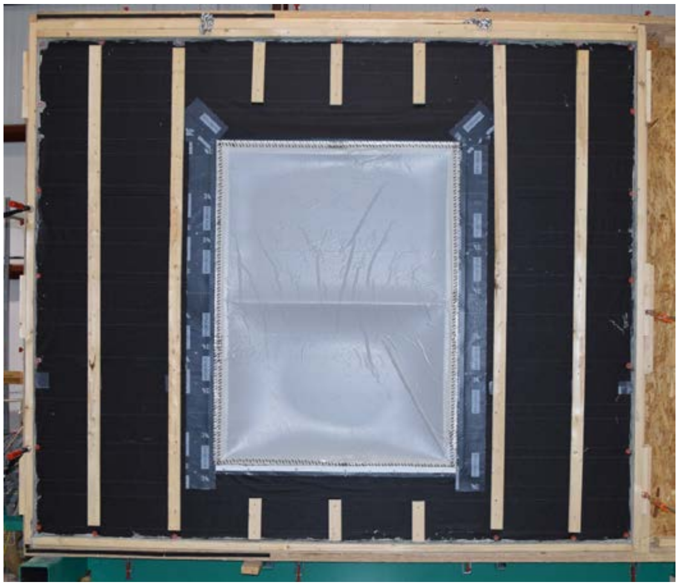


Figure 23. #15 Felt and OSB Undergoing Structural Performance Test

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
Continuous Insulation (CI): None
WRB and Fasteners: #15 felt paper with 1.5" cap nails
Sill Flashing: Vycor Flashing Tape
Head and Jamb Flashing: Vycor Flashing Tape
Window Fasteners: 1.25" nails
Furring Fasteners: 2" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 2.92 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 3.76 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Vertical displacement monitoring	Not applicable. Vertical displacement monitoring was not performed on this wall specimen based on results from other wall specimens.
Final water penetration resistance test	Not applicable. Vertical displacement monitoring not performed.
Structural performance test	Window opens and closes properly. No damage to window or WRB.

Specimen 3 – ROESE and OSB with 1-in. XPS – Single DH – PG25

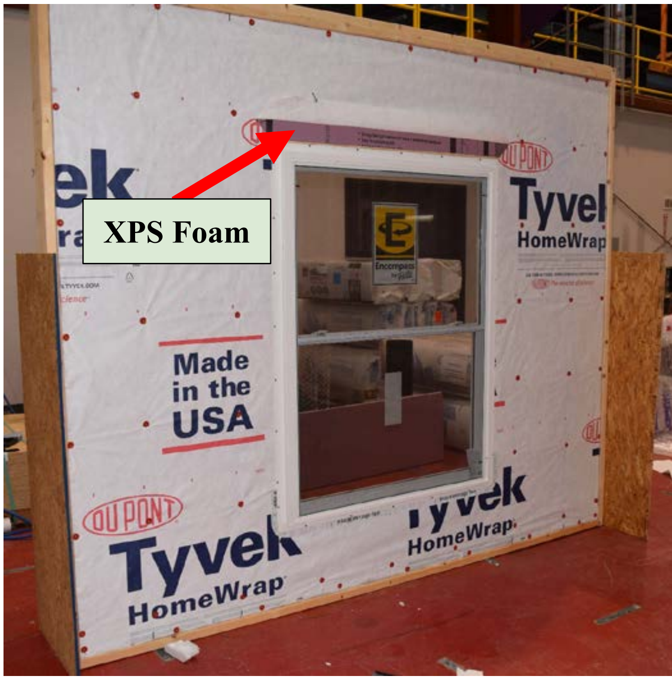


Figure 24. ROESE - XPS Foam and HomeWrap as WRB

Figure 25. ROESE – 2x Lumber Around Rough Opening

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
ROESE around perimeter
Continuous Insulation (CI): 1" of 15-psi XPS
WRB and Fasteners: DuPont Tyvek HomeWrap with 2" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: DuPont Flashing Tape
Window Fasteners: 2.5" nails
Furring Fasteners: 3" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 3.76 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 3.76 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Vertical displacement monitoring	Not applicable. Vertical displacement monitoring was not performed on this wall specimen based on results from other wall specimens.
Final water penetration resistance test	Not applicable. Vertical displacement monitoring not performed.
Structural performance test	Window opens and closes properly. No damage to window or WRB.

Specimen 4 – 1 in. of 15-psi XPS and OSB – Single DH – PG25

Figure 26. 1 in. of 15-psi XPS and OSB - Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
Continuous Insulation (CI): 1" of 15-psi XPS
WRB and Fasteners: Foam panels, seams taped with HomeSealR and 2" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 2.5" nails spaced 11.5" oc max
Furring Fasteners: 3" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 3.76 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 3.76 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Vertical displacement monitoring	Maximum total displacement: 0.023 in.
Final water penetration resistance test	Water bubbling under the sill at 3.76 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the double-hung window slides down after it is unlocked. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 5 – 1 in. of 25-psi XPS and OSB – Single DH – PG25

Figure 27. 1 in. of 25-psi XPS and OSB - Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5" **Continuous Insulation (CI):** 1" of 25-psi XPS **WRB and Fasteners:** Foam panels, seams taped with HomeSealR and 2" cap nails **Sill Flashing:** DuPont Flex Wrap NF **Head and Jamb Flashing:** FlashSealR and HomeSealR **Window Fasteners:** 2.5" nails spaced 11.5" oc max **Furring Fasteners:** 3" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test. No water bubbling or leakage observed during the cyclic water test.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test. No water bubbling or leakage observed during the cyclic water test.
Vertical displacement monitoring	Maximum total displacement: 0.025 in.
Final water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test. No water bubbling or leakage observed during the cyclic water test.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the double-hung window slides down after it is unlocked. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 6 – 1 in. of 15-psi XPS and no OSB – Single DH – PG25

Figure 28. 1 in. of 25-psi XPS and No OSB - Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
Continuous Insulation (CI): 1" of 15-psi XPS sheathing – no OSB sheathing
WRB and Fasteners: Foam panels, seams taped with HomeSealR and 2" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 2.5" nails spaced 11.5" oc max
Furring Fasteners: 3" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test. No water bubbling or leakage observed during the cyclic water test.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 2.92 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Vertical displacement monitoring	Maximum total displacement: 0.030 in.
Final water penetration resistance test	Water bubbling under the sill at 2.92 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the double-hung window slides down after it is unlocked. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 7 – 1 in. of 15-psi EPS – Single DH – PG25

Figure 29. 1 in. of 15-psi EPS - Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
Continuous Insulation (CI): 1" of 15-psi EPS
WRB and Fasteners: Foam panels, seams taped with 3M 8087 and 2" cap nails
Sill Flashing: Protecto Sill Pan Flash
Head and Jamb Flashing: BT20XL Butyl tape
Window Fasteners: 2.5" nails spaced 11.5" oc max
Furring Fasteners: 3" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test and the cyclic water test.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test and the cyclic water test.
Vertical displacement monitoring	Not applicable. Vertical displacement monitoring was not performed on this wall specimen based on results from other wall specimens.
Final water penetration resistance test	Not applicable. Vertical displacement monitoring not performed
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the double-hung window slides down after it is unlocked. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 8 – 1 in. of 16-psi PIR – Single DH – PG25

Figure 30. 1 in. of 16-psi PIR - Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5" **Continuous Insulation (CI):** 1" of 16-psi foil-faced PIR **WRB and Fasteners:** Foam panels, seams taped with 3M 8067 and 2" cap nails **Sill Flashing:** ZIP System Stretch **Head and Jamb Flashing:** ZIP System Stretch **Window Fasteners:** 2.5" nails spaced 11.5" oc max **Furring Fasteners:** 3" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 2.92 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 2.92 psf for the step portion of the water penetration resistance test. Water bubbling observed during the cyclic water test at 5.43 psf. There was no water pooling or any other leakage.
Vertical displacement monitoring	Not applicable. Vertical displacement monitoring was not performed on this wall specimen based on results from other wall specimens.
Final water penetration resistance test	Not applicable. Vertical displacement monitoring not performed.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The bottom sash of the double-hung window slides down when the window is opened. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 9 – 1 in. of 15-psi XPS – Single DH (Non-Structural Flange) – PG30

Figure 31. 1 in. of 15-psi XPS - Single DH (Non-Structural Flange)

Figure 32. Window Sash Damage

Wall Specimen Details
Rough Opening: 40" x 57"
Continuous Insulation (CI): 1" of 15-psi XPS
WRB and Fasteners: Foam panels, seams taped with HomeSealR and 2" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 2.5" nails
Furring Fasteners: 3" screws

Test Protocols	Observations
Initial water penetration resistance test	No water bubbling during the water penetration resistance test.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	Negative direction: No deformation or degradation of window observed. Positive direction: The window buckled at 23 psf. The window sash had cracks, and the sash was displaced from the window frame. The window had structural failures.
Service-conditioned water penetration resistance test	Not performed due to damage to window.
Vertical displacement monitoring	Not applicable. Vertical displacement monitoring was not performed on this wall specimen based on results from other wall specimens.
Final water penetration resistance test	Not applicable. Vertical displacement monitoring not performed.
Structural performance test	Not performed due to damage to window.

Specimen 10 – 2 in. of 15-psi XPS – Single DH – PG25

Figure 33. 2 in. of 15-psi XPS - Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
Continuous Insulation (CI): 2" of 15-psi XPS
WRB and Fasteners: Foam panels with seams taped and 3" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 3.5" screws spaced 7" oc max
Furring Fasteners: 4" screws

Test Protocols	Observations
Initial water penetration resistance test	No water bubbling or water leakage for the step portion of the water penetration resistance test. Water bubbling and slight pooling observed during the cyclic water test at 5.43 psf.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	No water bubbling or water leakage for the step portion of the water penetration resistance test. Water bubbling and slight pooling observed during the cyclic water test at 5.43 psf.
Vertical displacement monitoring	Maximum total displacement: 0.020 in.
Final water penetration resistance test	No water bubbling or water leakage for the step portion of the water penetration resistance test. Water bubbling and slight pooling observed during the cyclic water test at 5.43 psf.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the double-hung window slides down when the window is opened. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 11 – 2 in. of 15-psi XPS with Cabinet Screws – Single DH – PG25

Figure 34. Cabinet Screw Installed on 2 in. of 15-psi XPS - Single DH

Wall Specimen Details
Rough Opening: 48.5" x 64.5"
Continuous Insulation (CI): 2" of 15-psi XPS
WRB and Fasteners: Foam panels with seams taped and 3" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 3.5" cabinet screws
Furring Fasteners: 4" screws

Test Protocols	Observations
Initial water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test. Water bubbling and slight pooling observed during the cyclic water test at 5.43 psf. Water recedes once the pressure drops.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test. Water bubbling and slight pooling observed during the cyclic water test at 5.43 psf. Water recedes once the pressure drops.
Vertical displacement monitoring	Maximum total displacement: 0.025 in.
Final water penetration resistance test	Water bubbling under the sill at 5.43 psf for the step portion of the water penetration resistance test. Water bubbling and slight pooling observed during the cyclic water test at 5.43 psf. Water recedes once the pressure drops.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the double-hung window slides down when the window is opened. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 12 – 2 in. of 15-psi XPS – Mulled Casement Window – PG15

Figure 35. Mulled Casement Window on 2 in. of 15-psi XPS

Wall Specimen Details
Rough Opening: 72.5" x 72.5" **Continuous Insulation (CI):** 2" of 15-psi XPS **WRB and Fasteners:** Foam panels with seams taped and 3" cap nails **Sill Flashing:** DuPont Flex Wrap NF **Head and Jamb Flashing:** FlashSealR and HomeSealR **Window Fasteners:** 3-1/8" cabinet screws spaced 16" oc max **Furring Fasteners:** 4" screws

Test Protocols	Observations
Initial water penetration resistance test	No water bubbling in any water tests.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	No water bubbling in any water tests.
Vertical displacement monitoring	Maximum total displacement: 0.022 in.
Final water penetration resistance test	No water bubbling in any water tests.
Structural performance test	No deformation or degradation of window observed. Window is functional and operable.

Specimen 13 – 2 in. of 15-psi XPS – Mulled Double-Hung Window – PG35

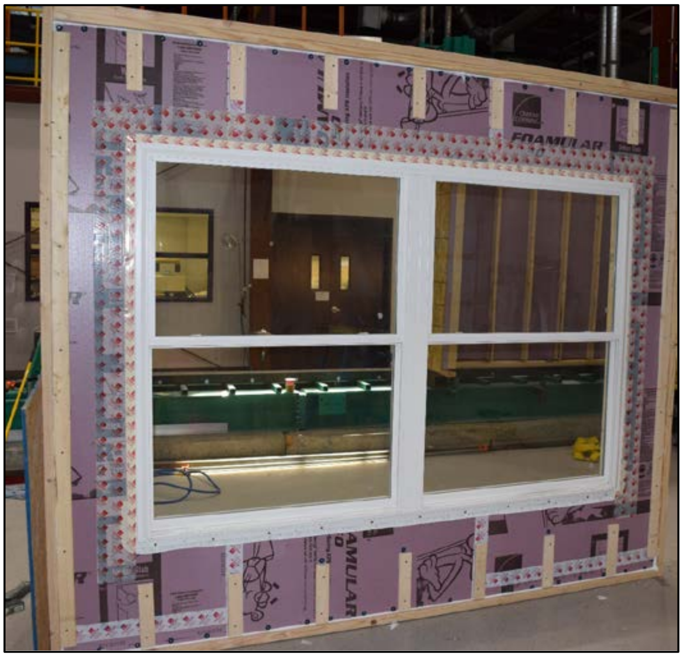


Figure 36. Mulled Double-Hung Window on 2 in. of 15-psi XPS

Wall Specimen Details
Rough Opening: 96.5" x 64.5"
Continuous Insulation (CI): 2" of 15-psi XPS
WRB and Fasteners: Foam panels with seams taped and 3" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 3-1/8" cabinet screws spaced 16" oc max
Furring Fasteners: 4" screws

Test Protocols	Observations
Initial water penetration resistance test	Slight water bubbling at 5.43 psf for both the step portion of the water penetration resistance test and the cyclic water test.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Slight water bubbling at 5.43 psf for both water tests.
Vertical displacement monitoring	Maximum total displacement: 0.032 in.
Final water penetration resistance test	Slight water bubbling at 5.43 psf for both water tests.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the window slides down when the window is opened. The counterbalance mechanism disengages from the balance key causing the top sash to slide down.

Specimen 14 – 2 in. of 15-psi XPS – Mulled Double-Hung Window, Heavy (IR glazing) – PG35

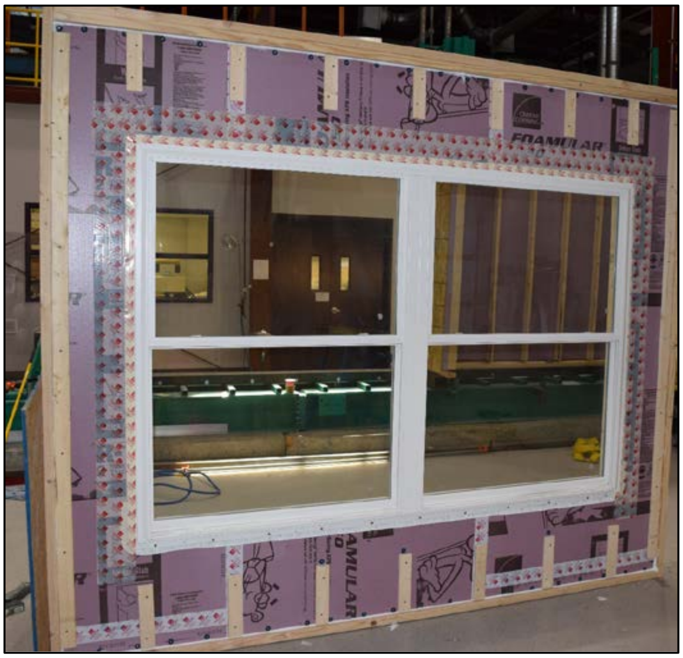


Figure 37. Mulled Double-Hung Window on 2 in. of 15-psi XPS

Wall Specimen Details
Rough Opening: 96.5" x 64.5"
Continuous Insulation (CI): 2" of 15-psi XPS
WRB and Fasteners: Foam panels with seams taped and 3" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 3-1/8" cabinet screws spaced 16" oc max
Furring Fasteners: 4" screws

Test Protocols	Observations
Initial water penetration resistance test	Slight water bubbling at 5.43 psf for both the step portion of the water penetration resistance test and the cyclic water test.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Slight water bubbling at 5.43 psf for both water tests.
Vertical displacement monitoring	Maximum total displacement: 0.016 in.
Final water penetration resistance test	Slight water bubbling at 5.43 psf for both water tests.
Structural performance test	Positive direction: No deformation or degradation of window observed. Negative direction: The top sash of the double-hung window slides down when the window is opened. The counterbalance mechanism disengages from the balance key causing the top sash to slide down. At the mullion region, there is damage to the balance key mechanism and damage to the sash hook. The counterbalance mechanism in the mullion region fell out.

Specimen 15 – 2 in. of 15-psi XPS – Large Slider Window – PG35

Figure 38. Large Slider Window

Figure 39. Window Sash Popping Out of Frame

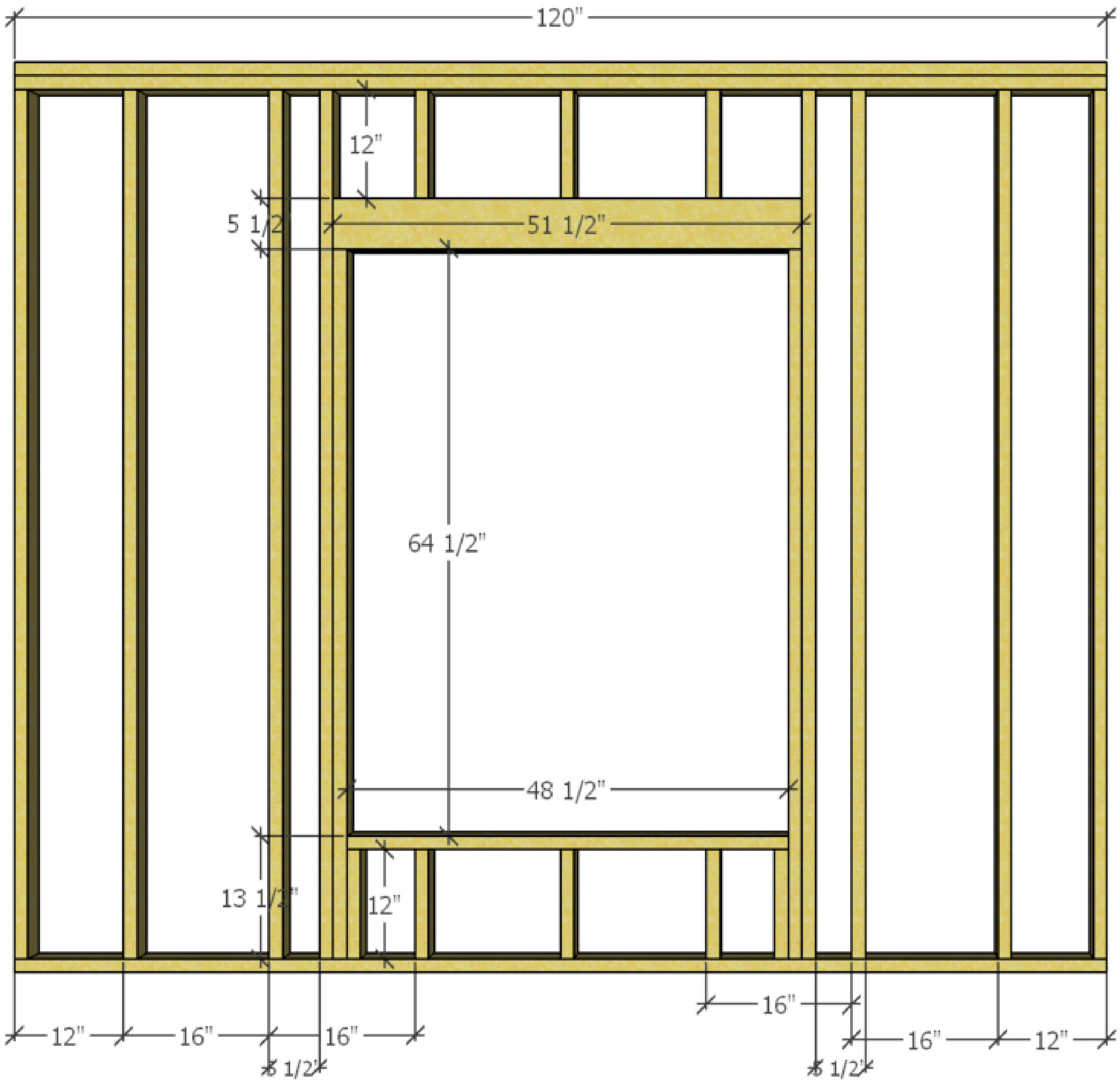
Figure 40. Water Pooling and Overflowing During the Water Test

Wall Specimen Details
Rough Opening: 72.5" x 72.5"
Continuous Insulation (CI): 2" of 15-psi XPS
WRB and Fasteners: Foam panels with seams taped and 3" cap nails
Sill Flashing: DuPont Flex Wrap NF
Head and Jamb Flashing: FlashSealR and HomeSealR
Window Fasteners: 3-1/8" cabinet screws spaced 12" oc max
Furring Fasteners: 4" screws

Test Protocols	Observations
Initial water penetration resistance test	Significant amount of water pooling and overflowing at 5.43 psf for both the step portion of the water penetration resistance test and the cyclic water test.
Temperature cycling	No deformation or degradation of window observed.
Service-condition loading	No deformation or degradation of window observed.
Service-conditioned water penetration resistance test	Significant amount of water pooling and overflowing at 5.43 for both the step portion of the water penetration resistance test and the cyclic water test.
Vertical displacement monitoring	Not applicable. Vertical displacement monitoring was not performed on this wall specimen based on results from other wall specimens.
Final water penetration resistance test	Significant amount of water pooling and overflowing at 5.43 psf for both the step portion of the water penetration resistance test and the cyclic water test.
Structural performance test	Positive direction: Significant deformation and degradation of window observed. The glass shattered at 32.5 psf. The window sashed popped out of frame. Negative direction: Not performed as the window became inoperable.

Appendix B: Specimen Construction

Sample Wall Framing – Single Double-Hung Windows



Appendix C: Step-By-Step Laboratory Procedures

Table 14. Testing and Observation

Step	Test/Observation	Duration
1	Initial water penetration resistance test • Part 1: step pressure test at 0 psf, 2.92 psf, 3.76 psf, 5.43 psf • Part 2: cyclic pressure test; four cycles at 5.43 psf	90 minutes
2	Temperature cycling	12 days
3	Service-condition wind cycling (20 psf)	60 minutes
4	Service-conditioned water penetration resistance test (step and cyclic pressure tests)	90 minutes
5	Vertical displacement (gravity load) monitoring	6 months
6	Final water penetration resistance test (step and cyclic pressure tests)	90 minutes
7	Structural performance test (up to 37.5 psf)	20 minutes
Note: Moving a wall specimen from one step to the next (e.g., uninstalling it from the wind-blown rain chamber and moving it to the Thermal Cycling Box and installing it) will take 30–60 minutes per move.		

Procedure: Water Penetration Resistance Testing

Approximate Duration: 1 hour 30 minutes

Reference Procedure for Step Test: ASTM E331

1. A 6 mil poly sheet is taped over the window assembly to confine any possible penetration to the flange, flashing, and WRB interface.
2. The wall specimen is installed in the wind-blown rain/air infiltration test chamber.
3. The water spray system inside the chamber is turned on and adjusted to deliver 5 gal/sf•hr.
4. The exterior surface of the specimen is sprayed for 15 minutes.
   A. The specimen is inspected for water penetration around the window assembly installation (interface between flange, flashing, and WRB).
   B. Water penetration is recorded.
5. The blower is turned on, and the pressure differential is increased to 2.92 psf as read from the inclined manometer while the exterior surface of the specimen continues to be sprayed for 15 minutes.

   A. The specimen is inspected for water penetration around the window assembly installation (interface between flange, flashing, and WRB).

   B. Water penetration is recorded.

6. The pressure differential is increased to 3.96 psf while the exterior surface of the specimen continues to be sprayed for 15 minutes.

   A. The specimen is inspected for water penetration around the window assembly installation (interface between flange, flashing, and WRB).

   B. Water penetration is recorded.

7. The pressure differential is increased to 5.43 psf while the exterior surface of the specimen continues to be sprayed for 15 minutes.

   A. The specimen is inspected for water penetration around the window assembly installation (interface between flange, flashing, and WRB).

   B. Water penetration is recorded.

8. The water spray system and blower are turned off.

Reference Procedure for Cyclic Test: ASTM E547

1. The 6 mil poly covering the window assembly is removed.

2. The water spray system inside the chamber is turned on and adjusted to deliver 5 gal/sf•hr.

3. The blower is turned on, and the pressure differential is increased to 5.43 psf as read from the inclined manometer while the exterior surface of the specimen continues to be sprayed for 5 minutes.

   A. The specimen is inspected for water penetration around the window assembly installation (interface between flange, flashing, and WRB).

   B. Water penetration is recorded.

4. The blower is turned off while the exterior surface of the specimen continues to be sprayed for 1 minutes.

   A. The specimen is inspected for water penetration around the window assembly installation (interface between flange, flashing, and WRB).

   B. Water penetration is recorded.

5. Steps 3 and 4 are repeated three more times for a total of four 5-minute cycles of water spray at 5.43 psf pressure differential separated by 1 minute of no pressure while the specimen continues to be sprayed.

   A. During each cycle, the specimen is inspected for water penetration and any penetration is recorded.

6. The water spray system and blower are turned off, and the specimen is removed from the test chamber.

Procedure: Temperature Cycling

Reference Procedure: ASTM E2264 Method B Level 1

Approximate Duration: 7 days (14 12-hour durability cycles)

1. A Thermal Cycling Box is built that will accommodate the wall specimen size.
2. Thermocouple and relative humidity sensors are attached to both wall specimen surfaces.
3. The specimen is installed in the Thermal Cycling Box with the rigid foam side facing the cold side of the hot box.
4. Air velocity, relative humidity, and temperature sensors are connected to the computer control system.
5. Power is provided to the heaters and fans, and the coolant lines are connected.
6. The computer control system actuates the chiller and heaters in order to control the temperatures of both sides of the hot box during each durability cycle.
   A. First half of durability cycle (six hours)
      a. The chiller lowers temperature in the box to 0°F, and then switches off to allow the cold side to return to 73°F.
   B. Second half of durability cycle (six hours)
      a. The heaters raise the temperature in the box to 120°F, and then switch off to allow the hot side to return to 73°F.
7. The process is repeated 13 more times, i.e., a total of 14 12-hour durability cycles.

Note: The temperature cycling covered in this procedure is approximate due to the transient heat transfer through the wall specimen.

Procedure: Service-Condition Wind Loading

Reference Procedure: ASTM E330

Approximate Duration: 60 minutes

1. The wall specimen is installed in the OOPS test frame with the rigid foam side facing away from the diffusers.
2. PLAs are connected via hoses to the diffusers so as to provide negative pressure loading (suction).
3. The computer control system actuates the PLAs.
   A. The PLAs provide 20 psf (= 0.8 x DP for PG25 window) of suction for 10 seconds.
   B. The load is removed (0 psf) for a 60-second recovery period.
   C. The load/recovery process is repeated for a total of 10 rounds.

4. The PLAs are turned off.
5. The wall specimen is removed from the test frame and flipped so that the rigid foam side is facing toward the diffusers.
6. The computer control system actuates the PLAs.
    A. The PLAs provide 20 psf of suction for 10 seconds.
    B. The load is removed (0 psf) for a 60-second recovery period.
    C. The load/recovery process is repeated for a total of 10 rounds.
7. The PLAs are turned off, and the specimen is removed from the test frame.

Procedure: Vertical Displacement Monitoring

Reference Procedure: Visual Observation

Approximate Duration: 6 months

1. Digital dial gauges are installed on each wall specimen to measure vertical displacement of the bottom corners of the window assembly in relation to the base of the wall specimen.
2. Multiple measurements are recorded daily by lab staff.

Procedure: Structural Performance Testing for PG 25

Reference Procedure: ASTM E330

Approximate Duration: 20 minutes

1. The wall specimen is installed in the OOPS test frame with the rigid foam side facing away from the diffusers.
2. PLAs are connected via hoses to the diffusers so as to provide negative pressure loading (suction).
3. The computer control system actuates the PLAs.
    A. The PLAs provide 12.5 psf of suction for 10 seconds (pre-load).
    B. The load is removed (0 psf) for a 60-second recovery period.
    C. The PLAs provide 25 psf of suction for 10 seconds (DP).
    D. The load is removed (0 psf) for a 60-second recovery period.
    E. The PLAs provide 18.75 psf of suction for 10 seconds (pre-proof load).
    F. The load is removed (0 psf) for a 60-second recovery period.
    G. The PLAs provide 37.5 psf of suction for 10 seconds (proof load/STP).
    H. The load is removed (0 psf) for a 60-second recovery period.

4. The PLAs are turned off and the wall specimen inspected.
    A. The window assembly fastener system is inspected for damage that prevents the windows from operating normally.
    B. Permanent deformation of the window frame is measured and recorded.
5. The wall specimen is removed from the test frame and flipped so that the rigid foam side is facing toward the diffusers.
6. The computer control system actuates the PLAs.
    A. The PLAs provide 12.5 psf of suction for 10 seconds (pre-load).
    B. The load is removed (0 psf) for a 60-second recovery period.
    C. The PLAs provide 25 psf of suction for 10 seconds (DP).
    D. The load is removed (0 psf) for a 60-second recovery period.
    E. The PLAs provide 18.75 psf of suction for 10 seconds (pre-proof load).
    F. The load is removed (0 psf) for a 60-second recovery period.
    G. The PLAs provide 37.5 psf of suction for 10 seconds (proof load/STP).
    H. The load is removed (0 psf) for a 60-second recovery period.
7. The PLAs are turned off and the wall specimen inspected.
    A. The window assembly fastener system is inspected for damage that prevents the windows from operating normally.
    B. Permanent deformation of the window frame is measured and recorded.
8. The wall specimen is removed from the test frame.

Appendix D: Generic Installation Instructions for Phase I

Per AAMA 504 requirements, each 120” x 100” wall specimen will consist of a 2” x 6” perimeter buck with 2” x 4” framing members spaced 16” oc. Framing members are joined with 3” drywall screws spaced 16” oc for stud-to-stud fastening and 12” oc for plate-to-plate fastening. 7/16” OSB sheathing is attached to the framing with 1-5/8” screws 12” oc. Unless otherwise noted, one 48” x 64” rough opening is centered on each wall specimen; each rough opening has a 2” x 4” sill, double 2” x 6” header, and crippled studs above and below.

Notes:

Specimen 1 has one double-hung window installed directly onto housewrap and OSB sheathing.

Specimen 2 is the same as Specimen 1 except that the water-resistive barrier will be #15 felt instead of housewrap.

Specimen 3 has a ROESE installed around the perimeter of the rough opening. The ROESE consists of 2 x 4s attached vertically, exterior to the OSB.

Specimen 4 has 1” of 15-psi XPS foam installed exterior to the OSB.

Specimen 5 has 1” of 25-psi XPS foam installed exterior to the OSB.

Specimen 6 has 1” of 15-psi XPS and no OSB.

Specimen 7 has 1” of 15-psi EPS foam installed exterior to the OSB.

Specimen 8 has 1” of 16-psi foil-faced PIR foam installed exterior to the OSB.

Specimen 9 has 1” of 15-psi XPS foam; the window will have less robust flanges.

Specimen 10 has 2” of 15-psi XPS foam installed exterior to the OSB using 3.5” screws.

Specimen 11 has 2” of 15-psi XPS foam installed exterior to the OSB using 3.5” **cabinet screws**.

Specimen 12 has a mulled window assembly; the rough opening will measure 48” x 72” to accommodate two tall casement windows.

Specimen 13 has a mulled window assembly: the rough opening will measure 96” x 60” to accommodate two large double-hung windows.

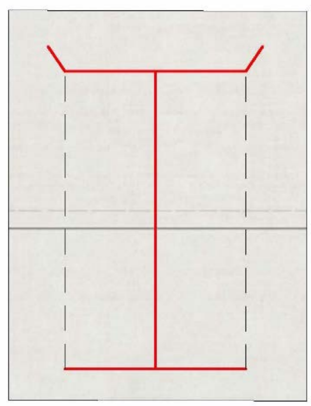
Specimen 14 is the same as Specimen 12 except that the window units will have triple-pane, impact-resistant glazing and will thus weigh more than twice as much.

Specimen 15 has one large sliding window.

Step 1: Water-Resistive Barrier

All window assemblies will be installed with the WRB applied prior to window installation, and head and jamb flashing applied over the face of the mounting flange (similar to ASTM E2112 **Method A1** procedures).

Specimen 1 has Tyvek HomeWrap (3-ft height) fastened horizontally onto the OSB with cap nails spaced 6” oc. The first layer spans the bottom of the wall, and top layer overlaps the layer below by 6”. The HomeWrap is rolled directly over the window rough opening. Horizontal seams are not sealed (the Tyvek is not installed as an air barrier). The HomeWrap is cut along the red line (8” diagonal cuts at the window head), the jamb flashing is folded in, and the head flashing is folded up and taped in place temporarily with Tyvek tape. The #15 felt WRB in Specimen 2 is installed in similar fashion.



Specimen 3 has rigid foam sheathing installed exterior of the WRB and a ROESE around the perimeter of the rough opening. Per Method A in the FMA/AAMA/WDMA Standard 500-16, Tyvek Home Wrap is installed exterior to the rigid foam sheathing *and* the ROESE following the same steps used to install the Home Wrap in Specimen 1.

Specimens 4–16 employ the rigid foam sheathing as the WRB. The rigid foam panels are installed vertically, exterior to the OSB sheathing with fasteners that penetrate the framing member a minimum of 3/4”. The fasteners used to install the foam sheathing depend on the thickness of foam to be installed on each specimen. (Note: Specimen 5 does not have OSB; the foam sheathing is attached directly to the framing members). Vertical furring strips are used to hold down the WRB (wrap, felt, or foam) during the positive wind loading portion of the service-condition cycling (step 3 in the test protocol) and structural performance testing (step 7). The furring strips are 1 x 3s and are attached exterior of the WRB to the studs using screws spaced 16” oc. Screw length will vary with the thickness of the WRB, but will penetrate the OSB sheathing and stud a minimum of 1-1/4”. Wall framing layout is such that there are furring strips within 6” of the window jamb flanges (see sample diagram at the end of this Appendix).

Foam Sheathing Thickness	Foam Sheathing Installation Fastener	Furring Strip Fasteners
None	N/A	2” screws
1”	2” cap nail	3” screws
1.5”	2.5” cap nail	3.5” screws
2”	3” cap nail	4” screws
3”	4” screws	5” screws

The foam panels’ seams are sealed using the manufacturer recommended tape in accordance with the product’s evaluation report. Examples include:

3M 8087 tape for Atlas ThermalStar LCi EPS panels (ESR-1962)

WEATHERMATE construction tape for Dow STYROFOAM XPS panes (ESR-2142)

R-SEAL construction tape for Rmax Thermasheath-3 polyiso panels (ESR-1864).

For all specimens, the perimeter edge of the specimen buck is sealed to the exterior face of the WRB using the manufacturer recommended tape (Tyvek tape for Specimen 1).

Step 2: Pan Flashing

Pan flashing is installed at the rough opening sill. The flashing tape is cut 12” longer than the rough opening’s width so that it extends 6” each jamb. The sill flashing extends 2” out onto the exterior surface of the foam sheathing. This type of sill flashing is commonly known as the drainage installation method.

WRB Product	Window Sill Flashing Product
DuPont Tyvek HomeWrap	DuPont FlexWrap NF
#15 asphalt	Vycor Flashing Tape
ThermalStar LCi EPS	Protecto Sill Pan Flash
STYROFOAM XPS	WEATHERMATE Straight Flashing
Thermasheath-3 polyiso	R-SEAL 600

Step 3: Perimeter Sealant and Mounting

Many (though not all) window manufacturers call for a continuous 3/8" bead of OSI QUAD Max window sealant to be applied to the interior face of the mounting flange at the head and jambs immediately before mounting the window. When used, sealant is not applied on the interior face of the flange at the sill in order to avoid trapping incident water from draining. For this test program, sealant is not used behind the flange in order to test the most conservative configuration.

The window assembly is mounted into the rough opening, and shims are installed at the sill and on both jambs to ensure the assembly is level and square. Sill shims are installed 3/4" from each side, underneath the mullion, and spaced no more than 18" oc. Jamb shims are installed 1" from the top and bottom of the rough opening, at the midpoint, and as needed elsewhere (e.g., at any required anchors directly through the window frame to rough opening framing). Manufacturer installation instructions shall be followed with regard to shim placement. In some cases, if a structural flange is used on the window unit, shimming may not be required. In other cases, window sills may be placed directly on the rough opening sill as a preferred method of continuous support for window sills. Shims under vertical mullions span the full width of the mullion.

Step 4: Window Fastening

The steel fasteners used to install the window assembly penetrate the studs (and OSB sheathing) a minimum of 1-1/4". The fastener length must account for the foam sheathing thickness installed on each specimen.

Foam Sheathing Thickness	Window Assembly Installation Fastener	Spacing (3 lb/SF window)	Spacing (9 lb/SF window)
None	1.25" roofing nail	manufacturer	manufacturer
1"	2.5" roofing nail	11.5" oc	3.5" oc
1.5"	3" roofing nail	8" oc	2.5" oc
2"	3.5" screw	7" oc	2" oc
3"	4.5" screw	TBD	TBD

Once the window assembly is level, two fasteners are driven into the pre-punched location at both top corners of the mounting flange. After the window assembly is confirmed plumb and square, fasteners are driven at the lower corners, at the mullions, at mid jambs, and then every other pre-punched fastener hole. (Note: Spacing may never exceed manufacturer maximum.)

Step 5: Jamb and Head Flashing

Jamb flashing is installed over the exterior face of both jamb flanges, extending 2” above both the window head flashing and below the sill flashing. Then, head flashing is installed on top of and 1” beyond the jamb flashing. Example products include:

WRB Product	Window Head/Jamb Flashing Product
DuPont Tyvek HomeWrap	DuPont Flashing Tape
#15 asphalt	Vycor Flashing Tape
ThermalStar LCi EPS	BT20XL Butyl tape
STYROFOAM XPS	WEATHERMATE Straight Flashing
Thermasheath-3 polyiso	R-SEAL 600

Step 6: Finishing Details

For Specimens 1 and 3 (employing Tyvek HomeWrap as the WRB), the tape previously holding up the HomeWrap flap above the head is removed. The flap is flattened, and Tyvek tape is used seal the diagonal seams to the head flashing. The #15 felt paper WRB in Specimen 2 is cut flush to the rough opening so there is no flap at the head.

For Specimens 4–15 (employing the sealed rigid foam insulation as the WRB), one strip of the tape used to seal the foam panel seams is used to seal the top of the head flashing to the rigid foam insulation. This final piece of tape extends beyond the end of the head flashing.

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