

# Fenestration Performance Testing Within the Building Envelope

By David Stammen

There are many factors to consider when incorporating fenestration products into a building envelope design. Aesthetics certainly play an important role in the design function for an architect or building owner, but building performance and appropriate installation play the critical roles. Improvements in codes and standards, as well as a greater focus on design principles, have contributed to significantly improving the performance of fenestration systems and their interaction within the building envelope. There are many aspects of fenestration performance to consider, such as resistance to water penetration, air leakage, and wind load resistance. Additional considerations are performance against debris impacts (hurricane-prone regions), thermal issues, security, acoustics, and many more. Fortunately, there are many ways to help ensure proper performance of these products throughout the design and in-service life cycle. *Figure 1* describes the path from code requirements, through performance testing, and then finally to the results that are typically provided to support these products within the industry.

Fenestration products can be analyzed and tested well before being purchased and installed, but they can also be tested during the installation phase on the building itself, and even field tested once the building has

been occupied and is in use. These three phases of testing, as shown in *Figure 2*, can provide greater assurance of achieving long-term performance within the building envelope when these products are properly specified and considered.

Within the United States and Canada, code requirements reference industry standards to establish performance requirements and test methods for fenestration products used within the building envelope. In the United States, the International Code Council (ICC) requires—through chapter 17 the International Building Code (IBC) and Chapter 6 of the International Residential Code (IRC)—that window and door assemblies be tested and labeled as conforming to AAMA/WDMA/CSA 101/I.S.2/A440, except that doors are still allowed an exception

to only be structurally tested if applicable. Canada requires—through the National Building Code of Canada (NBC) and within Part 5 and Part 9—that windows, doors, and skylights only be tested, not labeled, to the requirements in AAMA/WDMA/CSA101/1.S.2/A440 and CSA A440S1 (Canadian Supplement).

The standards mentioned above are the performance specifications or requirements for how these products are to perform and/or be rated; however, the test methods to evaluate laboratory, mock-up, and field performance are typically established by the American Society for Testing and Materials (ASTM) and the American Architectural Manufacturers Association (AAMA) for both countries.

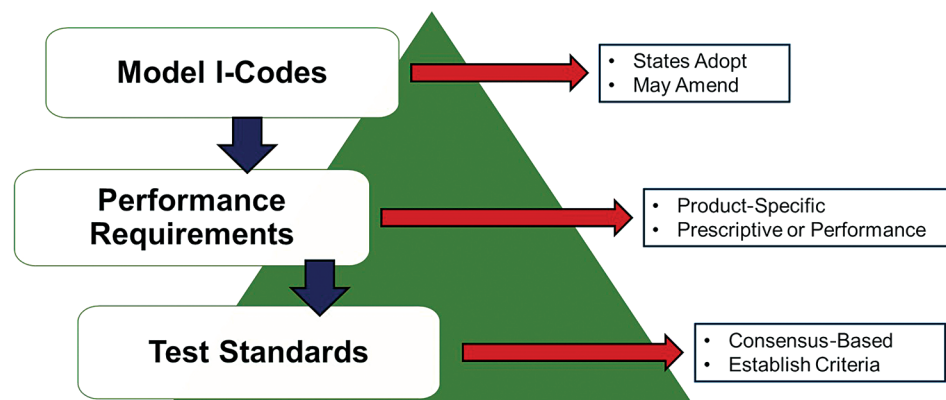


Figure 1 – Codes and related testing with results.

## Phases of Testing

### 1. Products Tested in the Lab

- Tested are windows, doors, curtainwalls, louvers, and skylights.
- Tested for ability to perform under weather conditions
- Tested to meet the building codes and market requirements

### 2. Preconstruction Mock-up Testing of Exterior Wall Systems

- Tested are exterior wall systems, including windows, doors, curtainwalls, concrete, steel, brick, glazing, and sealants.
- Tested to meet the requirements of the architect to determine that the system will meet requirements and materials will work together

### 3. Installed Windows Tested in the Field

- Tested are windows, doors, curtainwalls, and glazing after installation.
- Tested to verify proper installation and air- and watertightness

Figure 2 – Three phases of testing.

## LABORATORY TESTING

The building science laboratories where these fenestration products are tested are busy with air cycling experiments, water exposure simulations (as shown in Figure 3), and lumber impacts. These tests are significant in determining whether the fenestration products and design will perform once in a building and exposed to outside conditions such as wind, rain, natural weather events, heat, cold, and even flying debris. Laboratory tests are carried out to measure certain material properties, component and system durability and performance, and methods of assembly and installation.

Material testing is usually considered since these properties will play a role in the final component or assembly performance. Assembly or component testing in the lab helps to provide a better understanding of product design and performance, but it is still recommended that full-system tests be conducted for a more complete assessment. These system tests can be carried out on full-size prototypes, comprising both fenestration elements and portions of an exterior wall, in order to determine the performance of the full system assembly prior to construction and installation.

Laboratory tests are aimed at assessing the conformity of

materials, components, and/or systems, and they must be carried out according to standard procedures. For results and conclusions to be accepted in the United States and Canada, and since this is a requirement of the building codes, testing must be conducted by an accredited lab in order to provide assurance that the testing lab is independent, nonbiased, and that the testing facility has the appropriate equipment and

competent personnel to conduct and manage the tests. Accreditation is an official recognition and acknowledgment that an organization is competent to conduct conformity assessments and to determine whether products, services, or systems meet applicable standards.

The following is a list of the primary industry specifications, with air, water, and structural standards being the most commonly used to establish the laboratory performance criteria for fenestration products within North America.

**AAMA/WDMA/CSA 101/I.S.2/A440:** *NAFS – North American Fenestration Standard/Specification for Windows, Doors, and Skylights –*

Primarily outlines laboratory performance requirements with regard to water penetration resistance, air leakage resistance, and wind load resistance for windows, doors, and skylights in the United States and Canada.

**CSA A440S1:** *Canadian Supplement to AAMA/WDMA/CSA 101/I.S.2/A440, NAFS – North American Fenestration Standard/Specification for Windows, Doors, and*



Figure 3 – Water penetration lab test per ASTM E547.



Figure 4 – Mock-up test conducted at laboratory.

*Skylights* – Outlines simplified methods for calculating minimum performance levels for resistance to water penetration, wind loads, and snow loads for fenestration products on buildings in Canada, and must be used in conjunction with NAFS above.

- It is important to note that these two standards do not apply to storefronts, window walls, curtainwalls, and other glazed structures. However, for those products, the 2015 Canadian Building Code does specify the use of calculations detailed in CSA A440S1 to determine the minimum performance requirements for resistance to water penetration.

**ASTM E283:** *Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across*

*the Specimen* – Test method and procedure for determining the air leakage rates of fenestration assemblies and curtainwalls using a pressure differential applied across the test specimen.

**ASTM E547:** *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference* – Test method for determining the resistance to water penetration of fenestration assemblies and curtainwalls using a pressure differential applied across the test specimen.

**ASTM E330:** *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference* – Test method for determining the structural performance of fenestration assemblies and curtainwalls using a pressure difference from a test chamber.

## PRECONSTRUCTION MOCK-UP TESTING

Prior to installing the first window or door, or laying the first bricks or blocks of a well-thought-out architectural design, a preconstruction mock-up test (Figure 4) is an excellent means to evaluate air resistance, water resistance, structural integrity, and even thermal performance of fenestration and curtainwalls in order to validate installation, design, workmanship, and material selection of the complete envelope system. This testing allows building owners, architects, consultants, and manufacturers to represent the actual elements that will be used in the final work, as well as focus on specific areas such as the compatibility of the fenestration systems to the wall interface. This mock-up testing also allows for the actual contractors to install and become familiar with the products, as well

as the methods of installation, with the goal of ensuring a long-lasting and aesthetically pleasing building envelope construction.

Prior to testing a mock-up, it is imperative that the owners, building consultants, and contractors discuss design and installation details, since this is the crucial information that defines the mock-up construction. This information will also be used to document any remedial changes to the design or installation during the actual construction, as well as during the testing phase.

As it is required for laboratory and field testing to be conducted by an accredited lab, it is also important that mock-up testing be completed by an independent AAMA-approved testing agency, ensuring the lab is experienced with the required tests and approved by the owner.

AAMA 501, as shown below, is the principal industry guide specification that is most commonly used to establish the mock-up performance for wall systems, which includes fenestration assemblies within the United States.

**AAMA 501: Methods of Test for Exterior Walls** – Primarily outlines laboratory methods, specifications, and field checks with regard to resistance to water penetration, air leakage resistance, and wind load resistance for wall systems. Fenestration assemblies are also included under this method when they are installed as part of the exterior wall system.

The following test methods and standards are either referenced within the AAMA 501 guide or additionally used to evaluate mock-up performance:

- Air infiltration as per ASTM E283
- Water penetration under static pressure as per ASTM E331
- Water penetration using dynamic pressure as per AAMA 501.1
- Vertical interstory movements as per AAMA 501.7
- Structural performance as per ASTM E330
- Seismic and wind-induced interstory drifts as per AAMA 501.4
- Thermal cycling as per AAMA 501.5
- Condensation resistance testing
- Seismic drift causing glass fallout testing as per AAMA 501.6
- Anchor bolt testing
- Washer bolt testing
- Acoustical performance per AAMA 1801

## FIELD TESTING

In the building science arena, too often we see great material, product, and component designs do well under laboratory testing, only to have difficulties when installed and in service within the final building envelope. The most common problems are attributed to excessive air leakage, as well as water intrusion, which is most often due to the interface with the adjacent wall construction and the envelope's ability to perform as an integrated system. Laboratory testing is an excellent means of under-

standing individual product performance but does not always allow for a complete understanding of how the product will perform in combination with transitions or other integrally connected wall components. These interfaces are often the most critical elements of the individual product installation and may not have been fully validated by limited testing in the lab.

Actual field testing of fenestration products and its interaction with the building envelope can provide a good understanding of how the building is truly intended

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Figure 5 – Dynamic water penetration field test as per AAMA 501.1.

to function as an integrated system, while identifying sources of problems and providing information on how to mitigate or remediate those problems. It also helps to provide assurance for the building owners, contractors, and architects that the products perform after they have been installed. So, when considering field testing, it is important to identify the areas that are most representative of the building design, as well as including critical interface connections of fenestration products with the building envelope wall assembly. It should also be considered that field testing can be conducted at different stages of construction, or even years after in-service use.

The following is a list of the industry specifications and standards that are commonly used to establish the field performance criteria for installed fenestration products and their interaction with the building envelope within North America.

**AAMA 502:** *Voluntary Specification for Field Testing of Newly Installed Fenestration Products* – Outlines field performance requirements with regard to resistance to water penetration and air leakage resistance for windows and glass doors for use in the U.S.

**CAN/CSA-A440.4:** *Field Testing of Window and Door Installations* – Outlines field performance requirements with regard to resistance to water penetration and air

leakage resistance for windows and doors for use in Canada.

**ASTM E783:** *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors* – Outlines the test method for field measuring air leakage through installed exterior windows and doors. This test method is also used for measuring air leakage through curtainwall systems.

**ASTM E1105:** *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference* – Outlines the test method for the field determina-

Figure 6 – Interior chamber for field test.



tion of water penetration of installed exterior windows, curtainwalls, and doors.

**AAMA 501.1:** *Standard Test Method for Water Penetration of Windows, Curtain Walls and Doors Using Dynamic Pressure* – Outlines the equipment, procedures, and requirements for lab and field testing of exterior windows, curtainwalls, and doors for water penetration using

dynamic pressure (Figure 5).

When testing to any of the four test methods above, the approved laboratory will need to create a pressure differential by erecting a test chamber on either the interior or exterior side of the test specimen (see Figure 6), to simulate wind pressure. A minimum of three test sequences should be used: at the beginning of a project, midway through, and near the end of the project when conducting for quality control.

Another means of evaluating air leakage around the fenestration products, or the interaction with the building envelope in the field, is by means of smoke infiltration/exfiltration testing. This test is conducted by applying a pressure differential of 75 Pa

(1.57 psf) and using a portable smoke generator, then checking for any visible smoke through or around the product as well as the installation, depending on the direction of the pressure being used.


Full-scale testing used for research purposes is currently being conducted at the Insurance Institute for Business and Home Safety (IBHS), where their mission is to create stronger and more resilient building structures.<sup>1</sup> This allows for the next step in research and overall system performance to be tested and evaluated on a full building structure, to include all of the fenestration and exterior building envelope systems acting in unison.

### SUMMARY AND CONCLUSION

The building code requirements and methods of testing for evaluating fenestration performance and the interaction these products have within the building envelope can be determined in multiple ways. Three primary methods used within our industry today are 1) laboratory testing on representative samples of manufactured products, 2) testing a full mock-up within the lab or on a field mock-up at the jobsite, or 3) evaluating their performance after being installed within the field.

Whatever method is required or utilized, it is helpful to understand the full

requirements of the specification and standardized testing methods, or at least to enlist the expertise of those who are familiar with and conduct these tests on a daily basis. Fenestration assessment and evaluation are key to the overall building performance, so it is important to remember the following:

- 1) Ensure that performance of the window and wall systems that form part of the building envelope are evaluated by an accredited testing agency.
- 2) Laboratory performance testing to standardized test methods is typically conducted on materials and fenestration assemblies only.
- 3) Mock-up evaluations can provide quality assurance and an opportunity to remediate design changes prior to full construction.
- 4) Field testing on installed fenestration products within the building envelope can provide a more complete assessment of the overall construction. 

### REFERENCES

1. <https://disastersafety.org/about/>



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*Dave Stammen is the principal engineer for UL CLEB Building Science Group. He has over 25 years of experience designing and testing exterior building envelope products, and is active with development of building codes and test standards. He is a member of the American Architectural Manufacturers Association and ASTM International. Stammen's primary focus for UL covers the technical matters for building envelope performance testing for exterior building envelope products and materials.*