HOLES IN THE WALL:

WINDOW PERFORMANCE, INSTALLATION, AND FIELD QUALITY CONTROL STANDARDS

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INTRODUCTION

Holes in exterior walls enclosed with windows, doors, and other related components must be integrated with surrounding building envelope components to effectively separate the outdoor environment from interior conditioned space. At the most basic level, windows allow natural light into buildings and resist the passage of water and excessive air. Windows also limit sound and heat transfer into and out of buildings and, in some instances, are designed to protect building occupants from forced entry, hurricane-force winds, and/or explosions. Properly functioning windows must allow desirable elements to be transmitted through them (i.e., light) and limit the transmission of undesirable elements (i.e., air and water).

The in-situ performance of windows remains inferior to specified performance criteria in many instances due to inadequate detailing during the design phase, variation of window installation methods, and imperfect jobsite conditions. Air infiltration and water penetration through and around windows are two items commonly impacted by project-specific variables and window installation practices.

PERFORMANCE REQUIREMENTS

The American Architectural Manufacturers Association/Window and Door Manufacturers Association/Canadian Standards Association's (AAMA/WDMA/CSA's) 101/I.S.2/A440, *North American Fenestration Standard/Specification for Windows, Doors, and Skylights* (NAFS) is mandated by several modern building codes. Although a revised version of NAFS is anticipated to be published in 2017, the 2011 version is currently referenced in the 2015 versions of the International Building Code (IBC 2015) and International Residential Code (IRC 2015).

As defined within NAFS, window Performance Class roughly describes the likely target application for installed window products, ranging from single-family residential to high-rise commercial buildings. Current NAFS 2011 Performance Classes include R, LC, CW, and AW (*Figure 1*).

Performance Grade is a numeric designator that defines a set of performance requirements for a specific design pressure range. A window product achieves a Performance Grade designation upon successfully completing all applicable tests, primarily those for structural performance and resistance to air infiltration and water penetration. These required tests are performed on prototype window specimens in a controlled laboratory environment.

NAFS 2011 requires air infiltration testing to be performed in accordance with 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*; and water penetration testing to be performed in accordance with ASTM E547, *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference*; and/or ASTM E331, *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference*. Prototype test specimens are installed plumb, level, and square in a precise test buck opening in strict accordance with manufacturers' instructions. The required laboratory tests are used primarily to evaluate the performance of the fenestration product and are not intended

More Stringent Requirements ↓

Performance Class	
R	One- and two-family dwellings.
LC	Low-rise and mid-rise multi-family dwellings and other buildings where larger sizes and higher loading requirements are expected.
CW	Low-rise and mid-rise buildings where larger sizes, higher loading requirements, limits on deflection, and heavy use are expected.
AW	High-rise and mid-rise buildings to meet increased loading requirements and limits on deflection, and in buildings where frequent and extreme use of the fenestration products is expected.

Figure 1 – NAFS 2011 performance classes with descriptions used in helping to determine which class is suited for a particular application.

2.2 WINDOW PERFORMANCE REQUIREMENTS

A. Minimum NAFS Performance Class: <R, LC, CW, AW>
B. Minimum NAFS Performance Grade: <>
C. Thermal Transmittance (U-Factor): Maximum Whole Window U-Factor <>
D. Solar-Heat Gain Coefficient (SHGC): Maximum Whole Window SHGC <>
E. Sound Transmission Class (STC) or Outside-Inside Transmission Class (OITC): Minimum STC Rating or OITC Rating, as applicable <>
F. Condensation Resistance Factor (CRF): Minimum CRF Value <>

Figure 2 – Typical specification paragraph for window performance requirements.

to test performance of installation or perimeter seals.

Clearly, laboratory tests used to validate product performance ratings cannot account for excessive air infiltration and/or water penetration through or around in-service windows as a result of project-specific conditions or substandard installation practices. Even if installed in general accordance with manufacturer instructions and industry standards, in-service products are unlikely to find such ideal conditions as during laboratory testing. Handling prior to and during installation, acts of subsequent trades, and environmental conditions may all adversely affect installed product performance compared to published laboratory test results.

Window performance requirements are typically included in Part 2 – Products of the applicable project specification section. In addition to items related to thermal performance and sound transmission, window Performance Class and Performance Grade are typically specified (*Figure 2*).

Taken together, specifying the Performance Class and Performance Grade for windows provides a baseline for air infiltration and water penetration resistance requirements. However, since those requirements are not explicitly specified, some ambiguity regarding performance requirements remains. The following questions, among others, would remain unanswered:

- What is the maximum allowable air leakage at the specified positive test pressure? Although NAFS 2011 prescribes maximum allowable air leakage values for various products in different Performance Classes, actual performance of similar fenestration products can vary considerably.
- What is the specified water penetration test pressure? The Performance Grade rating for a product is sometimes limited by structural performance rather than water penetration resistance performance. In these cases, the tested specimen might have successfully passed a water penetration test at a pressure significantly greater than the minimum specified for the Performance Class and Performance Grade.
- What if mulled units are required for the project? Assemblies of two or more individual window units combined in the field without the manufacturer's involvement are typically not covered by NAFS 2011. Mulled units can either be tested as combination assemblies or with mullion performance tested separately in accordance with AAMA 450, *Voluntary Performance Rating Method for Mulled Fenestration Assemblies.*
- Is excessive deflection of window frame members a serviceability concern for the project? Deflection is not limited by NAFS 2011 for Performance Class R and LC windows.

The project team should adequately address these items during the design phase, and include appropriate accompanying installation and field quality control requirements within the specifications.

Figure 3 – Example of flanged window not installed in accordance with industry standard best practices.

INSTALLATION REQUIREMENTS

ASTM E2112-07 (2016), *Standard Practice for Installation of Exterior Windows, Doors, and Skylights*, is a consensus document maintained by ASTM International (ASTM). It acknowledges that window installation can significantly influence in-service performance of the units. Although ASTM E2112-07 (2016) defers to window manufacturers for product-specific installation instructions, it remains the default voluntary standard in cases where specific manufacturer recommendations are insufficient or otherwise not available. The document includes much useful information regarding the use of pan flashings, integration of weather-resistive barriers with flanged windows, and window installation best practices in wood-frame buildings (*Figure 3*), but it is not intended to be used as a project-specific resource. Stated within, the document is "intended to provide technical guidance to organizations that are developing training programs for installers of fenestration units in low-rise residential and light commercial structures."

Window installation requirements are typically included in Part 3 – Execution of the applicable specification section (*Figure 4*). Although well-intended, typical specification language often does not provide adequate window installation guidance. Drawings (and subsequent shop drawings) and specifications must clearly and definitively provide installation instructions to answer the following questions:

- How must windows be anchored to resist code-prescribed loads?
- How will windows be mulled to resist code-prescribed loads, and how will mulls resist air infiltration and water leakage?
- What sequencing will result in proper flashing and integration with adja-

3.2 WINDOW INSTALLATION

A. Comply with window manufacturer's written instructions for installing windows, hardware, accessories, and other components. Comply with ASTM E2112 for installation procedures and requirements not specifically addressed by manufacturer.
B. Install windows level, plumb, square, and anchored securely to the structure or supporting elements.
C. Ensure windows are integrated with adjacent construction and flashings, resulting in weathertight construction.

Figure 4 – Typical specification paragraph for window installation.

cent exterior wall components and flashings?

- Are pan flashings or subsills required, and if so, how should they be configured?
- What tolerances are allowable to account for imperfections or out-of-plumb fenestration openings?

The project team must clearly address these potentially unanswered questions prior to window fabrication, as relying on industry guidance and manufacturers' written instructions alone will typically not be sufficient. Preparing sequencing diagrams is a useful tool to resolve how many building components interface (*Figure 5*).

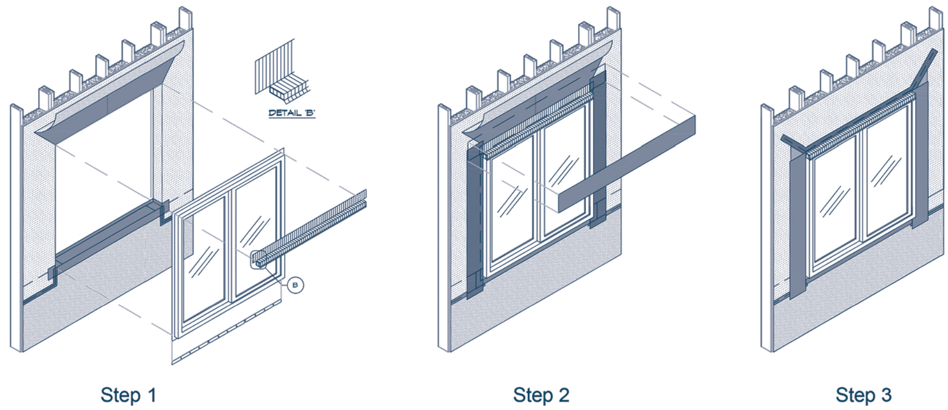

Figure 5 – Example of window installation sequencing diagram.

FIELD QUALITY CONTROL REQUIREMENTS

AAMA 502-12, *Voluntary Specification for Field Testing of Newly Installed Fenestrations*, is a consensus document maintained by AAMA. The AAMA 502-12 voluntary specification is used to verify air infiltration resistance performance and water penetration performance of newly installed window products.

Performing field quality control testing early during the project can prove beneficial in identifying window-related issues before they become overwhelming (*Figures 6* and *7*). Remedial work, if required, will be easier to implement early during a project than if the building has been substantially completed and is occupied.

Field quality control requirements for windows are typically included in Part 3 – Execution of the applicable specification section (*Figure 8*). Project specifications requiring windows to be tested for air infiltration and water penetration resistance according to AAMA 502-12, without inclusion of any additional project-specific requirements, stipulate the following:

- Three readily accessible windows shall be tested at locations chosen by the architect or owner's representative.
- Field test pressure for air leakage resistance tests shall be the same as laboratory test pressure designated in NAFS 2011. Allowable rate of air leakage during field testing shall be 1.5 times the applicable NAFS 2011 laboratory rate.

Figure 7 – Interior test chamber used to facilitate differential pressure across specimen.

Figure 6 – Calibrated water spray system used to perform field quality control testing.

> 3.3 FIELD QUALITY CONTROL
> A. Test windows for air infiltration and water penetration resistance according to AAMA 502-12.
> B. Prepare test and inspection reports.

Figure 8 – Typical specification paragraph for field quality control testing of newly installed windows.

- Field test pressure for water penetration resistance tests shall be performed at a static test pressure equal to two-thirds of the laboratory test pressure designated in NAFS 2011.
- Windows that do not pass air leakage and water penetration tests shall be repaired and retested. Remaining windows throughout the building shall be randomly checked for similar issues.
- An AAMA-accredited independent testing agency shall perform testing.

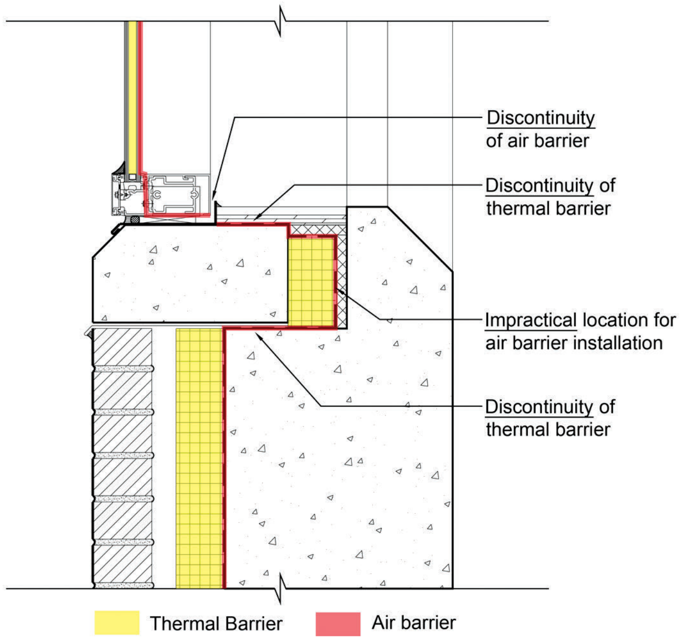

Figure 9 – Sketch demonstrating discontinuities of air and thermal barriers.

Specifications that solely reference AAMA 502-12 do not completely indicate requirements for quality control testing of installed windows. The following questions, among others, would remain unanswered:

- What specimens should be tested if there are several different window types and/or configurations at the building?
- Is the one-third reduction in test pressure for field testing a reasonable adjustment to account for variations inherent in a field test environment?
- Are additional tests required if retests of failed windows are also unsatisfactory?
- What entity is responsible for costs associated with additional testing and indirect costs associated with project delays?
- Does the owner have recourse in the case of continual window-testing failures?
- What if no local AAMA-accredited independent testing agencies are available to perform the testing?

The project team must clearly address these potentially unanswered questions before field testing commences.

Field Quality Control Requirements	
Quantity and types of windows to be tested	Determine how many specimens are required to establish a reasonable measure of quality for the entire project. The number of products tested, and the frequency of testing, should be clearly specified. Consider the need for testing different window types (casements, double-hung, etc.) and configurations (mulled assemblies, transoms, etc.). Testing only three windows may not be sufficient for large projects with many different window types and/or configurations.
Locations of windows to be tested	Clearly define field testing requirements in the project documents, including the number of tests and their locations. Proposed test locations are best graphically illustrated on the drawings. Determining which specimens to test is an important first step when planning field testing. The units chosen as test specimens should include typical perimeter joint and mullion conditions, in addition to atypical conditions.
Requirements for air leakage resistance testing	Determine if AAMA 502-12 default requirements are sufficient and/or appropriate. For some projects, including those that will require whole-building air leakage testing, more stringent requirements than those required by AAMA 502-12 (allowable rates of air leakage for the specimen shall be 1.5 times the applicable NAFS rate for the Product Type and Performance Class) may be advisable. In cases where the specimen has successfully passed laboratory air infiltration tests with leakage rates significantly less than the NAFS prescribed maximum allowable air leakage values, ensure field tests are performed to evaluate air leakage rates relative to the laboratory test rates.
Requirements for water penetration resistance testing	Determine if AAMA 502-12 default requirements are sufficient and/or appropriate. For some projects, higher test pressures than those required by AAMA 502-12 (two-thirds of the tested and rated laboratory performance test pressure as indicated by the applicable product designation in NAFS) may be advisable. In cases where the specimen has successfully passed a water penetration laboratory test at a pressure significantly greater than the minimum specified for the Performance Class and Performance Grade, ensure field tests are performed at static pressures appropriate for the relatively higher laboratory test pressures.
Procedures subsequent to failed tests	Although AAMA 502-12 suggests that "consideration should be given to the selection and testing of additional products," the document does not provide adequately specific guidance regarding protocols in the case of noncompliant tests. Specimens that do not pass air infiltration or water penetration tests should be adjusted, repaired, or replaced by the manufacturer and/or installer. Such windows should then be retested. Project specifications must clearly define whether additional testing is triggered in the case of failed tests, and the extent of such additional testing. Further, project specifications should clearly identify the party responsible for costs associated with the initial field testing, retesting, and any required forensic investigations.
Qualifications for testing agency	Clearly indicate whether testing must be performed by an AAMA-accredited independent testing agency, or if other qualified laboratory or consulting firms can be considered to perform testing. Define qualifications for field testing firms in the specifications to avoid uncertainties.

Figure 10 – Suggested field quality control requirements to include in project documents.

DESIGN CONSIDERATIONS TO IMPROVE IN-SERVICE WINDOW PERFORMANCE

Current building codes and industry standards include several significant informational holes and gaps regarding window performance, installation, and field quality control requirements. Careful detailing during the design phase and quality installation practices will improve the likelihood of acceptable in-service window performance. Inclusion of appropriately robust field quality control requirements within the project documents will likely also prove beneficial. Designers can take several steps during the design phase to increase the likelihood of satisfactory performance of window units during their service life:

1. Ensure continuity of air, vapor, water, and thermal barriers. Simple sketches can be used during design development to verify continuity of the various barriers (*Figure 9*).
2. Design pan flashings with properly sized upturned rear legs and end dams. Ensure details clearly illustrate how pan flashings integrate with air, vapor, water, and thermal barriers.
3. Drawings should be used to depict illustrative and quantitative project requirements. Specifications should be used primarily to indicate qualitative requirements. Thicknesses and configurations of materials and integration with surrounding construction are most appropriately shown on project drawings.
4. Consider the use of isometric details to illustrate conditions that cannot be depicted on two-dimensional drawings. Isometric details can be easily created in Sketchup or a similar graphical program by a qualified technician. These details can be exported to CAD or Revit® and be incorporated into the project drawings.
5. Include sequencing diagrams and/or interface drawings indicating substrate preparation; installation of the air, vapor, water, and thermal barriers; pan flashings; window installation; head and jamb flashings; etc. Such diagrams are best suited to be shown in isometric views.
6. Consider specifying factory-mulled units to the greatest degree possible. Windows can typically be shipped in large sizes with individual units mulled together to fit in a single fenestration opening.
7. Specify requirements for installation to the greatest degree practical. For projects where a window manufacturer has been selected in advance or the specifications include only a single product, provide accurate graphical depictions indicating installation requirements. The window manufacturer can be consulted regarding the use of strap anchors, through-jamb fastening requirements, etc. before project drawings and specifications are complete.
8. Specify field-constructed mock-up windows to be tested for air infiltration and water penetration resistance. Ideally, mock-up windows will satisfactorily pass required tests before the remaining windows for the project are procured. Project participants, including the designer-of-record, exterior wall consultant, manufacturer's technical representative, and general contractor should be present with the installer during mock-ups. Minor adjustments associated with window sizes and/or configurations can thus be made before the remaining windows are fabricated.
9. Clearly specify field quality control requirements, including quantity and types of windows to be tested, locations of windows to be tested, requirements for air leakage resistance testing, requirements for water penetration resistance testing, procedures subsequent to failed tests, and qualifications for the testing agency (*Figure 10*).

With demanding project schedules and budgets, designers must begin considering the above items early during the design process. Careful planning and project team collaboration can help ensure that holes in the wall will also serve as properly functioning windows upon project completion.

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