Considerations for Historic and Museum Windows

By Rachel C. Palisin and Richard W. Off

From the stained-glass windows that welcome variegated light into cathedrals, to the steel-framed geometric designs of Art Deco and the bold leaded glass of the Prairie style, windows have served to define the character of buildings and spaces since the advent of glazed fenestration. Not only do windows establish the aesthetics and ambiance of a structure, but they are also an integral part of the building enclosure.

More than ornament, windows serve a vital role in protecting a building from the elements, and in modulating the transfer of heat, moisture, and light from exterior to interior. This can be especially critical for museum environments, which often contain priceless works and artifacts that can be sensitive to temperature extremes, ultraviolet degradation, and humidity levels. In addition, the value of these objects presents added security concerns.

As windows age, their components are subject to the ravages of time and weather: sealant crumbles, wood decays, metal corrodes, glass deflects. If not properly maintained, historical windows are in danger of deteriorating to a point at which they become no longer salvageable. Even windows that have been carefully protected over the years may face performance demands that raise considerations regarding replacement with materials able to provide improved efficiency and durability. Determining a path for historic window treatment that balances aesthetics and historical integrity with contemporary performance

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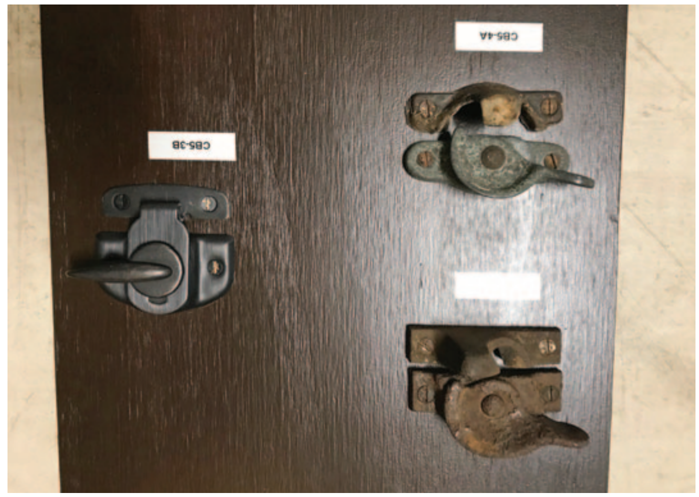
Meeting performance demands while preserving building character presents challenges for historical window projects.



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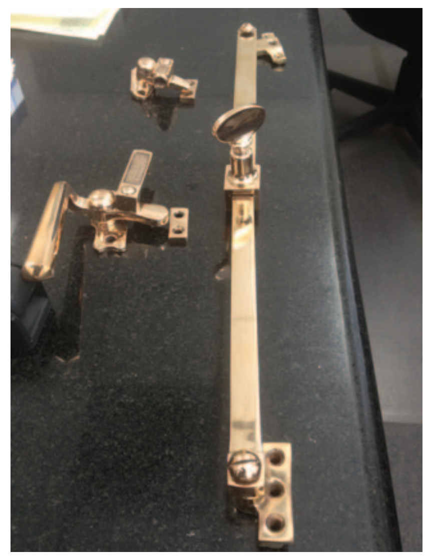

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Samples of original hardware (top) facilitate restoration and, where necessary, replacement. Existing historical hardware may be removed and restored (right), then re-installed (bottom).

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standards can be challenging, particularly if the windows are architecturally significant.

Through thoughtfully designed and executed repairs, some historic windows can provide performance gains that extend their lifespan and improve indoor comfort. When deterioration is advanced, however—or when there is a compelling need to modernize the assembly to meet current performance standards, or better protect and preserve precious objects within—replacement may be warranted. In such cases, careful consideration of materials and window design is critical to respecting historical character while meeting project requirements.

Decisions about wood frames versus metal or composite, insulating glazing versus single-pane, true divided lights versus applied muntins, and historical versus modern anchorage—among other considerations—require expert evaluation of the available options. Testing, both in the laboratory and in the field, is a valuable tool to verify performance and adjust the final design to meet the unique demands of the building and situation.

By applying the principles of window design with a sensitivity to the treatment of historic properties and museum environments, building owners and project teams can develop window-rehabilitation solutions that respect the original building fabric while providing lasting, reliable performance.

What Are the Key Principles?

Many of the performance requirements and standards that should be considered when approaching window-replacement projects are governed by code. For residential projects—including single-family homes and duplexes of not more than three stories—the *International Residential Code* (IRC) applies. For all other commercial and residential projects, the *International Building Code* (IBC) and *International Energy Conservation Code* (IECC) are the prevailing model codes.

Although replacement windows must comply with the performance standards outlined in these codes, in many jurisdictions, historic and landmark buildings are exempt, as long as such windows are replaced in kind, matching historical conditions. However, the IBC still requires that safety glazing be installed in potentially hazardous locations, such as windows at enclosed fire stairs. In general, performance requirements may be organized into three main categories: energy and thermal performance, structural considerations, and envelope integrity.

Energy and Thermal Performance

The thermal performance of a window is typically defined by **U-factor**, the measurement of how much heat is lost or gained in an assembly through radiation and conduction. The resulting numerical value, expressed in decimals, is the transfer rate of heat, divided by the difference in temperature, and is the weighted average of U-factors for the center of the glass, edge of glass, and window frame, as defined by the National Fenestration Rating Council (NFRC).

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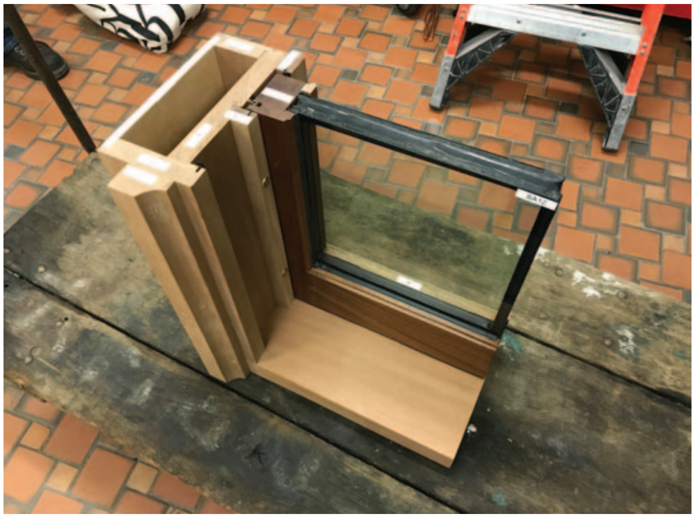

Visual mockups are useful in historical window projects to verify aesthetics.

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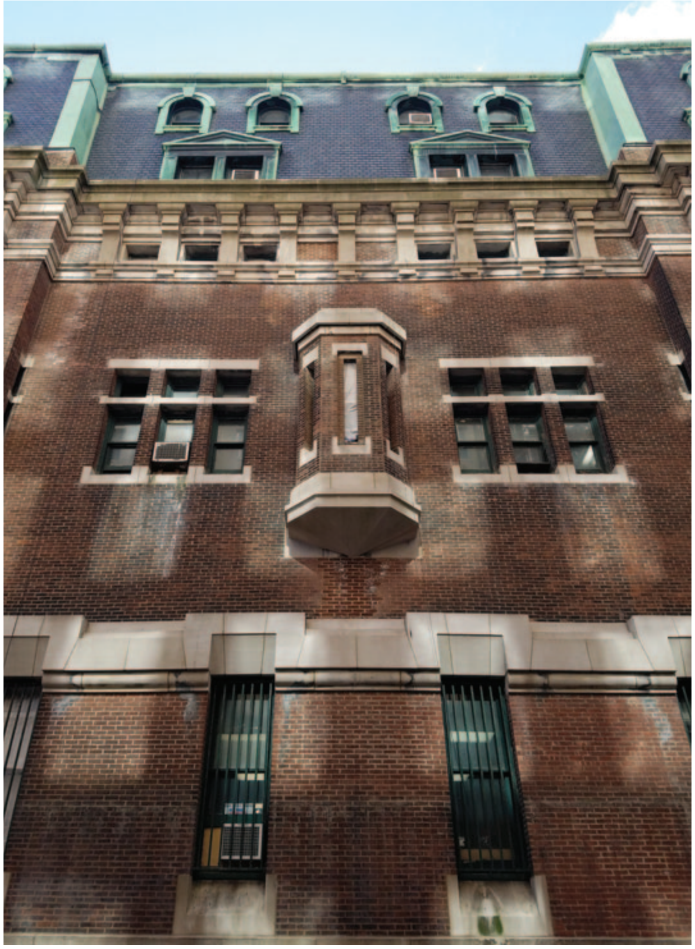


For this landmark military building, window security was a top replacement consideration.

The lower the U-factor, the better the energy performance. (R-value, used to measure the performance of opaque wall materials, is the opposite.) For single-pane historical windows, which have high U-factors, condensation may be an issue, particularly in environments with tightly controlled mechanical systems that limit natural ventilation.

Other common ways to evaluate the energy performance of windows are **Solar Heat Gain Coefficient (SHGC)** and **Visible Light Transmittance (VLT)**. SHGC measures the amount of solar radiation that passes through window glazing, and VLT measures the amount of visible sunlight that passes through the entire window assembly. Whether a high or low SHGC or VLT is required depends on the location and the use of the space, as there may be scenarios in which a high SHGC is preferred to allow passive heating, or a high VLT may be desired to maximize daylighting to reduce usage of electrical lighting and power. Although there are some jurisdictions that do not have specific energy codes, most building codes have minimum requirements tied to occupancy and climate.

Structural Considerations

Chapter 16 of the IBC defines structural requirements for windows, primarily in relation to lateral loads due to wind and other sources. To establish a uniform design pressure—commonly given in pounds per square foot—the project's structural consultant uses a wind speed mandated by applicable building code, with adjustment factors that account for building height, topography, exposure, and occupancy.

Windows and their anchorage must be designed to withstand these pressures, along with any other loads to which they may be subjected. The code also requires that window glazing itself have appropriate wind and/or other applicable lateral load resistance. This is typically established via deflection requirements, which indicate that glass cannot bend beyond a given maximum before breaking.

Certain regions—especially those susceptible to very high winds, such as hurricane-prone coastal areas—also have requirements related to windborne-debris resistance. During storm events, various forms of unsecured debris may become windborne and can potentially hit windows, break glass, create even more debris, while also potentially subjecting building interiors to wind loads that could destabilize the structure. Building height, configuration, and proximity to the coast are all critical factors when determining wind loads on buildings.

Envelope Integrity

Envelope requirements for windows are essentially concerned with keeping air and water out of the building. The two main metrics for evaluating the performance of a building's envelope involve testing for air leaks and water penetration. Both of these test windows in pressurized chambers to determine the extent of air and water that pass from one side of a sealed window to another.

Although the IECC outlines typical envelope requirements for windows—such as maximum requirements for air leakage—ratings laid out by the American Architectural Manufacturers Association (AAMA) are considered the industry standard for new windows. (Note that, as of January 2020, AAMA and IGMA have unified to create the Fenestration and Glazing Industry Alliance, or FGIA.)

According to the AAMA, following a series of performance tests, new windows can be placed into one of four performance classes, each of which is appropriate to a different degree of usage and type of setting.

- **AW**, generally used for high-rise and mid-rise buildings;
- **CW**, often used for mid and low-rise buildings;
- **LC**, typically used for multi-family dwellings; and
- **R**, used for one and two-family dwellings.

Each window class requires a different combination and quantity of tests, with decreasing performance requirements as the classes shift downward from AW to R. All, however, consider minimum structural loading, resistance to air and water infiltration, and security—or resistance to forced entry.

These performance classes can apply to windows in any material, although the highest classes are commonly achieved with steel- and aluminum-framed windows. The code does not require a specific window class for any particular situation, but it does require an AAMA 101 certification, which demonstrates compliance with minimum performance criteria.

Evaluating Window Performance

Energy/thermal, structural and envelope standards can all be evaluated in some capacity through testing. First, a series of laboratory tests establishes a performance baseline. This is done through both manufacturer/fabricator **qualification testing** and **performance mock-ups**—or with window units constructed solely for the purpose of laboratory testing—to ensure their ability to meet specified standards and requirements.

Depending on project specifications, samples and **visual mock-ups** may also be incorporated into the submission process to better evaluate window appearance—including a review of materials, finishes, profiles, and sight lines—before installation. This is especially critical with historical replacement projects, to verify that replacement windows match original or landmark conditions.

If one or more laboratory tests fail, or if appearances are not satisfactory, then mock-ups may be modified to achieve acceptable results. Such modifications are then incorporated into the final design and manufactured windows. Once windows have been fully installed and sealed into their respective façade openings, they may also be subject to in-situ/field testing to further evaluate their ability to meet performance requirements, along with the ability of the complete fenestration assembly to meet specified criteria. Typically, such onsite evaluation includes additional air and water testing, with some accounting for field conditions.

How Are the Principles Applied?

Industry standards and code requirements are well established for new windows; however, when it comes to applying these performance criteria to historical window replacement and repair projects, it can be more challenging, especially for projects with special considerations.

Replacement Projects

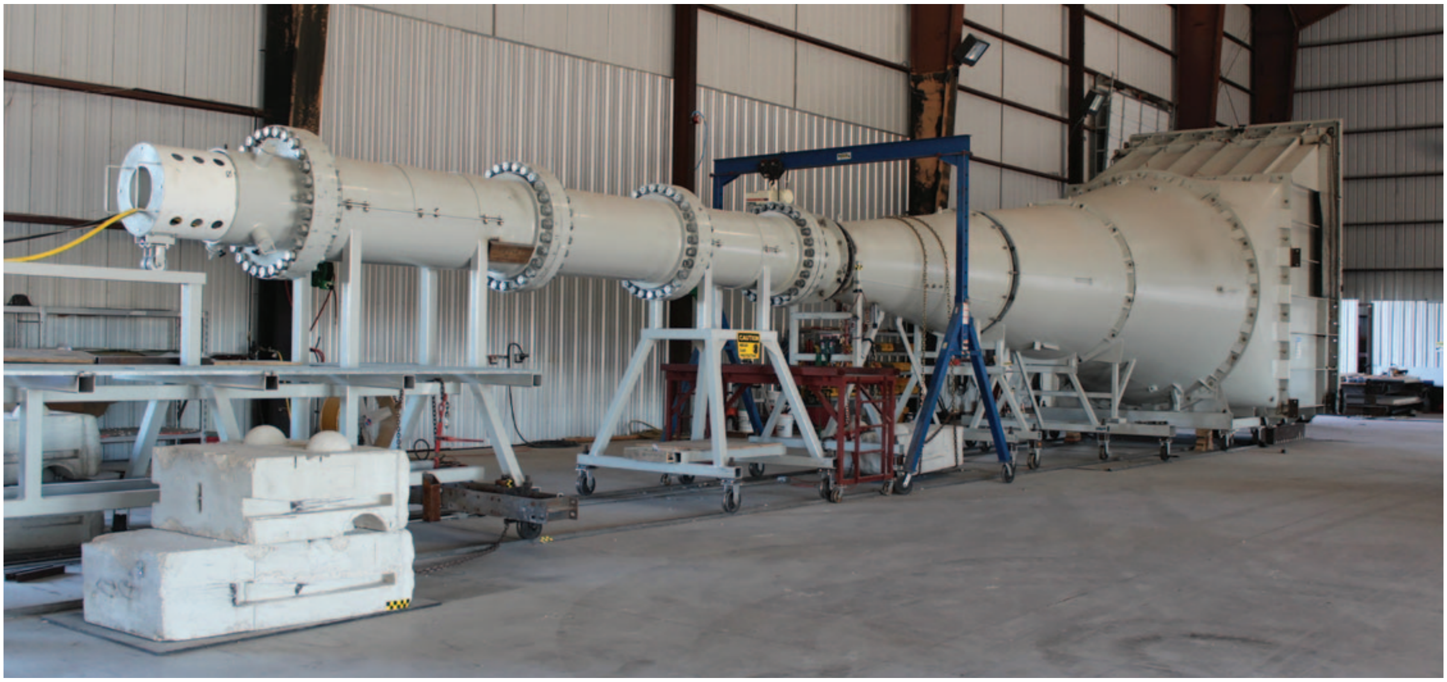
One example that illustrates these complexities is a window replacement project conducted at a turn-of-the-century National Historic Landmark armory building in a large metropolitan area. The project included comprehensive replacement of all original, deteriorated windows; however, since the building serves as an active military facility, the client required that the replacement windows meet contemporary performance standards, including energy code and anti-terrorism blast resistance.

The windows to be replaced were framed in old-growth softwood. Although the historically appropriate replacements could not achieve the same thermal performance as metal windows with thermal breaks, the new mahogany hardwood frames offered better performance than non-thermally-broken metal windows.

The original glazing was single-pane, so to achieve an acceptable U-factor, **Insulating Glazing Units (IGU)** were used—or two lites (panes) of glass, separated by an air cavity. To accommodate the IGUs, which are larger and heavier than the original single-pane units, the wood frame needed to increase in depth and weight. Fortunately, the replacement window frames had the same overall exterior appearance, and accommodated required operating hardware in a manner acceptable to the State Historic Preservation Office.

To further increase energy efficiency, a **Low-E (emissivity) coating** was incorporated into the IGU assembly. These coatings limit the amount of ultraviolet light that can pass through the glass, reducing the greenhouse effect on the building interior. However, it should be noted that some high-performing Low-E coatings can produce a colored tint, which may not be a desirable appearance for historic buildings, and, therefore, coating selection should be carefully considered. As with SHGC and VLT ratings, there can be situations in which not using Low-E coatings may be desirable, to increase the potential for passive solar heating.

Even more challenging was the need to meet anti-terrorism blast-resistance standards. All the replacement windows and glazing needed to be able to resist a shockwave from explosions or other ballistic forces at the exterior of the building. To achieve the requisite blast resistance, the IGUs incorporated layers of polyvinyl



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Shock-tube apparatus for blast-resistance window testing.

butyral (PVB) plastic lamination: the same material used in car windshields.

For this project, the lamination was applied to the inside surface of each glass pane of the IGU, creating what is known as a **double-laminated IGU**. For single-laminated assemblies, lamination can be applied to either the interior or the exterior lite. Double lamination maximized the glazing's resistance to lateral forces, as demonstrated by subjecting window performance mockups to laboratory-based shock-tube testing, during which the designed windows were evaluated for their ability to meet specified blast loads.

In addition to the glazing assembly, the anchorage also required special attention, as any lateral forces to which the IGUs are subject will be transferred through the frames to the surrounding masonry walls. A series of epoxy-adhesive anchors were originally considered for use, due to their high strength. However, given the position of the windows within the masonry walls, as well as anticipated design pressures, epoxy anchorage was not employed, because it could not achieve manufacturer-specified minimum edge distances, or the smallest allowable distance between anchors and the outer edge of the masonry. Instead, closely spaced mechanical anchors were ultimately specified, which are both suitable to the masonry substrate and able to achieve structural requirements.

Another example of the unique challenges of windows for historic buildings is a project with a series of storefronts installed at a large commercial building. In this case, the windows were not replacements, but new metal windows and doors installed in original loading dock entrances throughout the ground floor of a former warehouse, as part of an adaptive reuse project.

Since the loading docks were originally open without solid doors, and because it is a landmark building, the design team opted for large expanses of storefront glass with as few intermediate supports as possible, to preserve the original building profile. However, the building is located in a low-lying coastal area, so flood resistance and the potential for glazing deflection when subject to flood loading were both critical considerations. It was thus necessary to understand the stresses imposed on the glass, and its maximum span.

To verify engineering calculations, **flood-resistance laboratory testing** was performed. This included **flood-debris testing**, which evaluates the ability of windows to withstand large debris carried by fast-moving flood waters via impact loading, and **hydrostatic-pressure testing**, which measures the pressure of flood waters on glazing in a controlled chamber. To achieve a passing grade, it was again necessary to use laminated glazing in the storefront itself, as well as within the glass fin-wall system which was used to structurally support the glass.

The fin-wall system consists of a series of vertical glass fins. These run perpendicular to the glass storefront, directly behind it at the interior side, and are attached only by a very thin vertical line of structural silicone sealant. Glass fins were used in lieu of vertical metal mullions, in order to enhance the appearance of openness and minimize visual obstructions within the storefront system.

Alternative and/or supplemental means of flood resistance measures were also considered, such as flood barriers or gates. This typically consists of metal posts and panels which would be securely anchored to façades or in the ground, and requires trained staff capable of rapidly deploying the system before an anticipated flood event.

Other considerations in historic window projects include general security concerns, as well as fire-rating requirements. For a recent project at an urban library, a primary design concern involved determining whether wire-mesh glass, security guards, or integrated vandal guards were most appropriate. For lot-line windows, stair towers, and fire-rated wall assemblies, steel-framed fire-rated

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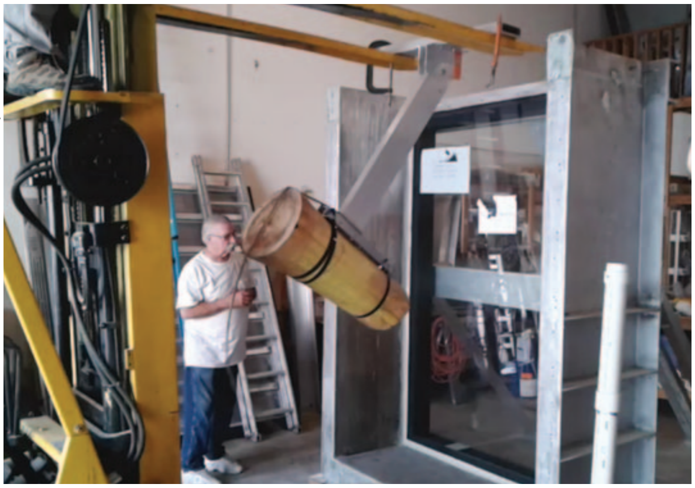

Flood debris testing of a proposed window assembly.

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Documenting and reconstructing stained-glass mosaics is painstaking work.

windows may be specified, despite considerations of historic accuracy, to comply with fire codes.

Repair Projects

Although high performance standards often can be achieved in some capacity in window-replacement projects for historical buildings, it can be even more delicate and difficult an exercise when it comes to window-repair projects. One example of what can potentially be accomplished is demonstrated in the restoration of an early-20th-century bronze-framed stained-glass window at a utility headquarters.

The large ornamental window on the entry façade showed numerous signs of deterioration, and forensic in-situ water-penetration testing—using an exterior spray rack which mimics wind-driven rain—confirmed that the window leaked and required extensive work. Given that much of the decorative glass and bronze frame components were in good condition, and that the window could be considered a priceless work of art, the project team decided to fully restore the window, rather than replace it.

The window was carefully disassembled, salvaged, and brought to a studio certified by the Stained Glass Association of America. This allowed for the cleaning and archival documentation of each component, which would also facilitate replacement should pieces become damaged during restoration.

Historical stained glass is typically held in place by thin lead components called **cames**, which are H-shaped for middle-section pieces and C-shaped for edge pieces. All lead cames were replaced and resealed to the adjacent stained glass with a linseed-oil-based waterproofing cement. Over time, as this cement deteriorates, windows are often temporarily repaired with elastomeric sealant. When maintaining historic windows, however, it is essential to use a sealant that is compatible with the original materials. Following restoration, the window was reinstalled and, although the performance and operability do not conform to contemporary standards, they are much improved.

When evaluating alternative methods for addressing deteriorated historic windows, or attempting to improve their performance, the use of **protective glazing** or **storm windows** is often considered, especially when replacement or full restoration is cost-prohibitive. Protective glazing is commonly installed at the building exterior, over existing stained-glass windows, to reduce air and water infiltration.

However, if such exterior glazing is not properly ventilated, hot air and condensation can become trapped in the air cavity between the interior and exterior glazing, and can further deteriorate the already distressed window. Metal components can become corroded and displaced, glass can crack and become dislodged, and additional leaks may be generated.

The use of engineered storm windows, on the other hand—especially when installed at the interior side—can be an effective means of improving both the energy/thermal and envelope performance of historic windows. Nonetheless, design professionals and storm-window manufacturers

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This bronze-framed Art Deco window was removed, restored, and re-installed.

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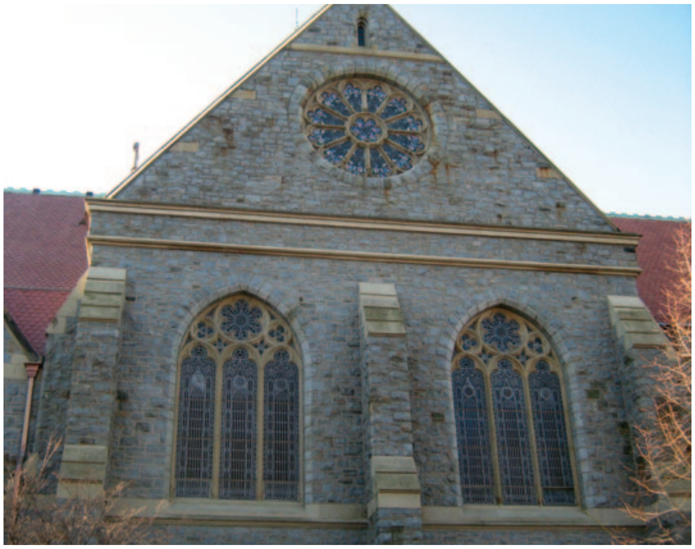
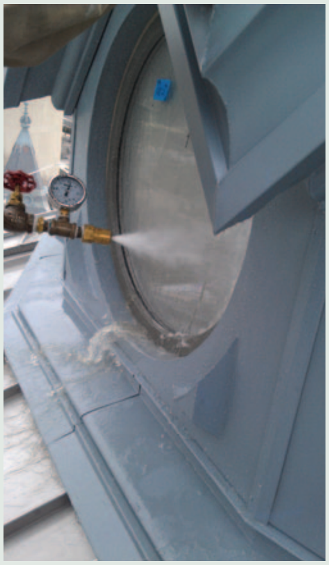


The stained-glass windows at this 1885 church were fully restored, including stone masonry surrounds.

Window-Performance Testing

Although contractors or manufacturers may refer to a window as having been "tested" in accordance with AAMA standards, building owners should note that the code only mandates **qualification testing**. This is performed on a manufacturer's sample unit to demonstrate that the typical unit produced in similar configurations will meet the required thresholds. This type of testing is what allows a window to be designated as a certain AAMA performance class, such as "LC" or "AW."



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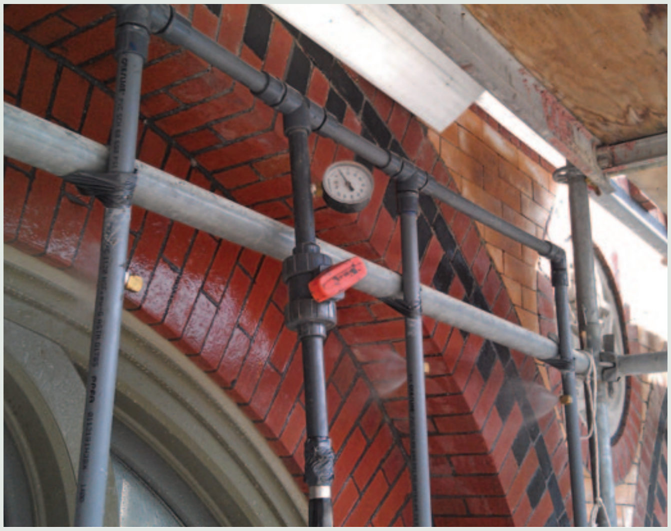
Water test of newly installed window.

Code-compliant qualification and labeling of a window system is a general certification and does not guarantee that a specific window unit will meet performance standards in a given installation. Although not required by building code, best-practice standards for project-specific **performance testing** of window assemblies may be included in a window replacement project.

Testing confirms the design intent and level of performance, and can provide quality assurance during construction. There are two types of performance testing commonly specified for window projects: offsite testing that occurs before construction, and onsite field testing that occurs during construction. Although similar in the performance metrics they are capturing, the methodologies and setups differ.



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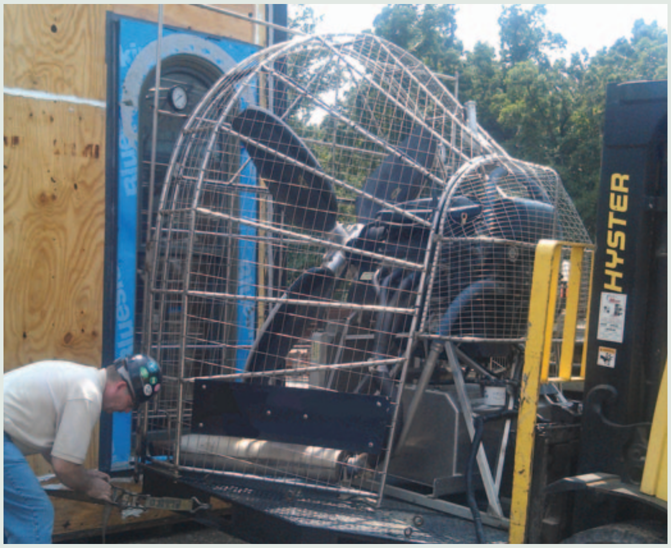
***In the field:** Spray-rack water test of a rehabilitated window.*



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***In the lab:** Wind and water test preparation for a window PMU.*

OffSite Testing

Also referred to as a **performance mock-up (PMU)**, offsite testing is usually carried out at an architectural testing laboratory. The parameters of a PMU are set by the project specifications to follow the procedures of *AAMA 101: North American Fenestration Standard/Specification*; the design professional may elect to test a single typical unit or multiple configurations.

A general test program includes multiple tests for water penetration (ASTM E 547 and/or E 331), air infiltration (ASTM E 283), and structural performance (ASTM E 330). Additional tests may be specified, depending on project requirements, such as lifecycle testing or lateral force (earthquake resistance). Tests may be repeated after one another to determine if air infiltration, for example, increases after the window is loaded with the maximum structural pressure. The PMU generally represents testing the "best-case" scenario for any installation, since it is a controlled and easily accessible lab setup.

Onsite Field Testing

During construction, onsite tests provide quality assurance. The general procedure for construction testing should follow *AAMA 502: Voluntary Specification for Field Testing of Newly Installed Fenestration*. Testing consists of visual assessment of seals, alignment, and window operation, as well as air- and water-infiltration tests, based on the standards of ASTM E 783 and E 1105, respectively.

The project designer must determine the number and frequency of field tests, as well as passing thresholds for the specific metrics. It is not sufficient to only reference "test according to AAMA 502" in the specifications.

should be consulted to evaluate the best approach, as each window-repair situation presents its own unique problems.

Balancing Performance with Historical Integrity

For historic and museum window projects, it is important to understand limitations and trade-offs. Although it may not be possible to realize all aspects of the desired aesthetic and performance, each project is governed by different dominant criteria, allowing the achievement of salient goals while making necessary compromises. Unfortunately, there is no perfect window that lasts forever, and ongoing inspection and maintenance will always be required. In particular, maintaining sealant joints and finishes is critical, as they are the first line of defense.

Historic restoration is dependent upon the availability of materials, as well as the properties and characteristics of the existing assembly, the surrounding structure, and repair and replacement components. Certain materials and forms may no longer be produced. Existing framing and attachment elements may not be able to support replacement glazing. Original materials may not perform as necessary to meet code requirements.

These, and a host of other considerations, mean that historic window repair or replacement is rarely straightforward. Understanding how to prioritize project requirements and evaluate available options—as well as how to test and adjust the design to improve performance and aesthetics—are key to a successful project outcome.

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Evaluating existing conditions—including anchorage, hardware, wall opening, frame, sealants, coatings, and glazing—allows the design team to determine the best approach for balancing historical integrity with modern performance.

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