WINDOWS AND DOORS:
HOW TO DO IT RIGHT AND STILL GET IT WRONG

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Abstract

Many window and door problems initially present themselves in ways that would suggest deficiencies with fabrication or installation, when in fact the problems relate to less obvious issues with design, adjacent building elements, or ancillary components. This makes it difficult to accurately diagnose such problems, allocate responsibility, and develop appropriate solutions.

This presentation will review examples of such issues and address:
- Common modes of window and door problems
- Factors contributing to those problems
- Applicable industry standards
- Appropriate and inappropriate investigative techniques and tests
- Differentiation between product and installation deficiencies
- Design, construction, and post-construction measures to help avoid problems

Speakers

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STEVEN GLEASON, PE, has over 25 years of experience in construction consulting, including evaluation, design, quality assurance, and expert testimony services related to moisture intrusion and building envelope assemblies. He has consulted regarding a wide variety of construction materials and building envelope components, with particular experience in masonry, precast and cast-in-place concrete, glazing systems, stone, stucco, EIFS, joint sealants, exterior coatings, and roofing and waterproofing systems. He is affiliated with ASTM International and RCI International.

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INTRODUCTION

Many problems related to windows and doors initially present themselves in a manner that would suggest performance deficiencies or problems with the fabrication or installation of the product, when in fact the problems relate to design deficiencies, adjacent building envelope elements, or ancillary components.

This presents unique challenges for investigators and those involved in resolving disputes among the parties involved to accurately diagnose such problems, allocate responsibility, and develop appropriate and effective solutions.

The following are case studies drawn from the authors’ field experience of apparent performance problems with window and door assemblies that initially appear to be defects in the product or installation, but ultimately relate to other factors. This paper addresses common modes of failure, factors that typically contribute to those failures, applicable industry standards and codes, appropriate and inappropriate investigative techniques, the challenges of allocating responsibility, and the necessity of determining the actual cause of failure prior to implementing repairs.

CASE STUDY 1: WINDOW FIELD WATER TEST FAILURES AT A UNIVERSITY CLASSROOM BUILDING

The project was a four-story classroom building completed circa 2012. The majority of the windows were fixed windows fabricated from aluminum framing with insulating glass units (IGUs). There were approximately 240 rectangular window openings on the building that were divided into four smaller sub-openings by aluminum “subframes” into which the window units themselves were installed.

The window unit was simply the glass unit sealed into a metal frame or sash. The subframe consisted of aluminum subsills, jamb receptors, head receptors, vertical tube mullions, and horizontal stack mullions. Taken together, the window unit and the subframe system were referred to as the window assembly.

Figure 1 shows an exterior view of a typical fixed window assembly, illustrating the four individual window units installed in the various subframe components.

The architect specified a high-performance window to comply with AAMA/WDMA/CSA 101/I.S.2/A440-08 requirements for a F-AW80 designation, indicating a fixed, architectural-class window (AW) fabricated to meet a design pressure of 80 psf. The specifications required preconstruction laboratory certification of the window unit per A440-08 in accordance with ASTM E547 and E331 for water resistance at 12 psf, which corresponds to a static water head of approximately 2.3 in. The glazing subcontractor submitted a window that met these criteria, and the product was approved for installation by the architect.

The specifications also required field-testing for water penetration resistance during construction in accordance with AAMA 502 and ASTM E1105 test procedures, which require testing not just the window unit, but also the subframe/receptor and the perimeter sealants between the window and window opening.

This created a significant discrepancy between what was required for laboratory
Following commencement of window installation, field water testing was performed as required by the specifications. Numerous leaks occurred, primarily at interfaces between the window unit and the surrounding subframe/receptor system (Figure 2).

The installer, manufacturer, and testing agency performed numerous diagnostic water tests to attempt to identify the sources of leakage; however, the diagnostic testing was not done in accordance with the protocol defined in the AAMA 502 guidelines, which require specific forensic testing in accordance with AAMA 511 that systematically masks off and tests individual components of the wall and window assembly to isolate the specific source(s) of leakage when the source of the leakage cannot be definitively determined. As the true source of the water leakage was not determined, the leakage and water test failures continued.

The locations at which the leaks occurred were required to be sealed in the field in accordance with the manufacturer’s installation instructions and approved shop drawings. Figure 3 shows the typical shop drawing detail at the subsill, indicating sealants required between the window unit, subsill, and jamb receptor. The detail also illustrates the profile of the back leg of the subsill, which was only approximately 1 in. high. Typically, the back leg is dimensioned so that the height of the leg is at least as high as the nominal water head developed by the pressure required for the water testing. The 12-psf water resistance rating required of the window equates to a nominal water head of 2.3 testing (i.e., testing of the window unit alone) and what was required for field-testing (i.e., testing of the window unit and the receptor system and seal between the adjacent construction).

Figure 3 – Detail from window shop drawings indicating sealants required between the window unit, subsill, and jamb receptor.

Figure 4 – Remedial interior sealant applied along the outer edge of the jamb, between the jamb receptor and the adjacent wall opening.

Figure 5 – Remedial interior “wet seal” sealant applied between each window unit and the subframe surrounding each window unit, essentially “picture-framing” the window unit with sealant.
inches—significantly less than the height of the back leg of the subsill. As a result, the watertightness of the system at the sill relied almost exclusively on the integrity of field-applied sealants between the subframe and window unit.

The glazing subcontractor installed various surface-applied supplemental sealants at the interior side of the windows in an attempt to correct the deficiencies in the internal seals between the window unit and subframe that were contributing to the leaks. The supplemental sealant work included a “wet seal” sealant joint between each window unit and the subframe surrounding each window unit at the interior—essentially “picture-framing” the window unit with sealant—as well as an additional interior sealant bead along the outer edge of the jamb, between the jamb receptor and the adjacent wall opening (Figures 4 and 5).

Ultimately, these surface-applied interior sealants were successful in preventing leakage during testing, and the windows satisfied the project field-testing requirements; however, the installer and general contractor incurred substantial unreimbursed costs for the remedial sealant work and extensive retesting required to resolve the leak issues.

Discussion
Although the leakage that occurred at the windows ultimately resulted from the failure of the installer to properly apply adequate sealant at the joints between the framing and the subframing, there were several issues that contributed to the unexpected failures during the field-testing beyond the installer’s workmanship.

1. The project specifier failed to appreciate the difference between the window unit itself and the entire window assembly, including subframe, receptors, and subsill. The project specifications did not require that the full window assembly meet the preconstruction laboratory water resistance requirements and certifications, creating a weak link in the window assembly. This was aggravated by specifying a field water test that was more stringent than the laboratory test, in that it required testing of the full assembly as well as the joint between the window assembly and the adjacent construction.

2. The subsill back leg was relatively short—nominally 1 in. high—while the nominal hydrostatic water head developed during the water testing was around 2.3 in. Ordinarily, the subsill back leg is sized so that it provides a physical barrier to water being pushed or drawn up and over it due to the water head created at the specified test pressure. In the absence of sufficient physical height to provide redundancy, the subsill relied entirely on the continuity of the sealant between the subsill and window frame for watertightness.

3. Although water testing of an on-site mock-up of the full window assembly was required prior to production installation, the project team did not allocate sufficient time and attention to the mock-up testing to thoroughly investigate and resolve the leaks that occurred. This was aggravated by schedule pressures that led to production and installation of the windows prior to fully understanding the nature of the leaks and necessary measures to correct them.

4. After the initial leakage occurred, the project team did not employ appropriate diagnostic testing to isolate and identify the specific sources of leakage. The follow-up testing largely consisted of running the same field test over and over again, without applying a comprehensive forensic strategy to definitively determine the leak source(s). The applicable AAMA field test protocols specifically stipulate a forensic approach to retesting in the event of water leakage. This type of approach requires performing retests in an incremental, systematic manner, masking off the different components of the window and wall assembly in order to isolate the specific source(s) of leakage.

CASE STUDY 2: EXCESSIVE WINTER CONDENSATION AND FROST ON RESIDENTIAL WINDOWS

The subject project was a two-story custom home in the southeastern U.S. constructed around 2013 with stone cladding and custom steel-framed windows. The steel windows were comprised of traditional steel framing with IGU glazing. Locations where the steel-framed windows were installed included:

- Bay windows at the master bedroom, dining room, and library
- Floor-level windows and doors at the family room

The homeowners experienced excessive condensation and frost/ice formation on the
steel bay windows during cold weather in the winter of 2014. The initial focus was on improper design, fabrication, or installation of the windows.

**Observations**

A site investigation was performed in January 2014 that included observations at both interior and exterior conditions associated with the condensation/frost issues. Ambient temperature and relative humidity measurements at the exterior were around 25°F (-4°C) and 15% RH. The typical dew point temperature of the interior space was 40°F.

The steel-framed bay windows were located in three rooms at both the north and south elevations. The bay windows were located at “bump-outs” of the exterior face of the residence that were approximately 3½ ft. deep by 8½ ft. wide (Figure 6).

No HVAC supply or return grilles were present at the bay window bump-outs. The nearest HVAC supply ducts were located around the corner from the bump-outs, approximately 10 ft. from the center of the windows (Figure 7).

At the time of the site visit, frost formation was observed on the lower portions of the frame, almost continuously along the back leg of the sill, and up the intersecting vertical framing members approximately 1 ft. (Figure 8).

Condensation also formed on the framing to about three-quarters the height of the window assembly (Figure 9) and on the lower edges of the glass along the lower row of lites.

The temperatures of the interior surfaces of the framing were typically around 25°F (-4°C) at the lower sill, 35°F (2°C) at mid-height, and 40°F (4°C) at the upper portion of the framing. These surface temperatures were below the dew point of the typical interior air at the lower portion of the windows, allowing condensation and frost to form.

The family room was located at the rear (south) elevation and included a large floor-to-ceiling style window assembly five lites wide by six lites high. The overall size of the window was approximately 14 ft. by 14 ft.

At the time of the site visit, no condensa-
tion or frost was present on the framing of the family room windows. Furthermore, the owner of the residence indicated that it was not typical for condensation to form on the family room windows. The temperature at the interior surfaces of the framing ranged from 40°F at the lower areas to 60°F at the upper portion of the framing (4 to 16°C). Two HVAC supply grilles were located in the floor adjacent to the windows (Figure 10).

Discussion

The condensation occurring on the steel-framed windows was not the result of improper selection, design, fabrication, or installation of the windows themselves. Rather, the condensation was the result of a combination of the use of traditional steel-framed windows and the lack of HVAC features to provide adequate warm airflow to the window surfaces.

The steel window frames had high thermal conductivity, and because they were custom windows utilizing traditional fabrication techniques, there were no thermal breaks or thermal improvements in the framing to minimize the heat transfer through the framing. As a result, when the exterior ambient temperature was low, the temperature at the interior face of the framing also would have been low, increasing the likelihood of condensation on the framing. The American Architectural Manufacturers Association (AAMA) provides design guidelines and testing protocols for condensation resistance of windows; however, these guidelines are optional and would not have been expected to be incorporated as part of the design of the custom-fabricated residential steel windows.

The low interior surface temperatures at the bay windows could have been addressed by providing sufficient “air washing” of the windows, (i.e., providing additional warm airflow from the HVAC system across the interior faces of the windows). Unfortunately, the closest air supply vents were more than 10 ft. from the bay windows, which did not provide adequate air washing. This was evidenced by the high severity of condensation and frost occurring at the bay windows, where there was relatively little air movement around the window frames, contrasted with the absence of condensation at the family room windows, where the presence of two HVAC supply vents at the base of the window assembly provided adequate warm airflow across the windows.

This deficiency would have been avoided if the HVAC design had complied with guidelines published by ASHRAE. Specifically, Chapter 25 of the 2009 ASHRAE Handbook – Fundamentals, in the “Building Envelope Heat, Air, and Moisture Control in Building Assemblies” section, states, “The likelihood of window condensation...may be reduced by washing the window with supply air.” In other words, sufficient circulation of warm air over the surfaces of the bay windows would have reduced the probability of condensation, and they would likely have performed in a satisfactory manner similar to the family room windows.

CASE STUDY 3: HUMAN IMPACT AND FALL INJURY THROUGH HOTEL WINDOW

In 2011, a hotel guest accidentally broke through a guestroom window and fell 10 floors to her death at a mid-rise hotel in the...
southeastern U.S. built in the early 1970s. The hotel construction included exposed concrete framing elements with floor-to-ceiling window systems between the floor slabs and columns. The guestroom window assemblies were comprised of six lites divided by aluminum framing members. Figures 11 and 12 show typical conditions at the interior and exterior of a typical guestroom window, respectively.

The guest reportedly fell against one of the bottom corner lites and broke through the glass. Figure 13 shows the broken glass retained in the window opening following the accident.

The hotel had been renovated shortly before the accident during a change in ownership. During the change in ownership, various inspections of the guestrooms and exterior were made. No significant violations or deviations from building code requirements were reported related to the guestroom windows. Various exterior renovations were performed as part of the change in ownership; however, none of the renovations reportedly involved replacing the windows or glass or other major changes to the guestroom window systems.

The glass used for the guestroom windows was reportedly single-pane, monolithic, annealed glass, which most likely complied with code requirements at the time of original construction. Current safety glazing requirements are outlined in the 2012 International Building Code (IBC), Section 2406.

- IBC Section 2406.4.3, Glazing in Windows, requires glazing in windows—whether fixed or operable—to be safety glass when all of the following conditions exist:
  - The exposed area of glass in a single pane is greater than 9 sq. ft.
  - The bottom edge of the glass is less than 18 in. above the floor.
  - The top edge of the glass is greater than 36 in. above the floor.
  - A walking surface is located within 36 in. of the glass, measured perpendicular to the glass surface.
  - An exception is when a protective horizontal rail is installed across the glass at a height of 34 to 38 inches.

According to information provided by the hotel management, safety glazing would not have been required for the specific lite of glass associated with the accident based on the dimensions of the window system. However, given the tragic nature of the accident, numerous questions arise both regarding what contributed to the accident, as well as what issues should be considered beyond minimum code requirements that might reduce the likelihood of such accidents in the future:

- Are current code requirements adequate regarding hazardous glass locations and the potential for human impact for the types of conditions associated with this accident?
  - Is a maximum glass lite size of 9 sq. ft. too large?
  - Is a rail at 36 in. sufficient as a preventive measure?
  - Should there be additional strength and deflection requirements for the framing in which the glass is retained?
  - Should there be additional requirements where there is a significant drop-off outside the window that could cause further injury in the event of a fall?

- What safety-related modifications or upgrades should be required to window systems during a major renovation based on the extent of work (if any) at the windows?

- Given the occurrence of the subject incident, what obligation does the present owner or a future owner have to modify or replace the window system to address the possibility of a similar accident?

**SUMMARY AND CONCLUSIONS**

The case studies illustrated above describe several ways in which even a qualified and experienced project team can get the basics of window and door systems right and yet still experience problems with the as-installed assemblies. Specific issues highlighted and means of avoiding the problems include:

1. Ensure specification performance requirements for windows that reference laboratory testing and certification include the entire window assembly—including subsills, receptors, etc.—not just the nominal window unit.
2. Ensure the specification requirements for field-testing match the preinstallation performance requirements in terms of test pressure and components to be included in the test.
3. In the event of failures during field-testing, ensure appropriate AAMA 502 and ASTM forensic diagnostic procedures are followed so that the source(s) of the leaks can be isolated and identified.
4. In selecting windows where condensation may be an issue, consider not just the condensation resistance factor (CRF) rating of the windows and AAMA/WDMA design guidelines, but also ensure that the HVAC design and installation provide for adequate airflow and “air washing” of the window surfaces with warm air.
5. Current code and industry recommendations regarding safety glazing at hazardous locations such as floor-to-ceiling windows should be reviewed to ensure adequate safeguards are provided to protect against fall hazards and persons accidentally breaking through windows. Specific concerns should include whether the maximum allowable dimensions are adequate, whether additional measures should be provided where a significant drop-off exists on the opposite side of the window, and whether existing noncompliant glazing should be allowed to remain in place during renovations even when no major changes to the window systems are made. (6)