PROCEEDINGS

Water Testing Misconceptions: Fenestration Product Certification and Forensic Investigation of Building Leakage

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Addressing the Building Envelope

ABSTRACT

One of the primary goals of building envelope leakage investigations is to trace the sources of building leaks. While national testing standards used to certify newly installed fenestration products for compliance with specified performance criteria can be adapted and used in building envelope leakage investigations, water testing for the purpose of tracing the sources of building leakage should be based on physical evidence, experience, and engineering judgment rather than on guidelines for product certification. Investigators and other professionals often mistakenly apply guidelines for product certification testing during building envelope leakage investigations, misunderstand the purpose of accepted test devices (such as the applicable water spray volume), and apply inappropriate test procedures.

This paper will provide an overview of fenestration product certification. Through a study of testing standards and case studies of building leakage investigations, the paper will differentiate between test methods applicable to fenestration product certification and those applicable to building envelope leakage investigations. It will also illustrate some common ways that product certification test methods are misapplied during building envelope leakage investigations.

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INTRODUCTION

Water testing is common practice to evaluate new building components (such as windows and doors) for resistance to water penetration or to diagnose reported leakage paths in buildings. The architecture /engineering (A/E) industry has developed methods and procedures for water testing as a way to standardize testing. Water testing for certification is the testing of fenestration products in a laboratory to confirm compliance with a stated level of performance and to provide rating to that product to identify its performance. Certification testing of fenestration products adheres to standardized test methods that differ from those for investigative testing to assess building leakage.

Water testing standards are often misused or misquoted during both certification programs and forensic investigations. Testing pressures, test durations, and methods for testing in general are often debated amongst investigators. Misuse of standards can result in misleading results, confusion, delay, and additional costs to a project; or delays and additional costs in dispute resolution. Understanding the standards and their intent is essential for investigators, whether the purpose is evaluating a fenestration product or identifying the cause of leakage in a building.

DEVELOPMENT OF STANDARDS

The development of current water testing standards dates back to 1950, when the University of Miami began a testing program to study the water penetration resistance of jalousie windows.[1] The testing involved subjecting the window to a water spray while an aircraft propeller forced air against the window specimens. This test method was a predecessor to the current AAMA 501.1. *Standard Test Method for Water Penetration of Windows, Curtain Walls, and Doors Using Dynamic Pressure.*

Around 1953 in Norway, researchers created an individual spray rack that moved vertically and horizontally along the test specimen face.[2] This spray rack, however, was not adaptable to larger specimens, so use dwindled. Also, in the early 1950s, researchers in the United States developed a spray rack consisting of a perforated horizontal pipe located at the top of a window specimen.[3] The testing setup wet the window specimen using gravity flow but failed to test overhang surfaces such as a meeting rail on a double-hung window. To increase the coverage, the spray rack was modified to include a grid of vertical and horizontal perforated pipes that covered the framing members of the window.

Around 1958, the Aluminum Window Manufacturers Association (AWMA) created a spray rack with a series of commercially available nozzles placed in a grid pattern.[4] The rack was adaptable to any size specimen and more economical to construct than its predecessors.

In 1964, the American Society of Testing and Materials (ASTM) began work on a static water pressure test for windows. The standard was published in 1967 as ASTM E331-67T, *Tentative Method of Test for Water Resistance of Windows by Uniform Static Air Pressure Differential.* Other standards followed with the publication of ASTM E547, *Test for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Cyclic Static Air Pressure Differential*, in 1975; and the publication of ASTM E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Air Pressure Difference*, in 1986, which adopted Standards E331 and E547 to perform water testing in the field.

In 1985, the American Architectural Manufacturers Association (AAMA) produced AAMA 101-85, *Voluntary Specifications for Aluminum Prime Windows and Sliding Glass Doors*, replacing AAMA 302.9-1977, *Voluntary Specifications for Aluminum Prime Windows,* and AAMA 402.9-1977, *Voluntary Specifications for Aluminum Sliding Glass Doors.* In 1997, AAMA published AAMA/NWWDA 101/I.S.2-97, a standard consolidating the I.S.2-93, *Wood Windows* by the National Wood Window and Door Association (NWWDA), which pertained to wood fenestrations, with AAMA 101-93, *Voluntary Specifications for Aluminum and Poly (Vinyl Chloride) (PVC) Prime Windows and Glass Doors*, which applied to aluminum and PVC windows.

AAMA published AAMA 502, *Voluntary Specification for Field Testing of Windows and Sliding Glass Doors* in 1990 to provide guidance for evaluating windows and doors in the field. This standard evolved into the current 2008 version of AAMA 502, *Voluntary Specification for Field Testing of Newly Installed Fenestration Products.* AAMA 502-08 provides guidelines for field-testing of newly installed windows to verify water penetration resistance and air infiltration resistance. The standard requires water testing the windows using the cyclic or uniform static air-pressure testing methods stated in ASTM E1105.

Today, ASTM Standards E331, E547, and E1105 are used in conjunction with AAMA 101 and AAMA 502 to evaluate the performance of installed fenestration products with respect to specified performance criteria. These standards provide requirements for the test pressure, procedures, and duration. These standards, however, are often misapplied during building leakage investigations, where the purpose (in part) is to replicate known building leakage and not necessarily to evaluate windows with respect to their originally specified performance criteria.

In 2001, ASTM published ASTM E2128, *Standard Guide for Evaluating Water Leakage of Building Walls,* to provide guidance in investigating water leakage through building walls. This differs from the previous Standards E331, E547, and E1105, which were primarily used to evaluate fenestration products. In 2008, AAMA published AAMA 511, *Voluntary Guidelines for Forensic Water Penetration Testing of Fenestration Products*, which focuses on identifying leakage paths of in-service fenestration products (as opposed to evaluating windows with respect to originally specified performance criteria) and follows guidelines set by ASTM E2128.

PRODUCT RATINGS

AAMA 103, *Procedural Guide for Certification of Window and Door Assemblies*, establishes the guidelines of the AAMA certification program. Products that are tested in accordance with AAMA 103 can be AAMA-certified and identified with a gold AAMA label, and certifications are valid for four years. AAMA 103 currently allows manufacturers to rate windows based on the 1997, 2002, 2005, or 2008 versions of AAMA 101. However, certification testing to AAMA 101-97 will end March 1, 2012; therefore, products certified under this standard will be valid until March 1, 2016.

AAMA 101-08 provides the performance-class rating system and testing requirements for windows, doors, and skylights. We will focus on this standard as it relates to water testing of windows.

Windows are designated based on performance class, performance grade, and maximum size tested. The performance class rating associated with a specific window indicates that the product meets a certain level of performance. Windows that are tested in conformance with AAMA 101 should exhibit a label similar to the following:

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where Y = Performance class (R, LC, CW, AW)

NN = Performance grade number

W x H = Maximum size tested, width x height of window (listed in inches, or metric with English standard units in parentheses).

Performance class ratings are defined as follows:

R = Residential

LC = Light commercial

CW = Commercial window

AW = Architectural window

This designation is slightly different from that included in the previous versions of AAMA 101 (1997, 2002, and 2005) in that the previous versions included product type and alternate performance-class designations (R, LC, C, HC, and AW).

CERTIFICATION TESTING

Water testing developed for certification of fenestration products stipulates certain air pressures, water distribution, and water volume. For example, AAMA 101-08 states that windows having performance classes R, LC, and CW are water-tested in conjunction with an applied air-pressure differential equal to 15% of the design pressure. Windows having performance class AW are tested using air pressure differential equal to 20% of the design pressure.

Using this standardized rating system and protocol, manufacturers produce windows with an expected level of performance and market the products as such. The intent is to allow designers, owners, contractors, and end-users to select window products with a performance that meets their project needs. Although this is also the case for doors, for brevity, we refer to windows only in this paper. It is the responsibility of the design professional to determine the required rating for a particular project based on various conditions, including type of building, typical weather, and building code requirements.

The laboratory certification testing programs only evaluate the individual products that are provided by the manufacturer for the testing. The manufacturer then applies the performance class rating to every window of that model that it produces. The rating assigned to a window product does not guarantee the reliability that a given production model will exhibit the same performance results in the field as the sample tested in the laboratory. Workmanship, adherence to material tolerances, material formulation, etc. can all result in variations from tested laboratory performance. Field inspection, critical review of perimeter details, and field-testing of mock-up window installations should be utilized to evaluate the performance of the fenestration product in the field.

AAMA 101-08 provides a clear distinction between performance grade (PG) and design pressure (DP). These terms often are inappropriately interchanged. Design pressure specifically relates to a window product's ability to perform adequately when tested at a structural uniform loading per ASTM E330. A performance grade is assigned to a window product when the product performs adequately when tested in accordance with air leakage resistance, water penetration resistance, uniform load deflection, uniform structural loading, operating force (if applicable), and force-entry resistance (if applicable). Designers/specifiers should specify the required performance grade of a product in their specifications, rather than just the design pressure.

Further, designers should specify the equation used to develop the water testing pressure such as, "Water testing pressure = design pressure x 15%," instead of specifying a test pressure. If the contractor provides a window with a performance grade higher than specified in the specifications, specifying the equation will ensure that the window is tested in relation to its corresponding rated test pressure rather than a lower test pressure that may be stated in the project documents.

A certification test report shows that a sample of a particular model of window of a particular size met a specified level of performance during certification testing. It does not indicate whether that window is appropriate for the winds, exposure, and other building-code requirements that a designer should consider.

AAMA labels showing the product rating as tested in accordance with AAMA 101 specify the maximum-size window tested. Prior to installation, the design professional should verify that the size of the window used for the project is smaller or equal to the listed "maximum-size-tested" value stated on the label for the window. In some cases, manufacturers will have multiple design pressures for the same window model. In general, when dealing with the same window model, smaller-sized windows will perform to a higher design pressure for water penetration, but this is not necessarily the case for other criteria such as air infiltration.

Certification testing is also not a quality control program and does not always guarantee comparable field performance, nor does it ensure reliability of manufacture or workmanship. Shipping, handling, and installation tolerance can affect the performance of installed windows on a project. These effects are not accounted for in laboratory certification testing. The testing also does not account for aging effects such as shrinkage and embrittlement of gaskets and deterioration of internal seals over time, all of which can detrimentally affect window performance.

It must also be noted that the rated performance of a window product is not indicative of the overall performance of the wall in which the window is installed. Window perimeter conditions can affect the performance of the wall system as a whole, and these components are not necessarily tested during certification testing.

This statement depends on the definition of leakage established for a particular project or testing program. The stated definition of water penetration in ASTM E331 (certification in laboratory), ASTM E547 (certification in laboratory), and ASTM E1105 is:

> Penetration of water beyond a plane parallel to the glazing (vertical plane) intersecting the innermost projection of the test specimen, not including interior trim and hardware, under the specified conditions of air pressure difference across the specimen. For products with nonplanar glazing surfaces (domes, vaults, pyramids, etc.) the plane defining water penetration is the plane defined by the innermost edges of the unit frame.

AAMA 502-05 defined water leakage in a similar manner. AAMA 502-08 makes a distinction between water leakage through the window product and water through the perimeter joint and defines water penetration as follows:

> The penetration of uncontrolled water beyond a plane parallel to the innermost edges of the product and that indisputably originates from the fenestration product. Water penetration attributable to the perimeter joint shall be defined as uncontrolled water that indisputably originates at the joint.

AAMA 502-08 states that if the origin of the leakage is inconclusive from testing, then AAMA 511 should be used to identify the cause of leakage.

These definitions require water to break the innermost plane of the window frame or product for water leakage to occur. Testing where water accumulates on interior surfaces without breaking the innermost plane such as at meeting rails (*Photo 1*) and surfaces of horizontal framing (*Photo 2*) do not constitute leakage by these definitions.

These definitions do not coincide with the typical end-user expectation (i.e., water will not pass through window), which should be paramount. Designers can specify their own definition of water leakage in the construction documents to clarify the project objectives; this should be brought to the contractor's attention during bid-

Photo 1 – Water accumulation on a window meeting rail.

Photo 2 – Water ponded on the interior of the window against the glazing unit seal.

ding/negotiation so he or she can make the manufacturer aware.

The 2005 version of AAMA 502 indicates testing of windows during the construction process and prior to final acceptance by the owner. The 2008 version applies only to windows that were installed prior to building occupancy and that are six months old or newer. There is no suggestion of a performance according to any accepted standard after six months, only an evaluation of how windows perform during the first six-month period. The standard states that windows tested after six months of installation or after issuance of the occupancy permit shall be tested using AAMA 511-08, *Voluntary Guidelines for Forensic Water Penetration Testing of Fenestration Products*—i.e., not a performance evaluation against levels promoted by the manufacturer.

As the title states, AAMA 511 is for forensic testing used when investigating windows that are known to leak. By referring to a forensic standard, AAMA implies that windows tested after six months of installation shall not be tested to determine if they perform to their original rating. Instead, AAMA 511 requires that a forensic investigator calculate differential pressures based on actual wind-driven rain events, which may be lower than pressures required by AAMA 502. This method does not adequately address reasonable performance expectations for a window that is less than a year old.

For fiel- testing, AAMA 502 specifies testing the windows at a pressure that is two-thirds that of the laboratory testing pressure, reducing the testing pressure by one-third. The reasons for the reduction include ambient environmental conditions, installation variations from laboratory to field, and shipping/handling by subsequent trades. While these are valid factors for a reduction, the one-third reduction in the testing pressure is without scientific basis; it is unknown whether this represents the true reduction in performance by the various factors. It does allow the window to perform at a lower level than the original certified/rated performance of the window and likely lower than specified for the design.

However, it is a misconception that designers are bound by this rule. Designers can specify that field-testing shall not include the one-third reduction; and if so, this should be brought to the attention of both the contractor and window manufacturer. Alternatively, designers can allow the one-third reduction and test to the code-required design pressure by specifying a performance grade with a design pressure that is 150% of the code-required design pressure.

Most window manufacturer warranties will allow one of the following three actions at the manufacturer's sole option: 1) provide a refund on the windows, 2) provide a repair/retrofit of the existing windows, or 3) provide new window assemblies. The warranties usually do not cover labor costs to remove/reinstall the windows, including any associated trim, interior wall finishes, or adjacent exterior wall claddings that may require replacement, which often are much larger costs than the window product itself. The warranties also likely do not cover consequential damage to framing, finishes, or surrounding materials.

FORENSIC TESTING

ASTM E2128, issued in 2001, provides a guide to conduct water testing investigations to identify leakage origins and paths. ASTM E2128 identifies a systematic protocol for investigating building leakage that goes well beyond the requirements found in the standards that govern certification testing. The distinction between forensic testing and certification testing needs to be understood prior to performing a forensic investigation; otherwise, confusion and invalid conclusions can result.

Forensic testing is a systematic approach to investigating leakage. ASTM E2128 suggests the following steps:

- Review of project documents
- Evaluation of design concept
- Determination of service history
- Inspection
- Investigative testing
- Analysis
- Report preparation

It is often the investigative testing phase where the procedures and methods employed during certification testing are confused with the "art" of water testing to trace building leaks. A key distinction is that ASTM E2128 applies to exterior walls inclusive of fenestration products and not just fenestration products themselves. ASTM E2128 references ASTM E1105 and AAMA 502, but these standards are not the sole basis of a meaningful leakage investigation. Overreliance on tests based on certification procedures can lead to points of contention among investigators, including:

- Test duration
- Testing apparatus volume, flow rate, and intent
- Methodology

These are discussed below.

Certification tests generally use 15 minutes of water application. Duration for water testing is not specified in ASTM E2128, but the standard does recognize that testing durations specified for product certification may not be sufficient for diagnosing in-service leaks. Factors such as wall construction, potential length of leakage paths, water absorption of materials, and internal storage capacity of the components being tested all factor into the required duration of any forensic water test. Investigators need to realize such factors. For example, mass masonry walls usually take much longer to leak than nonabsorptive systems such as a glass/metal curtain wall because (in the absence of discrete cracks or bridging elements) masonry has a much higher internal moisture-storage capacity.

Applying a water test duration that duplicates certification tests of an individual fenestration product during a forensic investigation can provide false results and prevent the investigator from identifying the leakage path.

ASTM E1105 requires a water spray system (such as a calibrated spray rack) to deliver water at a rate of 5.0 gal/ft^2 per hour. Investigators often will identify Note 3 of Paragraph 6.2.4 in ASTM E1105 as a reason to ignore the significance of leakage when subjected to a

Photo 4 – We observed leakage out of the interior-glazing stop at the sill of the fixed sash (at the location of the arrow).

Photo 3 – Window assembly consisted in part of operable casements over fixed sash (arrow points to casement).

spray rack calibrated in accordance with ASTM E1105. The note reads:

> The National Weather Service Technical Paper No. 40 records that in the contiguous 48 United States, the greatest rainfall for a 1-hour period is less than 5 inches. The rate of 5.0 gal/ft^2 per hour specified in this test method corresponds to a rainfall of 8 in./h unless otherwise specified.

The argument is that the area being tested will never see 5.0 gal/ft^2 per hour, and for that reason, the testing volume and rate are too severe. This note is confusing to many and should be removed from the standard. Correlation of the rate of spray to a rate of rainfall is misguided and ignores the purpose of the test setup.

ASTM E2128 clearly states that the intent of the spray rack is to "deliver a continuous water film to the test area, rather than to simulate a particular rain event." We find that placing a spray rack calibrated to a rate of 5.0 gal/ft^2 per hour approximately 1 ft. away from the testing surface produces a consistent film for testing. In some cases, though, site conditions such as wind or obstructions may prevent investigators from placing the spray rack as suggested. As a result, the spray rack may need to be placed farther away from the surface, and the pressure through the spray rack may therefore need to be increased to achieve a consistent film.

CASE STUDIES

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A recent field-certification water testing program on a high-rise residential tower in southern California illustrated how sometimes 15 minutes of certification testing simply is not enough.

The window configuration consisted of an operable casement over a fixed sash (*Photo 3*). We followed testing Procedure B of ASTM E1105, which applies a cyclic static air-pressure difference across the window test specimen. This test procedure requires a minimum total time of pressure application of 15 minutes, typically achieved by three five-minute pressure cycles with a one-minute period of zero air pressure between cycles.

Much to the initial disagreement of the observing contractor and window manufacturer's representatives, we chose to include six cycles of pressure (for a total of 30 minutes of pressure).

It was not until the last cycle of air pressure that we observed leakage out of the snap-in interior glazing stop at the sill of the fixed sash (*Photo 4*). After conducting isolation tests and disassembling the window, we discovered the source of the leakage. Water leaked through a hole in the frame corner seal at one of the sill corners of the operable casement. The water then flowed to the head of the lower fixed sash, collected in the hollow chamber of the head glazing stop, flowed to the jamb glazing stop, and then flowed down the jamb-glazing stop to the sill-glazing stop at the bottom of the fixed sash. Once water filled the chamber of the sill-glazing stop, it began to flow onto the interior sill and became visible to all observers (however, leakage occurred the moment water bypassed the frame corner seal of the operable casement).

Had we chosen to test for a shorter duration, this leakage path very likely would have gone undetected.

Photo 5 – Plaster damage at interior finishes.

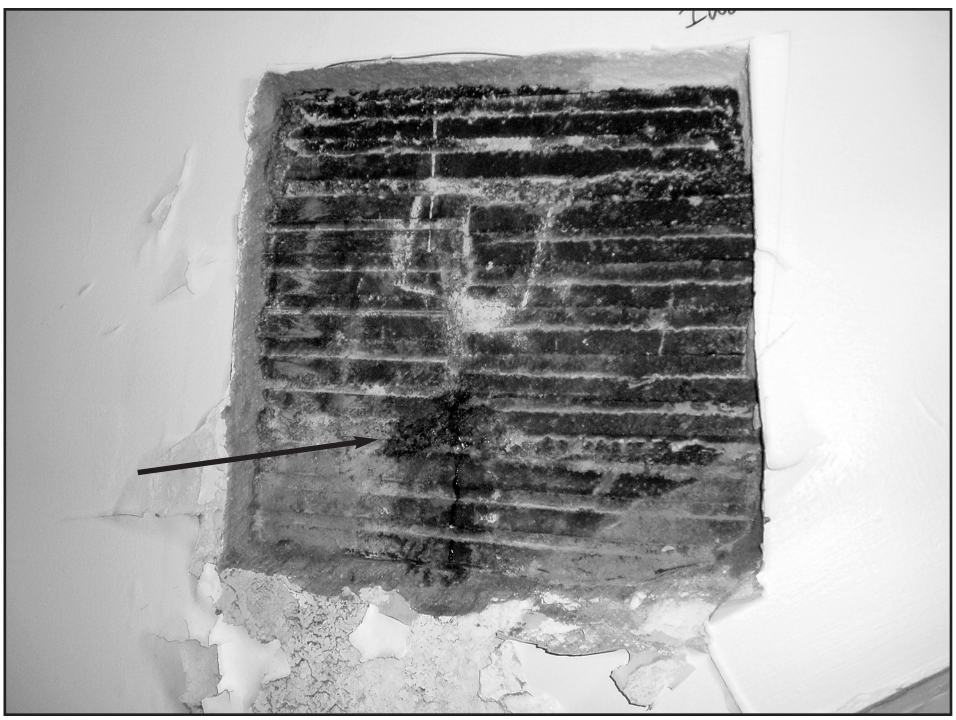

Photo 6 – Water leakage through brick and terra cotta at a location of exfoliated plaster.

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At an existing building, we observed exfoliated plaster on the interior, indicative of water leakage (*Photo 5*). Exterior openings around windows showed the wall construction to be solid masonry consisting of an outer brick wythe over a terra cotta backup wall with interior plaster finishes.

We water-tested the wall for one hour before we replicated leakage through the terra cotta (*Photo 6*) to the exfoliated interior plaster. The water soaked into the exterior brick through the mortar joints or through cracks in the brick and then flowed through joints or cracks in the backup terra cotta, where it wetted the interior plaster. The absorptive nature of the wall construction required a relatively longer testing duration than the 15-minute durations noted in certification standards. Had we tested for a shorter duration, we would not have replicated the leakage.

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You would think that diagnosing leakage of nonabsorptive materials such as a glass/metal curtain wall and sloped glazing assembly would require relatively short testing durations. Such was not the case at an office building in the Midwest on a recent investigation.

We tested the curtain-wall-to-sloped-glazing assembly for approximately four hours (*Photo 7*) but did not observe leakage to the interior. Upon arriving on site the next morning, maintenance personnel told us that approximately 20 minutes after we finished testing and left the site the previous day, leakage occurred in the exact location that they always observe leaks during rainstorms—40 ft. away from our test location. We continued testing at the same location and replicated this leakage within about ten minutes.

Contrary to what the shop drawings showed, removal of a metal flashing between the base of curtain wall and head of the sloped glazing revealed an unsupported silicone sheet gutter that sagged between the sloped glazing rafters (*Photo 8*). Each valley of the silicone sheet gutter contained approximately 3 in. of water after our testing (*Photo 9*).

We determined that water bypassed the metal flashing at a discontinuity (in the location of our test area) and filled the valley of the silicone sheet gutter directly below. The gutter valley filled with water, which then spilled into the adjacent valley. This process continued until water reached a defect in the gutter 40 ft. from our test location, at which point it drained to the interior of the building. Although we were testing nonabsorptive materials, in the end, it was a long leakage path that required a prolonged testing duration.

RECOMMENDATIONS

When testing for certification and field-testing of window products, the following recommendations can help to alleviate con-

Photo 7 – Water testing of a curtain wall and sloped glazing assembly.

Photo 8 – Removal of base flashing revealed an unsupported silicone sheet gutter filled with water.

fusion:

- Specify the required performance grade for fenestrations rather than just the design pressure.
- State the equation to be used to calculate the air-pressure differential (i.e., percentage of design pressure) to be used for water testing rather than stating the exact pressure to use in testing in order to ensure that the approved window is tested to a water test pressure corresponding to its certified performance grade instead of a test pressure that may be higher or lower.
- Confirm that the test reports provided by the manufacturer include a test specimen equal

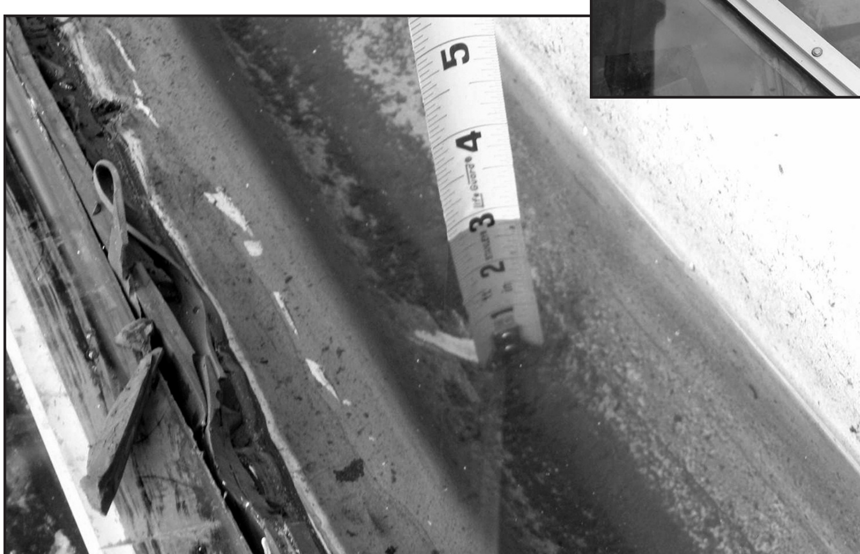

Photo 9 – Each valley of the silicone sheet gutter contained approximately 3 in. of water after our testing.

to or larger than windows used on the project.

- Specify field-testing of installed windows to evaluate the installed performance of the windows rather than relying solely on laboratory tests.
- Provide a definition of water penetration leakage in the specifications that meets end-user expectations.
- Field-testing standards include an effective one-third reduction in the field-testing pressure compared to the laboratory certification pressure. Specify to perform field-testing without taking the one-third reduction, and make the contractor and manufacturer aware; or specify windows with a performance grade having a design pressure that is 150% of the code-required design pressure.
- Specify that field-testing be performed within six months of installation or that the windows shall perform as rated until building occupancy.
- Do not rely on warranties as a safeguard against poor design or poor installation.

The specifications are part of the contractual requirements of a project. The designer can provide the safeguards stated above in the specifications as a way to clarify the required performance of the windows. The designer should specifically identify these requirements to the contractor to make sure they are aware of these provisions.

When investigating a building for leakage, investigators should use ASTM E2128 as the basis for the investigation and consider the following:

- Evaluate the wall construction, building materials, possible lengths of leakage paths, and the history of leakage to determine the appropriate duration and test pressures for testing of building components.
- Use a testing apparatus oriented and pressurized to provide a consistent film of water on wall surfaces.

SUMMARY

Understanding the intentions of testing standards (both for certification and for forensic testing) and the differences between standards associated with product certification and standards associated with forensic investigation of leakage is essential in eliminating some common misconceptions regarding water testing. By realizing these misconceptions and addressing them in project documents and during testing protocols, confusion, frustration, and inaccurate results can be avoided.

FOOTNOTES

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