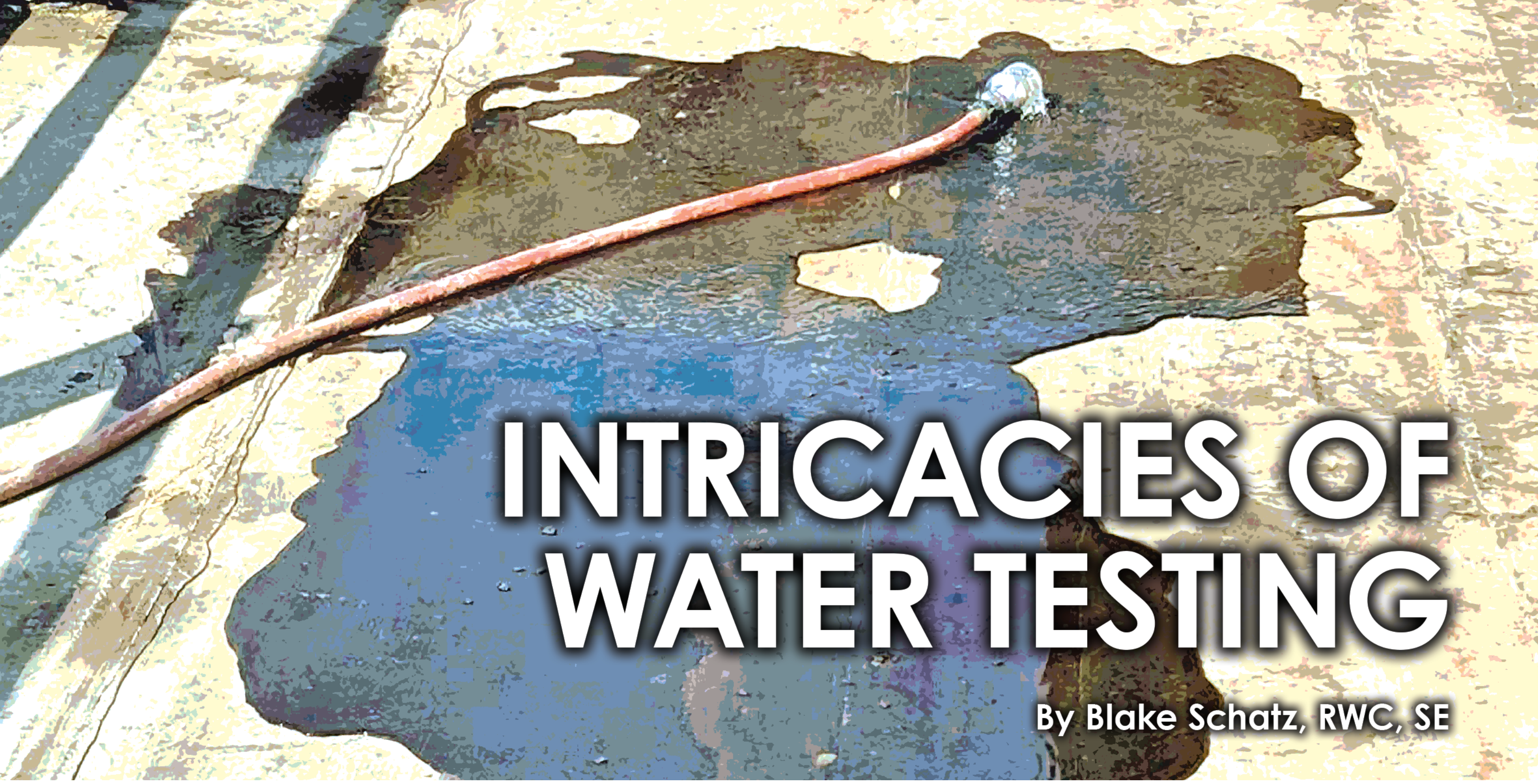

INTRICACIES OF WATER TESTING

By Blake Schatz, RWC, SE

Given all the aspects of building enclosure consulting, water testing can provide some of the most stimulating projects. It goes beyond drawing details and specifying products, allowing the consultant to work with hoses, test nozzles, and brass and polyvinyl chloride (PVC) equipment. There is an aspect of hands-on puzzle solving that mirrors the design process but can't be replicated in an office. It can be a messy, frustrating, exhausting, and rewarding job.

ASTM International and the American Architectural Manufacturers Association (AAMA; now known as the Fenestration and Glazing Industry Alliance) have published a number of documents related to testing building enclosure assemblies. These documents and standards, when read individually, provide tremendous guidance for specific procedures. However, there are few documents that compare and contrast the equipment, techniques, and conditions involved with each procedure. AAMA 511,[1] in conjunction with ASTM E2128,[2] provides some guidance on the diagnostic front, but it does not connect this information with performance testing. AAMA 501[3] provides further guidance on the array of available testing methods for assemblies and fenestration.

Water testing is generally placed into two categories:

- performance or quality assurance testing, which is used to ensure the performance of a recently installed assembly or determine the in-field rating or performance of an unrated unit, and
- diagnostic testing, which is used to evaluate observed water intrusion and attempts to re-create leakage.

ASTM E2128 includes several additional definitions that describe the type and severity of water intrusion. Moreover, the term "test-induced leak" is used to describe a diagnostic test that produces a result that is not seen outside of the test—that is, a test that results in water leakage that is not observed from natural causes. Finally, the reader is referred to the AAMA, Window & Door Manufacturers Association (WDMA), and CSA Group standard AAMA/WDMA/CSA101/I.S.2/A440[4] for a discussion on window ratings and minimum performance levels.

Definitions and background aside, it is not uncommon for investigators to include water testing during the investigative process in an attempt to identify the problem. However, it should be noted that the process described in ASTM E2128 outlines four comprehensive actions to take prior to testing, including the review of any available documents, evaluation of the design concept, determination of the maintenance and service history, and observation of existing conditions. These steps are intended to guide the investigator to the proper testing techniques and should not be sidestepped.

EQUIPMENT

The variety and availability of equipment used to apply water are sometimes not thought through. Water testing with a thumbed hose is an all-too-common approach. The author recommends that contractors and design professionals alike keep a variety of water applcation tools in their toolkit.

Even a typical multipurpose garden sprayer can be a step up from a thumbed hose. Although not a scientific approach, a sprayer provides some level of repeatability and control of water application. Further, a small brass bull's-eye nozzle (**Fig. 1**) can be effective in directing small amounts of water to specific locations.

Figure 1. A bull's-eye hose adapter.

Figure 2. Monarch B-25 nozzles.

A B-25 nozzle is a brass adapter (**Fig. 2**). Its use is standardized in AAMA 501.2.[5] It sprays a mid- to high volume under relatively high pressure (the volumetric rate is unspecified but is intended to be used at 35 psi [240 kPa]). When applied 12 in. (305 mm) from and perpendicular to a surface, the spray pattern is circular with an 18- to 24-in. (460- to 610-mm) diameter. This nozzle is intended for solo use and is typically attached to a PVC or metal wand for application.

ASTM C1601[6] and ASTM E514[7] test methods utilize a spray wand with 0.04-in.-diameter (1-mm-diameter) holes spaced 1 in. (25 mm) apart. While the test methods are intricate and difficult to implement, the wand can be used for a variety of other techniques and is easily constructed from PVC. It applies the water linearly and can easily be adjusted from low volume and pressure to high volume and pressure with the twist of a ball valve. It is particularly useful for transitions (for example, deck to wall, or roof to wall [**Fig. 3**]), tests that require little overspray, or directing water over a wide area. This equipment can also be used on horizontal or vertical surfaces.

The spray rack offers the broadest and most commonly known water application technique for investigators. Its use is standardized in ASTM E1105[8] and can be used on vertical (window and door) and horizontal (skylight) assemblies. The standard requires that the rack deliver 5 gallons of water per square foot per hour (200 liters per square meter per hour); that the system have "nozzles spaced on a uniform grid, located a uniform distance from the specimen"; and that the system "be adjustable to provide the specified quantity of water in such a manner as to wet all of the test specimen, uniformly and to wet those areas vulnerable to water penetration."

Racks can be designed to various sizes and shapes so long as the volumetric rate is maintained and calibrated. The rack provides a high volume of water (approximately 8 in. [200 mm] of rain per

Figure 3. Testing a deck-to-wall transition using an ASTM E514 wand.

Figure 4. Diagnostic testing using an ASTM E1105 rack without differential pressure.

hour, which is more than double the majority of 1-hour rainfall rates provided in Section 1611.1 of the 2018 *International Building Code*[9]) under low pressure for a large area. **Figure 4** shows a spray rack setup being used for diagnostic purposes on an exterior door. In addition to ASTM E1105, spray racks are used in several other standard test methods, including AAMA 501.1,[10] AAMA 502,[11] AAMA 503,[12] ASTM E331,[13] ASTM E547,[14] ASTM E1646,[15] and ASTM E2268.[16]

A typical garden-soaker accessory provides a high-volume, low-pressure water application, but it is not part of a standardized application method. Investigators may find this tool useful for inundating low- or steep-sloped roofs or decks, saturating the earth adjacent to a basement wall without purposefully eroding the soil, or observing drainage patterns. It can also be used to saturate a small area during a flood test while eliminating the risk of a high-pressure, undulating hose or the risk of spraying adjacent walls and transitions.

Lastly, ball valves located near the hose outlet are particularly useful for quickly shutting off a water application at the end of a timed test or in the event that there is a problem.

STANDARDIZED METHODS

As a general rule for any tiered or staged water testing, the lowest area under consideration should be tested first. This is explained in both AAMA 501.2[5] and ASTM E2128.[2] As noted in ASTM E2128, "starting at the bottom helps eliminate ambiguity about the origin of a leak that might result from water running vertically down the surface of the test area." Additionally, testers should take care to not overspray the area being tested, as this can lead to false positives and misunderstood results.

As described previously, the ASTM E1105[8] test method uses a calibrated spray rack to apply water to the specimen. Prior to testing, an airtight chamber is constructed around the specimen on the interior. In rare cases, the chamber is fabricated and fastened to the exterior. Air is exhausted from (or, in the case of the exterior condition, forced into) the chamber to artificially pressurize one side of the specimen. During this test, the chamber is used to induce a pressure differential across the specimen, effectively forcing water through any openings in the assembly. The amount of pressure across the specimen is typically determined by the specimen's rating (in the case of performance testing).

If the specimen is unrated, its performance can be determined by taking a tiered approach that incrementally increases the pressure after each pressure cycle until failure. The ASTM E1105 test procedure calls for either Method A, which is a continuous 15-minute differential pressure, or Method B, which includes 5-minute pressure cycles with a 1-minute pressure rest between "on" cycles.

AAMA 502[11] and AAMA 503[12] specifications both utilize the procedures outlined in ASTM E1105. There are, however, a few notable differences between AAMA 502 and AAMA 503. Additionally, AAMA 511[1] includes several testing techniques, including ASTM E1105. The differences among these three AAMA standards are outlined in **Table 1**.

Related to ASTM E1105, sill track or sill dam testing is a quick and often overlooked performance and diagnostic technique. Explained in former versions of AAMA 502 and now in AAMA 511, this method is specifically for sills of fenestration units. Essentially, the weep system of a fenestration unit is plugged or blocked, typically with plumber's putty or tape. The sill is then filled (if the specimen's sill can be filled) with water to a height equivalent to the window's rating.

For example, if a window's water penetration resistance rating is a pressure of 2.0 lb/ft^2 (99 Pa), then its sill would be filled with ⅜ in. (10 mm) of water. This correlation is related to

Standard designation	Specimen types	ASTM E1105[8] procedure	Minimum field test pressure, lb/ft² (Pa)	Field test pressure based on gateway requirements*	Definition of leakage
AAMA 502[11]	Fenestration products, excluding those listed under AAMA 503	A or B, depending on specimen rating	1.9 (91)	For R, LC, and CW Performance Classes: ⅔*15% of the design pressure (DP). For AW Performance Class: ⅔*20% of the DP.	There are definitions for types of leakage, but the definition of leakage typically reverts to the ASTM E1105 concept of "water penetration beyond a plane parallel to the glazing."
AAMA 503[12]	Storefronts, curtainwalls, sloped glazing	A only	4.18 (200)	"⅔ of the specified project water penetration test pressure." Typically, this is ⅔*20% of the positive design wind load.	"Any water that is not contained in an area with provisions to drain to the exterior or the collection of more than 0.5 fl. oz. [15 mL] of water."
AAMA 511[1]	Any specimen	Not specified; choice relies on investigator's judgment	0 (0)	Calculated from local weather data and wind pressure approximations.	No definition of leakage. As a diagnostic procedure, the investigator attempts to re-create any leakage experienced by occupants.

*The reader is directed to AAMA/WDMA/CSA 101/I.S.2/A440[4] for an explanation of gateway requirements and window ratings.

Table 1. Differences in testing procedures among AAMA 502, AAMA 503, and AAMA 511

the density of water, 62.4 lb/ft³ (9.9 kg/m³) or 5.2 lb/ft² per inch (9.9 Pa/mm). The depth of water can be calculated by dividing the intended pressure by the density of water. That is, 2 lb/ft² / 5.2 lb/ft² per inch (9.9 Pa/mm) of water = ⅜ in. (10 mm) of water. This is the same amount of water that would appear in the sill if the specimen were tested with the ASTM E1105 method using a differential pressure of 2 lb/ft².

It should also be noted that the ⅔ factor used to obtain a test pressure from gateway requirements applies to field tests only; lab tests are not afforded this reduction. Therefore, the rated fenestration product's sill should still hold the full depth of water at lab test pressures even in a field environment. It is the author's belief that sill dam testing should be conducted using the equivalent hydrostatic pressure of a lab test even in a field setting. **Table 2** shows the relationship between lab test pressures, fenestration design pressures, and minimum dam heights Additionally, the sill dam test is particularly useful before ASTM E1105 testing is done. The ASTM E1105 process will effectively perform the same test, but conducting a sill dam test before ASTM E1105 testing can verify that the sill is intact and suitable to hold standing water. Any subsequent failures during ASTM E1105 testing will direct the investigator to mechanisms other than a damaged sill.

Flood testing is a technique that uses only water, gravity, and drain plugs to test low-slope deck surfaces. The procedures for this test are outlined in ASTM D5957,[17] and the test's intent "is to provide a measure of confidence of the waterproofing installation to remain watertight for the service life of the system." The test specifies a minimum of 1 in. (25 mm) and maximum of 4 in. (100 mm) of standing water be held (using dammed edges where necessary) for a period of 24 to 72 hours on the deck surface. **Figure 5** shows the beginnings of a flood test using a soaker hose attachment.

As a final note on test methods, there are more ways to apply water to a surface than can be addressed here. The intent for any testing regimen is to provide a documented and repeatable mechanism to apply water. However, nonstandardized techniques should be reserved for diagnostic purposes only. That is, quality assurance objectives should only use standardized test methods.

The reasoning here is that performance testing is intended to meet a certain standard and requires a higher degree of care to implement, quantify results, and document findings. Conversely, troubleshooting to determine the cause of an existing problem can involve just about any form of testing, so long as the conclusion reasonably reflects the observations and is properly documented.

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When comparing testing procedures between ASTM E1105[8] and AAMA 502,[11] the

Design Pressure, lb/ft² (Pa)	Lab Water Test Pressure, lb/ft² (Pa)	Water Height and Minimum Leg Height, in. (mm)
15 (720)	2.86 (140)	¹¹⁄₁₆ (18)
20 (960)	3.0 (150)	¾ (19)
25 (1200)	3.75 (180)	⅞ (21)
30 (1440)	4.5 (220)	1 (25)
35 (1630)	5.25 (260)	1-⅛ (31)
40 (1920)	6.0 (290)	1-⁵⁄₁₆ (34)
45 (2160)	6.75 (330)	1-⁷⁄₁₆ (37)
50 (2400)	7.5 (360)	1-⅝ (41)
55 (2640)	8.25 (400)	1-¾ (45)
60 (2880)	9.0 (440)	1-⅞ (48)
65 (3120)	9.75 (470)	2 (50)

Table 2. Design pressures, lab test pressures, and associated back-dam heights from ASTM E2112-07, Table A3.1.

Figure 5. Flood testing with a soaker attachment.

investigator realizes that ASTM E1105 requires a minimum of three 5-minute pressure cycles ("In no case...shall the total time of pressure application be less than 15 minutes") whereas AAMA 502 requires "four cycles." Given these discrepancies, the investigator is best served to perform four cycles so as to satisfy both requirements.

ASTM E1105 also includes language to examine the test specimen "by opening, closing, and locking the unit five times prior to testing." It notes that this action is intended to force the investigator to observe the condition of the specimen and its adjacent construction. Oftentimes, in situ performance testing is conducted during active construction. In such cases, the glazing may be installed but the window installation may not be finalized.

In many instances, weatherstrips, gaskets, and lock mechanisms may not be complete but are necessary for the specimen to perform as intended. Interestingly, ASTM E1105 does not expressly require the investigator to check that the specimen be plumb, level, and square; AAMA 502 does require this, but it does not specify what values would be unsatisfactory. In this case, the author directs investigators to ASTM E2112[18] Table 4, which provides acceptable guidelines for shimming.

It should also be noted that when measuring for plumb, level, and square, plumbness is measured out of the plane of the wall—that is, a level placed vertically on the interior or exterior faces of the specimen. If the specimen has straight edges and is confirmed to be level and square, it will necessarily be plumb in the plane of the wall. Thus, plumbness still needs confirmation out of the wall plane.

It should be noted that the ASTM E1105 appendix mentions that the water-spray volume is not tied to a specific rain event. In fact, the comparison between any given event and water-spray volume is misleading. The water spray is intended to fully and uniformly wet the entire exterior for the duration of the test. This purpose ultimately leads to an overwhelmed weep system, which is then exacerbated by the differential pressure. This test is intended to completely inundate the specimen's water management system and is not "intended to reproduce or simulate any given rain event." For windows with sills that can collect water, the test will necessarily produce standing water (in the sill), whose depth is proportional to the differential pressure applied.

The testing guidelines outlined in AAMA 511[1] rely on the procedures explained in ASTM E1105, with an exception being the determination of the differential pressure. For diagnostic testing, AAMA 511 describes a method to estimate the pressures that have acted on the specimen, which is based on recorded wind speeds. Based on the ASTM E1105 appendix, this method does not seem to be consistent with the intended use of ASTM E1105.

AAMA 511 relies on determining a wind pressure from actual conditions, whereas ASTM International explains that "there is no evidence that the developers of Test Method E1105... intended to reproduce or simulate any given rain event." In fact, AAMA TIR-A13[19] quotes a window manufacturer as saying,

> I recall only one documented case of leakage where it was determined through examination of the National Oceanic and Atmospheric Administration data that heavy rain with sustained wind pressure of more than 12 lb/ft^2 (575 Pa) occurred.... However, it was also determined that windows had likely been left unlocked by construction personnel on floors above, and probably blew open during the storm.

An additional point is that all AAMA tests require an AAMA-accredited independent testing agency (see guidelines in AAMA 204[20]). AAMA tests conducted by nonaccredited agencies should therefore be considered "modified" as they do not comply with the accreditation requirement.

For flood testing, it is necessary to understand that the weight of water is 5.2 lb/ft^2 (250 Pa) per inch of depth. That is, 4 in. (100 mm) of water—the maximum depth allowed by ASTM D5957[18]—equates to over 20 lb/ft^2 (1000 Pa). This pressure is the structural design live load for unoccupied roofs. Explicitly, the maximum water depth allowed per ASTM D5957 is intended to match a typical minimum structural design load.

Additionally, residential decks were historically designed for a minimum design live load of 40 lb/ft^2 (1900 Pa) (or more in some cases), doubling the necessary structural capacity for flood testing. The flood test standard (ASTM D5957) requires "constant monitoring during the full duration of the flood test" and documentation in 4-hour intervals. In the author's view, these observation and documentation requirements are unrealistic as no reasonable investigation would require this level of detail or continuous time on-site.

Furthermore, ASTM D5957 should primarily be used as a performance assessment. Flood testing used as a diagnostic tool is generally ineffective—it indicates that a problem exists but not necessarily what that problem is or where it might occur in the assembly. If flood testing is used diagnostically, it requires that each penetration, transition, and area be isolated and tested separately. If flood testing is not practical or desired, the reader is directed to electronic leak detection standards, namely ASTM D7877[21] and ASTM D8231.[22]

Lastly, it is important to consider how wind pressures are calculated. ASCE 7-05[23] has been the mainstay for wind pressure determination, particularly in AAMA 511,[1] which references ASCE 7-05 procedures to determine differential pressures across a specimen. However, current structural codes have adopted ASCE 7-16,[24] and there are notable differences between the ASCE 7-05 and ASCE 7-16 editions in their quantitative approaches to converting wind speeds into wind design pressures.

ASCE 7-05 uses an allowable stress design (ASD) methodology for pressure determination. In contrast, ASCE 7-16 uses a load and resistance factor design (LRFD) methodology. The takeaway here is that the LRFD method produces higher design pressures. Additionally, a quick comparison of basic wind speeds listed in the two editions shows higher wind speeds in ASCE 7-16 compared with ASCE 7-05. With this information, one might ask, "How have wind pressures suddenly increased?"

The answer is that neither wind speeds nor wind design pressures have substantially increased in recent years. Again, this is a change in the design methodology and not a change in the actual pressures applied against buildings. Closer evaluation of the changes between ASCE 7-05 and ASCE 7-16 reveals that the load combination factors listed in chapter 2 have also changed. Applying these factors to the appropriate methodology results in comparable wind pressures between the two standards and the two methods. The load combination factors effectively convert the listed wind speeds from one methodology to another.

Once again, this is an oversimplification but sufficient for this discussion. Although not explicitly stated by AAMA or ASTM International, the author believes that test pressures are and should be conducted at service or ASD-level forces. If and when AAMA updates their test pressure determination procedure to use a more current version of ASCE 7, that procedure will likely include an appropriate reduction factor to return the elevated LRFD pressures back to ASD levels.

CONCLUSION

The testing process, whether for performance or diagnostic objectives, requires more than a basic understanding of test procedures. It also requires a critical thought process, based on knowledge and experience, which is necessary to provide suitable consulting for building enclosure testing services. This thought process should consider the test methods chosen, the equipment used to perform the tests, the water and air pressures necessary to provide reasonable results, and how all these elements correlate to realistic conditions.

Even after all considerations have been taken, it may be difficult to understand the reasons behind an enclosure failure. This challenge should only further stimulate the investigator to understand more about the assembly, specimen, procedure, or equipment. Experience cannot be gained from reading an article, but experiences can be shared, and knowledge can be gained, from others' experiences. When applying guidance from any code, standard, or publication, a skilled investigator will not just follow the text but also think critically about the purpose and intent of their actions.

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