An Overview of Diagnostic Water Leakage Testing of Building Façades

By Matthew C. Farmer, PE

Introduction

Over the past several decades, there has been a steady increase in demand for services related to evaluating uncontrolled water leakage through the building envelope (roofs, walls, and foundations), both through enhanced quality control procedures and investigation of water leaks in existing building stock. Many construction professionals have migrated away from more traditional areas of practice to specialize in "chasing leaks." Like so many areas of specialized expertise, success is dependent upon relatively few fundamental principles: knowledge of building envelope systems, familiarity with the tools and testing techniques commonly used, the ability to apply logic and deductive reasoning to problems, and lots and lots of practice. This article will attempt to summarize some of the basic knowledge that construction professionals should know about diagnostic water leakage testing of building façades. Regardless of a person's role in the construction field or his or her level of involvement with new or existing construction, an increased understanding of water leakage and methods for its evaluation will likely be of benefit on current or future projects.

Why the Increasing Demand?

There are many reasons why the demand for diagnostic water leakage testing has increased in recent years. One major factor is the changes and innovations in building façade technology itself: wall systems are taller, lighter, and more flexible than they have ever been. These advances often result in improved cost-effectiveness as well as greater exposure to environmental moisture, higher applied loads, larger deflections, and reduced water storage capacity. Modern wall systems have become increasingly complex (*Photo 1*) and reliant on maintenance-sensitive bridging materials within the system itself or where it interfaces with other building systems. Use of new, innovative materials often leads to compatibility problems with other systems that can accelerate deterioration or induce premature failure.

A good example of this impact of technology on façade performance can be seen in the contrast between solid masonry-wall construction and curtain wall systems. Masonry represents a stiffer, more rigid material that has the ability to absorb large amounts of moisture before it reaches the building interior, but it is somewhat limited due to its weight and lack of flexural strength. In contrast, a typical aluminum and glass curtain wall is less restricted by limitations of weight or height, but it offers comparatively little capacity for water storage in the event that water management systems fail.

Another reason often cited for the increase in demand for diagnostic water leakage testing is the boom in construction, which brings with it the associated challenges of maintaining high standards and a well-trained workforce, and for quality control procedures to keep pace with increased construction activity. In the end, it seems our need for quantity often outweighs our desire for quality construction.

There has also been an increasing focus on expectations of comfort within our buildings. We expect temperatures to be consistent, the air to be clean, and for ambient noise to be minimal. In the past, a small leak might have been overlooked or addressed with a strategically placed potted plant; now, our tolerance for nuisances

Photo 1 – The complex façades of "The Dancing House" by Frank Gehry in Prague, Czech Republic.

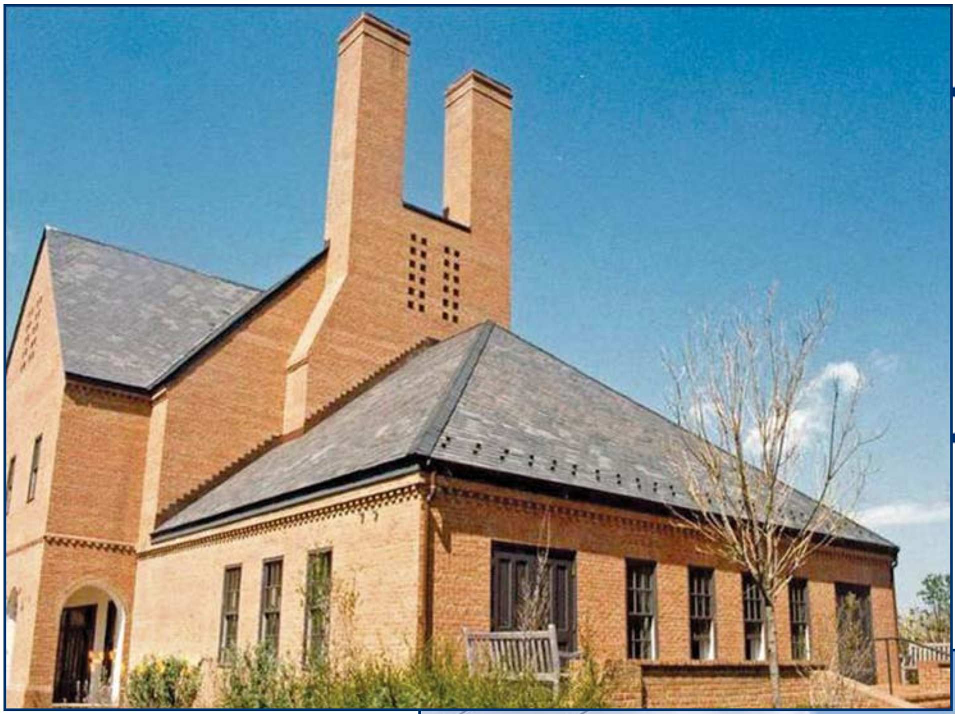

Photo 2 – Example of modern cavity wall construction.

Photo 3 – This wall system incorporates a drained window assembly in a continuous band.

such as drafts, poor lighting, or leaks in our workplaces and homes is far lower. We expect no leaks, no finish damage, no structural damage, and no uncontrolled water penetration.

Lastly (and perhaps most importantly) is what we have learned over the past several decades about leaks and their impact on the health of our buildings and their occupants. We have all become aware of the potential for mold growth and its associated health risks. What may not be as evident is the detrimental effect water can have on the integrity of our structures through corrosion and rot, the loss of thermal performance due to wet insulation, interior finish damage, freeze-thaw distress, or other moisture-related deterioration. In fact, uncontrolled water penetration and other forms of moisture ingress are two of the most common threats to the structural integrity and performance of the building envelope. Together, they have represented up to 80 percent of all construction-related claims in the United States in the recent past.[1] What is even more surprising is that 90 percent of all water-intrusion problems occur within 1 percent of the total building area.[2]

Understanding Building Façades

Building façades can be defined as the vertical components that are assembled to create the walls of the building envelope, including both wall and window assemblies. Virtually all building façade systems or components in use can be generally categorized into three types by how they control or resist water penetration: drained, barrier, and mass systems.

A **drained wall system** is composed of an exterior weathering plane or veneer and a drainage plane with provisions for collecting, controlling, and directing moisture from within the system to the exterior. It resists water infiltration – both by deflection at the exterior weathering plane and at the drainage plane. An example of a drained wall system would be a cavity wall (*Photo 2*). A drained window system is designed primarily to deflect water; however, water that does enter around the glazing perimeter is controlled within the glazing channel or pocket and redirected back to the exterior through weeps or open joints. Since the glazing channel can contain water, it requires internal seals to prevent water within the channel from reaching the building interior (*Photo 3*).

A **barrier wall system** is composed only of a weathering plane and resists water penetration by deflection only. Examples are precast concrete, metal, or stone-panel systems. They often rely on maintenance-sen-

Photo 4 – The precast concrete wall panels and spandrel glass in the curtain wall are barrier systems.

sitive materials to maintain a watertight skin, such as sealant or gaskets (*Photo 4*). In a barrier window system, gaskets or sealant are critical in resisting water penetration by keeping water out of the interior of the window assembly (*Photo 5*).

Mass wall systems are the oldest form of wall construction and are primarily composed of masonry materials such as brick or stone in single- and multiwythe configuration. They rely on deflection at the wall surface to resist water infiltration, but also on their ability to absorb and store moisture without its reaching the interior. The masonry then dries out slowly, freeing up capacity for more moisture. If the storage capacity of the mass wall is exceeded, water will reach the interior (*Photo 6*).

Photo 5 – An example of a structurally glazed barrier window wall assembly.

Photo 6 – This façade is a brick masonry mass wall assembly.

Moisture Sources

Building envelopes are exposed to three main sources of moisture: 1) liquid water from environmental sources such as rain and snow, 2) from groundwater migrating through the subgrade surrounding a building due to absorption/redirection of surface water or the natural water table, and 3) vapor drive associated with high differentials in temperature and humidity between the interior and exterior. While severe damage to our buildings can occur due to the latter two sources, rainwater is considered by far to be the major contributor to problems associated with water infiltration. It is interesting to note that rain deposition on roofs is often 20 to 40 inches per year in moderate- to high-exposure climates and that façades typically receive 25 to 50 percent of this load.[3]

Basis for Diagnostic Testing Methods – Quality Control

The basis for many of the techniques used to diagnose the source of leaks can be found in quality-control procedures developed for the curtain wall industry. The principal test methods used are largely based on testing standards developed and accepted by the American Architectural Manufacturers' Association (AAMA) and ASTM International, formerly the American Society for Testing and Materials. The quality-control test methods are voluntary standards and must be specified by the designer of a building to be enforced.

It is important to distinguish between quality control and diagnostic testing procedures; they are frequently confused due to the reliance on similar test methods. When testing is performed for quality-control purposes, it is typically associated with new construction and is intended to assure the parties involved that the window or wall system installed will perform to an expected minimum standard. It can be used to accept or reject products or installations that do not meet the expected standards.

The objective of diagnostic testing is to employ standardized test methods to isolate and identify a specific water leak source such that targeted corrective action can be taken to eliminate or substantially reduce future water ingress and associated damage to the building fabric. Diagnostic testing is not intended to evaluate whether a particular wall or window system is deficient or able to meet performance expectations, although it may lead to that type of evaluation if the system being tested is not performing as expected. Identification of the specific building systems that are deficient (windows, masonry, roof) is accomplished by replicating the prior water leakage using a systematic, verifiable, rigorous approach under controlled conditions whereby the leak's source can be traced and documented.

Commonly Used Testing Procedures

One of the more commonly used test methods for diagnostic purposes is AAMA 501.2, "Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing Systems." This test method is most often used to test joints within and between façade systems such as windows or metal panels. It employs a common ¾-inch inside diameter (ID) rubber water hose fitted with a standardized nozzle, with an applied pressure of 30 to 35 psi at a distance of 12 inches from the specimen. The application rate is 5 minutes per 5 feet of joinery within the test area. The flow rate, distance from the test area, and the duration of testing are often modified to narrow down or refine specific sources of water infiltration (*Photo 7*).

Another common test method is sill drainage testing. This technique is used to

Photo 7 – Nozzle testing in progress; note the minimal flow rate to isolate a specific leak source.

Photo 8 – This sill drainage test is being conducted without the glazing installed.

evaluate the drainage systems for window or curtain-wall systems that are designed to allow water to enter the glazing pocket where the glass is set. Water is directly introduced into the glazing pocket and maintained at a constant level, either by blocking the system weeps or continuing to introduce water into the system at the same rate it is exiting. The test durations should be a minimum of 15 minutes, though longer durations are preferred to allow time for water to migrate through interior finishes. A sill drainage test is suitable for testing joint plugs and other internal glazing pocket seals that are often not properly installed. The test can be performed with or without the glass in place. Its diagnostic purpose is to rule out drainage provisions within a glazing system as a leak source (*Photo 8*).

When it is helpful or necessary to completely expose a large area of a test specimen to a more widely applied, uniformly delivered flow of water and a simulated, wind-driven rain, the ASTM E 1105, "Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference," is often adapted for this purpose. Referred to informally as the "spray-rack" or "chamber" test, E 1105 consists of applying water to the outside of a test specimen and simulating exposure to rainwater (*Photo 9*) while simultaneously applying either a positive (exterior-mounted chamber) or negative (interior-mounted chamber) air pressure differential across the specimen to simulate the effects of a wind-driven rain (both with regard to air pressure differential and in-service deflection under applied wind loads). See *Photo 10*.

When used for quality assurance purposes, E 1105 can be run using a cyclic application of pressure and water (Procedure A), or as a static test in which the application of pressure and water remain unchanged through the test duration (Procedure B). The most appropriate test procedure depends upon the type of sample. The E 1105 test procedure can also be applied with or without the perimeter sealant/flashing interface included (identified as Method A or Method B) to help distinguish whether any identified problems are related to manufacturing of the window product or its installation.

The E 1105 test equipment consists of a modular grid of calibrated spray nozzles spaced at 24-inch centers. One of the major advantages of this test is the ability to create a rack that matches the test-specimen area by varying its dimensions within the 24-inch spacing parameter. The water pressure necessary to maintain the minimum flow rate used for this test of 5 gal/sf-hour will vary depending upon the rack configuration. For diagnostic purposes, the appropriate water pressure at the spray rack is the minimum necessary for the water leaving the nozzle to form a full cone. Often, multiple sources of water into the rack are necessary to supply larger rack configurations and maintain the desired test pressure. The pressurized chamber on the interior can be made from basic materials such as lumber and polyethylene sheeting. The pressure differential is induced by a blower and monitored with a manometer.

For use in diagnostic testing, it is recommended that an E 1105 spray rack be modular so that it can be configured for varying specimen dimensions, have multi-

Photo 9 – ASTM E 1105 spray rack in use on the exterior of an aluminum and glass curtain wall.

Photo 10 – Interior isolation chamber and test apparatus for a pressurized E 1105 test.

Photo 11 – A sealant breach (inset) was the leak source within this multicomponent wall assembly.

ple input locations, include a pressure gauge and shut-off valves, and be easily suspended for test specimens not at grade. Often, racks are constructed of galvanized steel, copper, or polyvinylchloride (PVC) piping with calibrated brass or stainless-steel nozzles. In the author's experience, application of the spray rack is excellent for finding and replicating leaks that occur on a regular and frequent basis. Once the leak is replicated in a particular test area, nozzle testing can be used to narrow down the specific source or sources.

Photo 12 – Plastic sheeting is used to isolate the window system from the wall panels during testing.

Photo 13 – Duct tape and putty are used to mask joints within a window to isolate a leak source.

Photo 14 – A spray rack in use to test the interior side of a parapet wall.

Diagnostic Testing and Evaluation Procedures

Diagnostic water leakage testing requires several procedures prior to, during, and after actual testing to aid in the selection of test locations and methods, and ultimately to confirm the results. They can be described as follows:

Due Diligence. It is important to gather the history of the reported leakage by interviewing building engineering staff or occupants who are familiar with the leaks; to review prior leakage reports; to compare as-designed and as-built construction documents; to review shop drawings for manufactured components such as windows or cladding panels; to identify the products or systems; to obtain manufacturers' literature regarding installation; and to understand the type and extent of any repairs previously performed.

Survey. To establish the best test sites or specimens, one must understand the condition of the building façade in the area of the leaks by performing a visual survey of the exterior building façade in the proximity of reported leaks. Document any visible conditions that could lead to water infiltration, survey the interior surrounding the leak locations, and identify any patterns of leakage or groupings of common types of water-induced damage.

Close-Range Examination. Once the test sites are selected, it is critical to examine them in detail and at close range. This helps confirm potential sources of water leakage, identify the systems that will be impacted by testing, establish the best sequence of testing, and determine if there is a need for isolation between systems or components during the tests (*Photo 11*).

Isolation. Isolation of specific components within a test area is often necessary to rule out known sources of water infiltration or to isolate specific conditions within a system that is deficient. Materials such as duct tape, polyethylene sheeting, and sealant can be used effectively to limit exposure of specific components to direct water during testing or overspray (*Photos 12* and *13*).

Execution of Testing. For successful water leakage testing, it is important to

Photo 15 – Moisture-sensitive paper indicating a leak at the window interior perimeter.

Photo 16 – Exterior inspection shows an opening exposing flashing deficiencies in a masonry cavity wall.

start broadly and narrow down to specific sources. Start at the bottom of a test specimen and work upward, confirming obvious sources first. Remember that everything in the test area will get wet; therefore, plan the isolation and test sequencing accordingly. Do not forget to rule out potential contributions to water leakage from the roof and parapets, since they can also cause leaks that appear to be façade-related (*Photo 14*).

Test Monitoring. During the actual testing, numerous activities must take place, including monitoring of test duration, water pressure, and air pressures (if necessary). The area of water coverage must be checked to make sure overspray will not impact the results. Spaces adjacent to the test site must also be checked for leakage; often leaks can be ongoing but go unreported and show up when inadvertently tested. Most importantly, it is critical to monitor any damage or evidence of prior water leakage within the test specimen to determine whether it is being replicated during the testing (*Photo 15*). Any apparent new leak sources should also be documented for later review.

Inspection Openings. Once the leaks have been replicated, inspection openings may be necessary to trace back to the specific sources, such as defective conditions concealed within the wall system. It is important to wait until after leakage is replicated and testing is complete so that any disruption from the inspection openings will not change the original leakage path (*Photo 16*).

BUILDING ENVELOPE KNOWLEDGE ASSESSMENT

Test your knowledge of building envelope consulting with the following questions developed by Donald E. Bush, Sr., RRC, FRCI, PE, chairman of RCI's RRC Examination Development Subcommittee.

1. **Why do compression seal windows generally provide better long-term air infiltration and water penetration resistance?**
2. **Describe four types of compression seal windows commonly used in today's construction.**
3. **Which drainage materials are used for below-grade enclosures?**
4. **Aggregate drainage layers include pea-gravel aggregate or coarse sands. What is graded pea gravel?**
5. **What are suitable coarse sands?**
6. **What is diffusive vapor flow?**
7. **What is advective moisture flow?**

Answers on page 26

Conclusion

Diagnostic water leakage testing has become more widely utilized as a result of increased intolerance for water leaks and the problems associated with them. Understanding façade construction (as well as the appropriate test procedures and practices) to determine the source of water leaks is essential to correcting them. Correct diagnoses of water leakage sources can also prevent further deterioration of façades. The knowledge and experience gained through evaluating and diagnosing water leaks are also invaluable in avoiding conditions that increase the risk of water infiltration in future construction.

Acknowledgement

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References

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2 Ibid.

3 Lstiburek, J., "Moisture Control for Buildings," *ASHRAE Journal*, February 2002, pp. 36-41.

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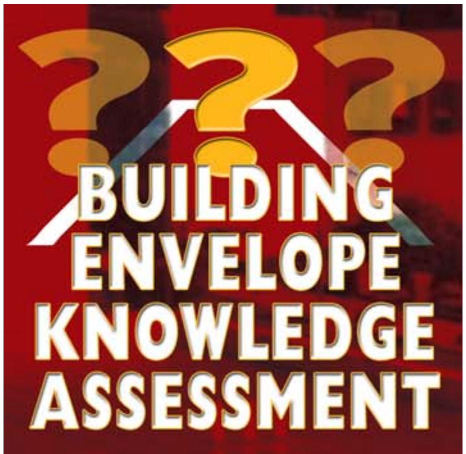
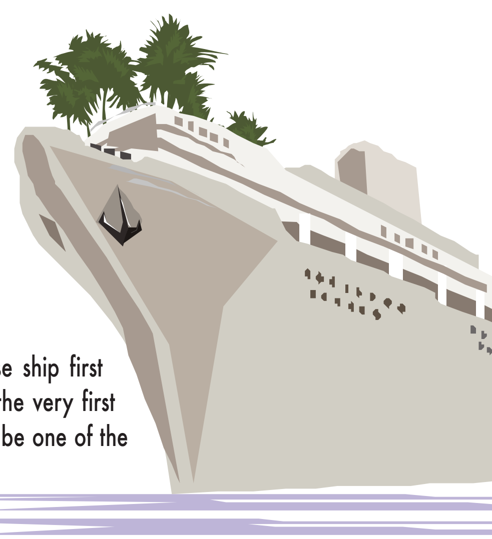


Answers to questions from page 25:

1. **Compression seal windows reduce friction and wear on the weather stripping.**
2. **A) Awning (top-hinged, project-out bottom).**
   B) Hopper (bottom-hinged, project-in top).
   C) Casement (side-hinged, project in or out)
   D) Pivoted (vertically or horizontally pivoted windows).
3. **A) Aggregate drainage layers.**
   B) Prefabricated synthetic drainage layers.
4. **Naturally rounded stone between 3/16-in and 3/8 inch-in diameter.**
5. **Coarse sands varying from No. 30 to No. 8 sieve.**
6. **The transfer of moisture in its gaseous state through the various layers of an exterior wall system or assembly.**
7. **The bulk movement of air as a mechanism for the transfer of moisture in its vapor state across an exterior wall system or assembly.**

Reference: **Postma, Mark, PE, "Building Envelope Design Guide – Below-Grade Systems,"** ***Whole Building Design Guide*****, Carl Walker, Inc., National Institute of Building Sciences, 2008, (http://www.wbdg.org/design/env_bg_overview.php).**

CRUISE SHIP RECEIVES FIRST GREEN ROOF OF ITS KIND



When the new Celebrity Solstice cruise ship first pulls anchor on its inaugural trip this fall, the very first green roof installation on a cruise ship will be one of the many amenities passengers will find. The " Lawn Club" will span the upper deck of the ship for over half an acre. It will include a practice putting green/croquet court, two grass bocce ball courts adjacent to a patio bar, and an oversized chess and checkerboard.

This will be the first of four 122,000-ton ships by Celebrity to offer a living lawn for recreational activities. W.P. Hickman Systems has been selected to provide the green roofing system for all four ships. Its parent company, A.M. Technologies, will be responsible for final design elements, installation, and long-term maintenance. As part of the full-service package, Celebrity will also receive a W.P. Hickman warranty on the entire system.