Doing It Right the *Second* Time –

Designing Minimally Invasive, Cost-Effective Solutions for Window Repair vs. Replacement

By David Boyer, Ron Tatley, and Paul Grahovac

Many well-built or recently repaired structures continue to leak air, water, and energy through the building envelope in spite of the best efforts of construction professionals.

Since many leaks are first seen around windows, many property owners conclude that the only way to eliminate leaks and improve the comfort and efficiency of their buildings is complete window replacement. The considerable time and inconvenience of such an undertaking, however, frequently delays essential repairs until damage caused by those initial leaks progresses beyond the scope of available funding.

Working with those same property owners, qualified leak investigation and repair professionals, utilizing real-world performance testing and forensic investigation, can often develop minimally invasive, high-performing repairs that reduce waste and dramatically improve the performance of existing windows.

VARIETY OF CAUSES

Many standards that govern the design and construction of high-performing buildings fall short of performance expectations. Leaking windows are a good example.

Standardized blower door tests to evaluate building airtightness do so at pressure differentials that simulate mild weather conditions. Those pressure differentials do not begin to approach the moderate-to-severe weather events that cause initial water penetration and create a pathway for future leakage at lower pressures.

Design pressures that windows are required to meet assume that some water leakage is acceptable when the window is exposed to wind-driven rain that exceeds 15% of the design load…acceptable until it's your window that leaks.

Then, there is the growing variety of self-adhering membranes, flashing tapes, fluid-applied sealants, foams, and other components intended to fill, waterproof, and air-seal the gap between the building's rough opening and the window assembly.

Figure 1 – A puddle beneath the window causes most property owners to suspect windows are leaking. When simple efforts to stop the leakage fail, many surrender to the costly cycle of window replacement.

Many of those components are difficult to fit, or they exhibit incompatibility with one another or the conditions under which they are installed. In many instances, this causes water to leak around—rather than through—the window itself.

Whatever the cause of a water leak—the window, the integrity of the rough opening, or the marriage between the two—is irrelevant. People suffering the consequences of water leakage blame the window. That phenomenon often leads competent and cost-conscious building professionals down the path of full window replacement before even considering the possibility of a less-invasive and lower-cost alternative of window repairs.

This article discusses the use of design verification testing to isolate the cause of water leakage. This allows existing windows to be repaired and their performance to be improved as an alternative to more invasive and costly window replacement (*Figure 1*).

ONE STEP FORWARD, TWO STEPS BACK

Through the closing decades of the 20th century and the years since Y2K, increasing expectations for building occupant comfort have been matched by mechanical systems that are more efficient at pressurizing and conditioning interior spaces.

Over the past two decades, pursuit of improved energy efficiency has prompted more liberal use of insulation, expanding foams, and high-performance windows.

Coupled with code-mandated interior vapor barriers, water-resistive barriers, air barriers, and durable exterior finishes, such design improvements have made the prospect of owning a truly energy-efficient building seem well within reach. This has pushed a group of environmentally conscious, "deep-green" designers to pursue the dream of homes, apartments, and businesses that produce and store sufficient energy to avoid the need to be connected to public utilities.

Figure 2 – Energy-efficient walls that incorporate windows constructed with multi-layered, gas-filled, insulated glass with low-e films and thermally efficient window frames make it easy to justify an increased footprint and a higher window-to-wall ratio.

Today, the positive impact that a small percentage of "energy-neutral" structures has made on our nation's energy demands is easily overshadowed by design professionals who embrace this trend for more marketable reasons. Energy-efficient wall assemblies that incorporate windows constructed of multilayered, gas-filled, insulated glass with low-emissivity films and thermally efficient frames make it easier to justify the larger floor plans and higher window-to-wall ratios that prospective buyers demand (*Figure 2*).

IS THE PROBLEM THE WINDOWS OR THE INSTALLATION?

While sample window installation may be easy to detail or mock-up under ideal conditions, executing those details under less-than-ideal weather conditions can be challenging. Factor in contractors pressed to stay on tight construction schedules using inexperienced labor and outmoded materials, and it's easy to understand why a higher number of windows—even better-performing windows—increases the likelihood of water penetration in modern buildings (*Figure 3*).

To get high-performing windows, and building owners and occupants who are happy with the windows' performance for more than a few years, we need to rethink how we install those windows.

Continuing to install windows the way we have been installing them reduces the service life of modern buildings. Why? Because as both our walls and our win-

Figure 3 – Want to know why a window leaks? Install windows.

Figure 4 – The leak that got away.

Figure 5 – Perimeter window flashing that performs as an air and vapor barrier prevents drying of water that is trapped or accumulates between the window and the rough opening.

dows become more resistant to air moving through them, we sacrifice their ability to dry. And their ability to avoid wetting is now disproportionately dependent upon a connecting transition that, for most windows, is poorly designed and impractical to execute.

Minor leaks or condensation that may have gone unnoticed just a generation ago now accumulate within rough openings and the adjacent, air-sealed wall assembly. That water causes progressive decay of interior finishes or the structure itself. Once initiated, such water-related decay can quickly snowball out of control and cause mold growth (*Figure 4*).

BUT IT'S NOT JUST THE WINDOWS, IS IT?

Much of the water-related decay in modern buildings can be traced back to poor design or execution of critical building details that are unrelated to windows. This point is rightly made in the recently adopted ASTM E2128-12, a field standard for evaluating water leakage.[1]

However, in more than two decades of leak investigation and lasting repairs to modern multifamily and mixed-use buildings by contractor Tatley-Grund Construction Repair Specialists, the windows—or the way those windows are installed—have consistently contributed more water leakage than any other building detail. This observation holds true for new or recently constructed buildings and for an alarming number of recently repaired buildings. In some cases, water leakage can be traced back to use of individual or ganged windows, which, though code-compliant, are not capable of withstanding moderate-to-severe weather events. That should not be a surprise: codes are minimum standards.

Then there's the issue of integrating—or failing to integrate—that transition with the primary weather-resistive barrier (WRB) or air barrier (AB). Given the variety of window claddings, self-adhering tapes, fluid-applied sealants, and WRB or AB materials in use today, durable product compatibility is critical

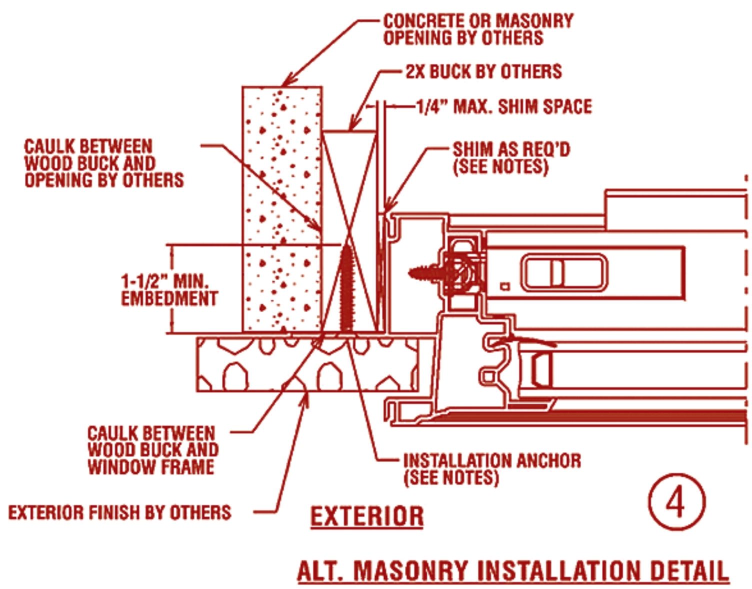

Figure 6 – Popular window installation detail.

at these transitions.

Many of these materials perform as air and vapor barriers. Most are marketed more for their ability to prevent penetration of unwanted air or rainwater than for their capacity to accommodate drying of water that may be present or accumulate within the walls (*Figure 5*).

Keeping water out of the wall assembly is a good thing. Keeping water in? Not so good.

Figure 7 – When using a shingled series of straight and flexible flashing or both to waterproof the rough opening, it is easy to underestimate the impact several layers of thick membranes have on the distance between corners of the rough opening.

THE DEVIL IS IN THE DETAILS

On projects in which Tatley-Grund is involved, the rate and severity of window failures caused by a poorly designed marriage between the window assembly and the structural wall are increasing. Either the connections are not continuous, or the materials used to execute those connections are incompatible with one another or incompatible with conditions under which most construction is carried out (*Figure 6*).

Figure 8 – This fiber-reinforced hybrid liquid-flashing membrane is designed to become totally opaque when applied at the proper 12- to 15-mil thickness.

It is not uncommon for adhesive failure to occur between layers of materials days or months after installation. Often, components of the overall water management/waterproofing system are cut short, insufficiently lapped, or reverse-shingled, causing bulk water to funnel directly into the wall assembly or interior spaces under even modest pressure differentials.

One of the most common problems relates to use of premanufactured, self-adhering flashing membranes. Today, most window manufacturers recommend a shingled series of straight, flexible, and pleated flashings to waterproof the rough opening before installing the window.

While such details seem logical on paper, many are impractical to execute and fail to consider the impact that several layers of thick self-adhering membranes have on the distance between corners of the rough opening (*Figure 7*).

There is an answer to this problem. Durable, fluid-applied flashing membranes eliminate the need to sequence, measure, cut, prime, crease, and stick layer upon layer of self-adhering flashing tapes to the perimeter and inside corners of rough openings. Formulations exist that tolerate wet conditions, fill cracks, adhere to most building materials without a primer, are immediately waterproof, and allow moisture that may have collected in the wall assembly to dry out due to their vapor permeability (*Figure 8*).

In the hands of experienced installers, such products save time, avoid most weather-related delays, and eliminate fish mouths and water-channeling interfaces. They simplify a waterproof and airtight installation of window assemblies, in part because they have minimal impact on the rough-opening dimension. This makes it easier and faster to install the window and a seamless, continuous air and water seal between the window and the rough opening.

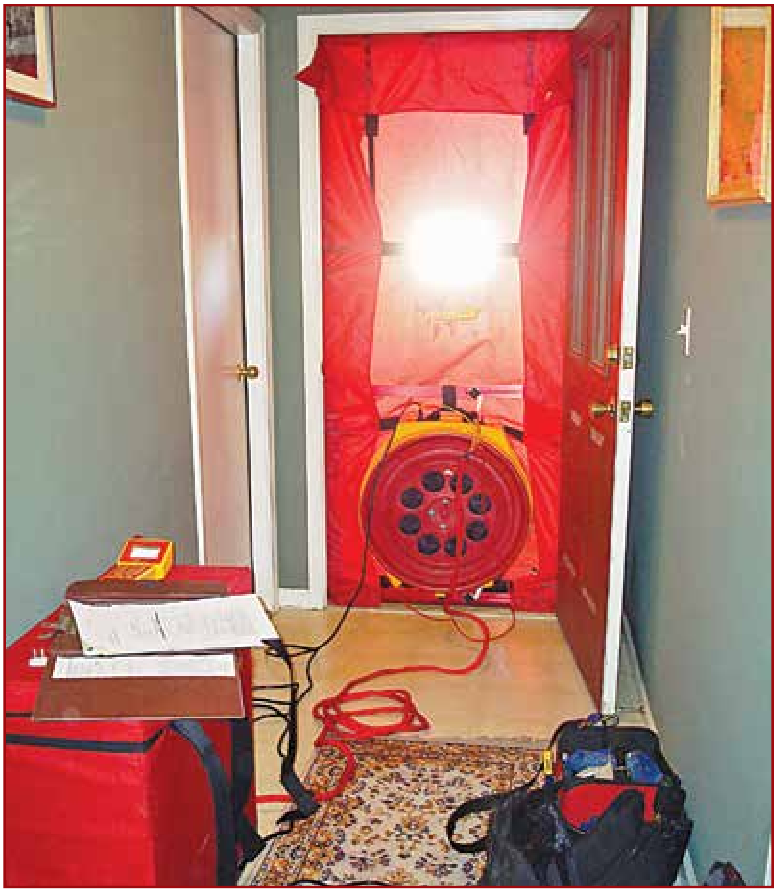

Figure 9 – This flexible, airtight, perimeter-sealed blower door is fitted with a variable-speed fan and at least two pressure gauges—one outside, one inside. The gauges measure the pressure differential across the building envelope. After closing all windows and doors to isolate the test area, the fan depressurizes the conditioned space until a pressure difference of 50 Pascals is achieved across the building envelope. (This is roughly equivalent to 0.2 in. of water column, a 20-mph wind, or 1.04 lbf/ft^2.) If the wall leaks, more fan pressure is required to maintain 50 Pascals. That fan pressure is then converted to a measurement of air leakage usually reported as air changes per hour at 50 Pascals (ACH50).

So why haven't more window producers embraced the use of fluid-applied flashing? Because in spite of the rapidly evolving demand for more efficient and sustainable structures, many facets of the construction industry remain slow to change. In a March 12, 2013, communication with a leading window manufacturer, the company president commented, "In manufacturing of our windows, we do not take responsibility for the installation. Seldom do we experience a claim, but we recognize that the blame often does come back to the window manufacturer rather than the installer."[2]

Many window producers refuse to endorse any installation methods, or merely defer to outdated, industry-sanctioned best practices that have been embraced by window installers over the past 10 to 20 years.

ATTENTION: THERE WILL BE A TEST

Over the past decade, Energy Star® and other evolving building standards have stressed the importance of air sealing around windows and doors as a means of achieving the goal of energy-efficient buildings. This has prompted development and promotion of many of the window flashing and air barrier products illustrated and discussed above.

As each newly implemented building or energy code is enacted, design professionals and the individual building trades have slowly embraced products and processes designed to improve air sealing, albeit in a somewhat haphazard fashion.

As early as 2009, some cities in the U.S. began requiring most new construction to be blower-door-tested (*Figure 9*) as part of the commissioning process. This standardized test method creates a pressure differential across the building envelope and measures air loss through individual windows, rough openings, isolated rooms, or entire living units. For large structures, energy auditors employ more than one fan or multiple blower-door units.

The purpose of blower-door testing is to determine whether certain airtightness targets are being met. In the past, most testing was conducted at or near the end of the construction process, leading many testers to adopt a simple pass-or-fail grading criteria. The theory is if you pass the test, you have earned bragging rights; if you fail the test, you will try harder the next time.

Even if you took time to isolate a particular crack or point of air leakage over the past ten years, few builders had the luxury of resources or time to deconstruct wall sections in pursuit of repairs, particularly when passage of the test was not code-mandated.

Today, forward-looking cities like Seattle—jurisdictions that view building and energy codes as aspirational tools to help push our industry forward—have begun putting some teeth into their commercial building codes, making failure to achieve acceptable airtightness standards increasingly onerous for members of the construction team.

Duane Jonlin, energy code and energy conservation advisor for the city of Seattle, Department of Planning and Development, makes these points in his department's online publication, *Building Connections*:

- Continuous air barriers ... have been required by the Seattle energy code for more than a year now.
- The air barrier must be pressure-tested, typically using a "blower door" apparatus.
- For a 2,000-square-foot house, air leakage is limited to about 1,500 cubic feet per minute.
- These dwelling units must pass the air leakage test to get a Certificate of Occupancy.
- For all other buildings in Seattle, the air leakage rate ... must be less than 0.40 cubic feet per minute for each square foot of building envelope, at a pressure of 1.57 lbf/ft^2.
- In future code cycles, passing the test will likely be mandatory for all buildings.[3]

In other words, what used to be good enough a short time ago will not be good enough in the very near future.

Even now, the 2012 International Residential Code and the U.S. Army Corps of Engineers require that whatever repairs are necessary to pass the test be made.

DOES AIR LEAKAGE EQUAL WATER LEAKAGE?

It depends. Most construction professionals recognize that if you can effectively waterproof a crack or building transition to prevent water leakage during weather conditions common for a given location, you will stop the unwanted passage of air.

But that does not mean that connections that achieve a passing grade on a blower-door test will withstand peak wind pressures that accompany frequent rain showers in many parts of the country. Remember, the blower-door test simulates a pressure differential that is roughly equivalent to a 20-mph wind. It's not uncommon for wind-driven rain to exceed 20 mph, particularly on upper elevations. Field and test-chamber demonstrations have shown

Approximate Timeframe: 10 to 12 months

Construction Hard Costs	
Access – fixed-frame scaffolding with safety and weather enclosure	$240,000
Demolition, disposal, or both of construction waste at $0.65/lb.	$240,000
Window and door replacement	$320,000
Flashing, coatings, and sealants	$200,000
New three-coat stucco cladding	$685,000
Interior finish restoration	$90,000
General conditions	$225,000
Subtotal Hard Costs	$2,000,000
Construction Soft Costs	
Investigation and compilation of construction documents	$125,000
Relocation of tenant, owner, or both, including additional living expenses, rent concessions, or both. (Many condominium owners rent their units out and are subject to rent concessions.)	$300,000
Loss of business	$100,000
Attorney costs at 30% to 33% of hard costs	$650,000
Subtotal Soft Costs	$1,175,000
TOTAL PROJECT COST	**$3,175,000**
Per Unit Cost ($3,175.00 ÷ 50 units)	**$63,500**

Table 1 – Full window replacement, stripping, and recladding project.

one wind gust of 35 mph or higher can cause sufficient deflection in some window assemblies to compromise perimeter sealants and establish a pathway for leakage. Repetitive testing proves that leakage of air and water in those same locations will occur in subsequent weather events at greatly reduced wind speeds.

THE WELL-DESIGNED, PERFECTLY ASSEMBLED, LEAKY BUILDING

This case study involves evidence of water penetration and superficial damage to interior finishes. There is no evidence of structural decay in the wall assembly. The fit and finish of all exterior claddings is of the highest quality.

The structure is a mixed-use facility built in 2008 with more than five stories, including ground-floor retail and common areas with luxury condos above. Fully occupied, the energy-efficient complex includes 350 windows and 50 sliding-glass doors that access balconies.

The construction is stick-frame with oriented strand-board sheathing with two layers of WRB; metal lath; and traditional, 7/8-in., three-coat hard stucco. It is located on a sloped urban site with limited street access and site storage.

Preliminary field-testing conducted in accordance with AAMA 511-08, *Voluntary Guideline for Forensic Water Penetration Testing of Fenestration Products*, revealed that 15 of 20 sample windows leak air and water. There is evidence of water leakage and minor interior damage in several additional units. There is no evidence of structural damage.

The building envelope consultant who conducted all preliminary field investigations concluded that a majority of the windows are in a state of progressive failure. His report prompted the property manager, on behalf of the homeowners' association (HOA), to approve total window replacement

Due to the building's geometry and the proportion of finished wall versus window or sliding-glass doors, the most cost-efficient window and door replacement included a total strip and reclad of all exterior finishes.

The cost estimates in *Table 1* for the full window replacement are based on similar projects completed over more than 20 years in and around Seattle. That is what the owners thought they would be forced to do. The repair program reflects what was actually paid for a durable repair.

The general contractor who prepared the bid offered the following warranties:

- Two- to five-year workmanship warranty provided by the contractor
- More than ten-year limited warranty provided by the manufacturer(s) of the replacement windows and doors

To fund the project, the HOA can hire a lawyer to file a multiparty claim against the:

1. Original developer or general contractor and subcontractors, or both, provided the state of Washington statute of six years (four years for condominiums) has not expired. These statutes vary by state.
2. Original window manufacturer's limited warranty. Note that the warranty's limitations may cover only a small percentage of the total project costs.
3. First-party property insurance. In years past, this would be the most straightforward claim for damage to real property. Today, many insurers limit coverage for damage caused by water penetration and require proof of significant structural damage or imminent collapse before participating in costs of needed repairs. In this case, the absence of structural failure makes a successful insurance claim highly unlikely.

Alternatively, the HOA can pursue bank financing to fund necessary work immediately, or initiate an affordable special assessment that delays work until funds are available.

Of course, the cost and extent of additional repairs needed in the future cannot be predicted. Costs will likely increase. Additional monies may be needed to address structural repairs that begin and progress during a lengthy fundraising period.

Compare the estimated costs in *Table 1* with a proposal for window repairs on the same project (*Table 2*).

A different general contractor, who prepared the bid for window repairs shown in *Table 2* using the design verification testing (DVT) approach, offered a contractor warranty of two to ten years.

Repairing versus replacing yields savings of approximately $50,000 per unit and minimizes site disruption. The HOA can hire a lawyer to file a multiparty claim against:

1. The original developer or general contractor and subcontractors, or both, provided the state of Washington statute of six years (four years for

Approximate Timeframe: two to three months	
Construction Hard Costs	
Access – swing stage or man lift	$100,000
Demolition, disposal, or both, of construction waste at $0.65/lb.	$75,000
Window repair	$275,000
Finish restoration of interior, exterior, or both.	$50,000
General conditions	$50,000
Subtotal Hard Costs	$550,000
Construction Soft Costs	
Investigation and compilation of construction documents	$25,000
Relocation of tenant, owner, or both, including additional living expenses or rent concessions, or both. (Many condominium owners rent their units out and are subject to rent concessions.)	$0
Loss of business, minor disruption	$10,000
Attorney costs, if legal settlement is required	$100,000
Subtotal Soft Costs	$135,000
TOTAL PROJECT COST	**$685,000**
Per Unit Cost ($685,000 ÷ 50 units)	**$13,700**

Table 2 – Site-tested, design verification testing (DVT), chamber-verified window repair project.

Figure 10 – In this photo, the joint between the window and the wall opening is masked to determine watertightness of the window unit. By masking the window unit and repeating this same test, the watertightness of the perimeter joint can be determined.

condominiums) has not expired. These statutes vary by state.

2. The original window manufacturer's limited warranty. Note, that warranty's limitations may exclude or cover only a small percentage of the total project costs.

Alternatively, the HOA can pursue bank financing to fund necessary work immediately, or initiate an affordable special assessment that delays work until funds are available.

In our experience, lawyers working for HOAs are more likely to recover 80 to 100% of a $685,000 repair project than 50 to 75% of a $3,175,000 strip/replace/reclad project.

SO HOW ARE THE SAVINGS OUTLINED HEREIN ACHIEVED?

Savings are achieved through design verification testing. Design verification testing arrives at creative ways to arrest window leaks with repairs to portions of the window or window installation (or both) that are easiest to access for removal and testing. To arrive at such solutions, it is common for at least one representative of each existing window type to be removed for detailed evaluation so that others may be repaired in place.

The term "design verification testing" is derived from concepts inspired by John A. Burgess in his book *Design Assurance for Engineers and Managers*. In a section titled "Design Verification," Burgess describes the objectives of:

- Development tests conducted ...for determining the feasibility of design ideas and gaining insights that further direct the design
- Prototype tests that generally stress the product up to and beyond specified use conditions and may be destructive
- Proof tests used to identify where eventual failures might occur
- Nondestructive acceptance testing conducted on random or specified samples[4]

The baseline field testing related here relied on a combination of traditional methods outlined in ASTM E1105, *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.* AAMA 511-08, *Voluntary Guideline for Forensic Water Penetration Testing of Fenestration Products*, was also conducted at the request of the owner's attorney.

Such traditional pass-or-fail testing typically relies on external spray racks calibrated to deliver a minimum of five U.S. gallons of water per hour per square foot. These spray racks are calibrated to deliver six gallons per hour (*Figure 10*).

Using a simple wooden frame, tape, polyethylene, weather stripping, and a vacuum, an interior chamber is constructed to create a test pressure difference of 0.55 in. of water column (137 Pascals, just less than a 34-mph wind, or 2.86 lbf/ft^2).

Often, both tests described above result in water penetration.

Though short-term fixes—a little caulk here, some more there—may yield passing results, the window may still leak under fairly average rainy-day conditions. Then those short-term fixes just mask the underlying problem. The better response is to carefully remove the window to determine the actual pathway(s) of failure. After all, what happens when the winds gust to 35 mph?

When leakage occurs, the window being tested has failed. The time, visible point(s) of failure, and pressure differential are noted. The window is then carefully removed to reveal the size, geometry, and detailing of the rough opening.

In Example 1, we selected an easily accessible, failed window of the owner's choosing that minimized damage to the surrounding claddings. The window was then replaced with a temporary, weathertight enclosure.

Figure 11 – Mobile DVT chamber.

The DVT chamber used on this project is mobile. This allows the chamber to be located on-site to streamline the testing process (*Figure 11*). A side benefit of on-site DVT testing is that other members of the construction team, the owners, or their

Figure 12 – Calibration of the mobile DVT chamber.

representatives can witness and participate in the testing and proofing process. This improves understanding and acceptance of the final repairs.

Before initiating any testing, the mobile DVT chamber's calibration is verified in accordance with ASTM E783-02 (2010), *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors*; and ASTM E283-04 (2012), *Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen* (*Figure 12*).

Once calibration is confirmed, the rough opening is replicated in the test chamber to create a removable assembly mock-up. The field installation materials and methods for the rough-opening treatment and window assembly are replicated as closely as possible.

The DVT chamber is then charged to match test pressures used in the baseline field testing described above. Evidence of leakage occurring at the same time, pressure, and locations as determined in the baseline field-testing confirm the accuracy of the DVT mock-up.

But understanding the cause of leakage and designing an effective repair require more than pass-or-fail testing. This is where more advanced test chambers and the concept of DVT come into play (*Figure 13*).

The accuracy and pressure capabilities of the mobile DVT chamber allow for precise measurement of air leakage through the specimen up to structural design loads that are typical for most modern wall assemblies. After all, is it not reasonable to expect our buildings to remain watertight as long as the structure remains intact?

In the case study detailed here, such capabilities were critical in determining the cause of widespread window leakage, and to the design of a lasting repair. The findings included the following:

- Negative air pressure testing revealed that the glazing tape had been intentionally cut (in attorney speak, "disabled") to allow the insulated glass units (IGUs) to be adjusted. This created one pathway for failure.
- The glazing tape appeared to have been disabled in order to adjust the alignment of deflected horizontal mullions in ganged window units.
- Removal of the glazing bead and glazing tape revealed additional setting blocks placed on top of lower IGUs to support the horizontal mullion. The excessive loading this produced created another pathway for failure and helped to explain similar deformities of horizontal mullions in a majority of the windows on the project.
- Deformities in the horizontal mullions caused the glazing beads to exert uneven pressure on the underlying glazing tape. For some windows, glazing beads were cupped sufficiently to channel water into the window assembly, creating another complex pathway for water entry (*Figure 14*).
- Removal of the IGUs allowed closer inspection of the window frames. Partial disassembly of the frame revealed that the reinforcing steel was insufficient to prevent further deflection of the horizontal mullions. Under high winds, such added deflection created another pathway for failure.

The findings outlined above relied on the company's ability to conduct testing under

Figure 13 – The mobile DVT chamber is designed to provide testing capabilities that can simulate wind pressures and rainfalls far in excess of a 155-mph Category 5 hurricane. This is possible by use of construction detailing, methods, and materials commonly found on commercial fishing vessels. The interior is accessed by a sliding glass door produced specifically for this test chamber. When closed, the door provides visual access for testing in progress. The closed chamber has zero extraneous airflow. A laminar flow element (far too expensive for routine field testing) precisely measures airflow.

positive and negative pressure differentials of up to 1.15 in. of water column (286 Pascals, just less than a 49-mph wind, or 5.98 lbf/ft^2). The cause of additional water leakage—pathways of failure that were not apparent from typical baseline field-testing—was revealed at these still relatively low test pressures. More importantly, testing identified several low-cost components of the window assembly that could be replaced to improve performance of the existing windows and to stop the water leaks.

The higher test-pressure capabilities of the DVT chamber also made possible the design of an aluminum "strongback" to reinforce the critical horizontal mullions. Once installed, the strongback (*Figure 15*) allowed the repaired window to withstand pressure differentials that exceed the building's structural design load and all of the window manufacturer's original performance data… for the first time.

The prototype repair package included the following:

Figure 14 – Deformities in the horizontal mullions caused the glazing beads to exert uneven pressure on the underlying glazing tape. For some windows, glazing beads were cupped sufficiently to channel water into the window assembly, creating another complex pathway for water entry.

- Existing glazing beads and glazing tape were removed.
- Individual IGUs were temporarily removed.
- The horizontal mullions were heated to correct deformation.
- The aluminum strongback was bonded and mechanically fixed to the interior face of the horizontal mullion and the rough opening.
- The original setting blocks were installed at proper spacing.
- The original IGUs were reinstalled.
- An upgraded glazing tape with

increased durometer and bite was installed.

- New glazing beads were installed.
- The interior face of the aluminum strongback was painted to match interior trim.
- Minor damage done to interior finishes was repaired and repainted.

After reinstalling the repaired window prototype in its original rough opening, the baseline field testing described above was repeated. The system then passed.

Minimally invasive repairs were then carried out on all windows.

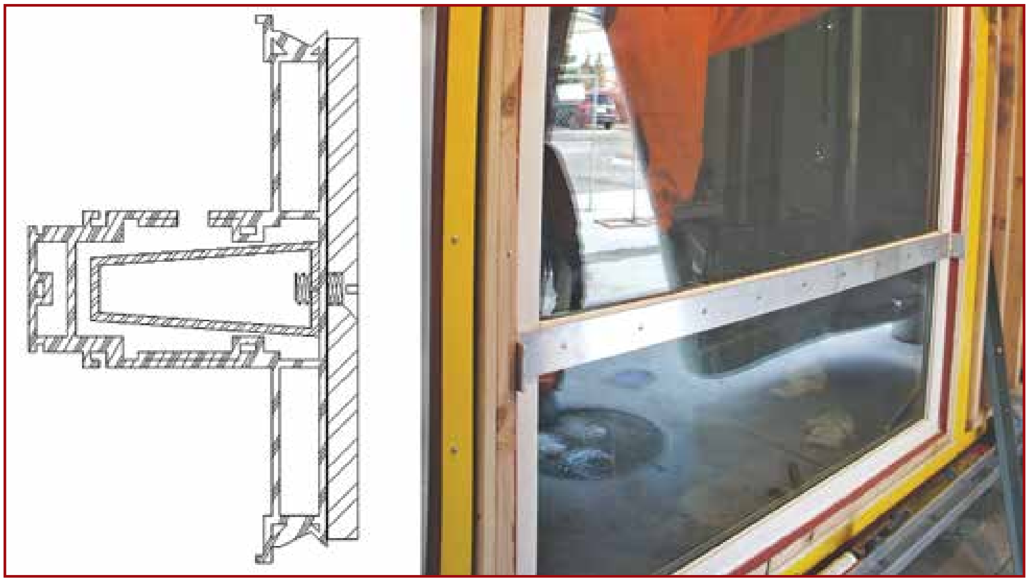

Figure 15 – Once installed on the repaired window, the aluminum strongback was tested and passed at 11.53 in. of water column (2,872 Pascals, 155-mph wind, or 60 lbf/ft²).

CONCLUSION

The purpose of this article is not to suggest that window replacement is never a good idea. There are lots of leaky windows that were a poor choice in the first place, or may have been so badly compromised during installation that the only responsible remedy is full replacement. In those cases, there are many North American producers of high-performing, high-quality windows from which to choose. Seek out manufacturers that recognize and endorse the role that proper handling and installation play in achieving the promised performance and longevity of their product.

Many and perhaps most of the buildings constructed over the past ten years, however, have already invested in high-performance windows. Using the techniques described above, many of those windows can be repaired in place to achieve a higher level of performance than they have yet achieved over their short history.

Addressed early in the building's life, such repairs are affordable and can arrest and prevent more costly structural damage before it gets out of control.

The savings such opportunities represent—in time, money, resources, and inconvenience—do more to promote building sustainability than any other intervention we can make in existing buildings.

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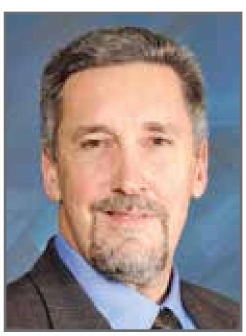

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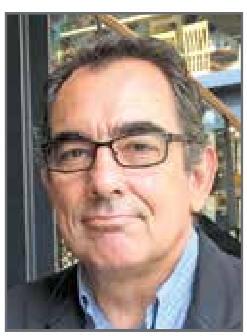
David Boyer joined PROSOCO in 1980, serving as its president since 1992 and its CEO since 2012. He also acts as a director for Architectural Materials Testing Laboratory and Building Envelope Analysis. Boyer has written and lectured extensively on the topics of cleaning, protecting, and preserving masonry construction; finished concrete flooring; the importance of air tightening in building retrofits; and the role of air barriers in durable, energy-efficient construction. Boyer earned a degree in architecture and urban design from the University of Kansas.



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