Water-Penetration and Air-Leakage Testing of Flanged Commercial Windows

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Images courtesy of Keith Simon

Figure 1. Examples of commercial aluminum flanged windows.

Flanged windows are typically considered a product for low-rise residential buildings, and unflanged window systems (curtainwall, window wall, storefront) are typically considered products for commercial and high-rise construction. A new type of window system is becoming more common on high-rise construction: flanged, aluminum windows designed for high-rise buildings (**Fig. 1**). While numerous industry standards exist to guide the installation of flanged windows in low-rise construction, the only guidance that exists to inform best practices for the installation of higher-performance flanged windows in high-rise construction comes from manufacturers for their specific systems.

Figure 2. Tremco testing facility in Cleveland, Ohio.

Terracon Consultants Inc. and JE Dunn Construction partnered in 2017 to perform water-penetration and air-leakage testing of flanged window details, which resulted in a chapter in the ASTM International publication *Whole Building Air Leakage: Testing and Building Performance Impacts*.[1] For the purposes of this article, the results of this 2017 testing will be referred to as round 1 testing. While valuable conclusions resulted from that collaboration, the team was limited in their testing capability. Therefore, Terracon and JE Dunn have now partnered with Tremco to expand upon our previous research efforts. Tremco has a large, sophisticated testing facility in Cleveland, Ohio, that provides controlled indoor laboratory testing capability and the capacity for a much greater quantity of tests compared with the initial 2017 study (**Fig. 2**). Our 2020 research efforts, for the purposes of this article, will be referred to as round 2 testing. This research and collaboration effort regarding window details is part of a greater effort to establish a high-rise detailing manual greatly needed by our industry.

Testing	Research team	Air-leakage test method	Water-leakage test method	Mock-ups 1-6
Round 1 (2017-2018)	Terracon, JE Dunn	ASTM E783 (field test)	ASTM E1105 (field test)	Mechanically fastened WRB system
Round 2 (2019-2020)	Terracon, JE Dunn, Tremco	ASTM E283 (lab test)	ASTM E331 (lab test)	Fluid-applied WRB system

Note: WRB = water-resistive barrier.
Table 1. Summary of the two rounds of testing.

Research methods for both round 1 and round 2 testing consisted of construction of full-scale wall mock-ups with window "blanks" installed with distinct integration details with the surrounding air- and water-resistive barrier system(s). The window blanks and air- and water-resistive barrier system(s) act as controls within the testing and therefore allow the integration details themselves to be isolated and quantified in terms of water- and air-leakage performance. The round 1 testing utilized a mechanically fastened water-resistive barrier (WRB) system, and the round 2 testing utilized a fluid-applied WRB system. Both rounds of testing utilized the same six mock-ups/integration details. Test methods used for the round 2 testing were ASTM E331, *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference*,[2] and ASTM E283, *Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen*.[3] **Table 1** summarizes the two rounds of testing.

A significant amount of testing and data within the building industry is available for air barrier systems (e.g., mechanically fastened WRB, fluid-applied WRB, sheathing board with integral WRB). There is also a great amount of testing and data within the building industry for manufactured products, such as windows, doors, and louvers. However, there is a lack of knowledge within the building industry of how these products are integrated into air-barrier systems to prevent air infiltration and water penetration. The goal of the ongoing research project described in this article is to use test methods to evaluate detailing at the integration between fenestration products and air systems. This study will not evaluate or compare air-barrier systems or products. However, it aims to specifically evaluate the integration details with respect to both air and water, and how well products are designed and integrated with the building's primary air- and water-resistive barrier systems.

Multifamily construction has seen tremendous growth in recent years and is projected to continue growing for at least the near term. Flanged windows are a dominant window type in multifamily construction. In round 1, the research team tested flanged windows integrated with a mechanically fastened WRB system and determined the conclusions listed as follows. **Table 2** presents the results of the round 1 testing. It should be emphasized that these conclusions are relevant to low-rise, wood-framed construction only, and more study was required to determine best practices for high-rise installations.

A new type of window system is becoming more common on high-rise construction: flanged, aluminum windows designed for high-rise buildings.

Round 1 testing conclusions are as follows (Table 2):

- Testing showed that the open-at-sill installation method manages water better than the barrier-at-sill installation method. *Open at sill* indicates there is not sealant behind the window sill flange and there is not tape/membrane over the window sill flange. *Barrier at sill* indicates that there is sealant behind the window sill flange and also there is tape/membrane over the window sill flange.
- Testing showed that while the barrier-at-sill installation method may be more airtight than the open-at-sill method at 300 Pa (typical of high-rise construction), the open-at-sill method can be very airtight (close to zero air leakage) at

Mock-up information			Mechanically fastened WRB		
Mock-up no.	Installation method	Interior air seal	Air leakage through specimen, ASTM E783, cfm/sf	Air leakage through specimen, ASTM E783, cfm/sf	Water leakage through specimen ASTM E1105 (cyclical) at 10 psf (23 total minutes)
			300 Pa	75 Pa	Summary
1	Open at sill	Nothing	1.37	0.33	10 seconds (480 Pa)
2	Barrier at sill	Nothing	0.35	0.23	19 minutes (480 Pa)
3	Open at sill	Foam	0.15	0	Pass (480 Pa)
4	Barrier at sill	Foam	0	0	23 minutes (480 Pa)
5	Open at sill	Sealant	0.12	0	Pass (480 Pa)
6	Barrier at sill	Sealant	0	0	13 minutes (480 Pa)
			(0.04 is pass)	(0.04 is pass)	(No water observed is pass)

Note: WRB = water-resistive barrier.
Table 2. Summary results of round 1 testing (mechanically fastened WRB system).

Figure 3. Mock-up 1, round 2 testing, fluid-applied water-resistive barrier system.

Figure 4. Mock-up 2, round 2 testing, fluid-applied water-resistive barrier system.

75 Pa (typical of low-rise construction) if foam or sealant is installed from the interior around the full perimeter of the windows.

- The test results showed that the low-rise foam or backer rod and sealant that are typically installed from the interior of flanged windows around the full perimeter of the windows are extremely important to both air and water performance.

While the round 1 testing made recommendations for low-rise construction very clear (use the open-at-sill method and install foam or sealant from the interior around the full perimeter), it was determined that further testing would be required to be able to make recommendations for high-rise construction. That determination led to our partnership with Tremco and round 2 testing.

SUMMARY OF GUIDING INDUSTRY STANDARDS, INSTALLATION INSTRUCTIONS, AND TEST METHODS

Installation Standards

AAMA (American Architectural Manufacturers Association) Standard 100, *Standard Practice for the Installation of Windows with Flanges or Mounting Fins in Wood Frame Construction*,[4] states, "This standard practice includes procedures for the installation of windows into buildings of no more than three stories in height."

ASTM E2112, *Standard Practice for Installation of Exterior Windows, Doors and Skylights*,[5] states, "This practice covers the installation of fenestration products in new and existing construction. For the purpose of this practice, fenestration products shall be limited to windows, sliding patio-type doors, swinging patio-type doors, and skylights, as used primarily in residential and light commercial buildings."

Note that while both of the aforementioned standards serve as the most common installation methods within the multifamily building industry, neither standard is designed for high-rise construction. Therefore, as a research baseline, it was determined to use a major WRB manufacturer's installation instructions for multifamily high-rise construction.[6] Note that the installation instructions for high-rise construction generally align with Method A1 installation procedures as noted in Table 8 of ASTM E2112.

Air-Leakage Standards

ANSI/NFRC 400-2014, *Procedure for Determining Fenestration Product Air Leakage*,[7] states that ASTM E283[3] shall be the only method used to measure product air-leakage rates. The standard also states, "A differential pressure of 300 pascals (6.24 psf) shall be acceptable if the North American Fenestration Standard (NAFS) is used for products obtaining an HC or AW rating."

However, while 300 Pa is an appropriate pressure to test as representative of high-rise construction, the research team decided to also test all of the mock-ups at 75 Pa, which is the metric used by the *International Building Code* (IBC) as well as the Passive House Institute US (PHIUS) and is more representative for low-rise multifamily construction. In other words, all mock-ups were tested for air leakage at both pressures—75 Pa and 300 Pa—during air-leakage testing.

Water-Penetration Standards

Table 2 of AAMA/WDMA/CSA 101/I.S.2/A440-08, NAFS—*North American Fenestration Standard/Specification for Windows, Doors, and Skylights*,[8] indicates the following in its: "Gateway Requirements" lists AW (architectural window) with the highest PG (performance grade) of 40, corresponds to a minimum design water-resistance test pressure of 8.00 psf. AW windows can be rated as high as PG 60 (corresponding to a 12.0 psf water-resistance laboratory test pressure).

Note that our research team initially chose to water test at 10.0 psf as a typical high-rise value from our experience with common high-rise construction products and methods for the round 1 testing and a value a bit higher than the corresponding AW window pressure of 8.00 psf. However, during round 2 testing, we used ASTM E331, which gradually works up to 25 psf and therefore will be used with any future testing as a more rigorous method.

Two test methods for water penetration were evaluated to determine which would be the most appropriate: ASTM E3312 and ASTM E547, *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors and Curtain Walls by Cyclic Static Air Pressure Difference*.[9] ASTM E547 was identified as a method developed more recently and is noted to be more realistic with regard to actual atmospheric conditions experienced on a building site, according to Bob Braun's article "Building Wall Assemblies: Focus on Testing for Water Leakage and the Role for Sealants and Adhesives."[10] Initially, the research team decided to test per the corresponding *field* testing standards (i.e., ASTM E783[11] and ASTM E1105[12]) in lieu of the laboratory standards as more representative of our mock-up conditions during round 1 testing. However, after partnering with Tremco, the team's expanded testing capability led us to perform the round 2 testing, using a fluid-applied WRB system, with the corresponding lab tests (i.e., ASTM E331 and ASTM E283). The change in test method did make it somewhat harder to compare the results of the two rounds of testing, as round 1 testing utilized field test methods with a mechanically fastened WRB system and round 2 testing utilized laboratory test methods with a fluid-applied WRB system.

METHODOLOGY

For each round of testing, six mock-ups with the following identical construction were built:

- Metal stud framing
- 4 ft × 8 ft sheet of gypsum sheathing with a 24 in. × 36 in. rough window opening
- Wood palette base with castors, 4 ft × 4 ft

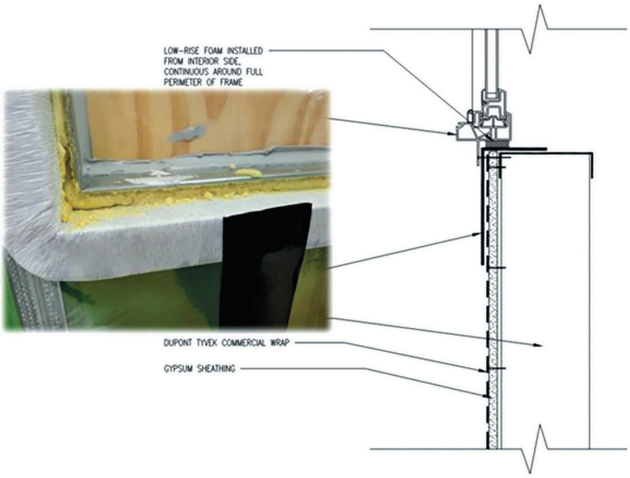

Figure 5. Mock-up 3, round 1 testing, mechanically fastened WRB system. Note: WRB = water-resistive barrier.

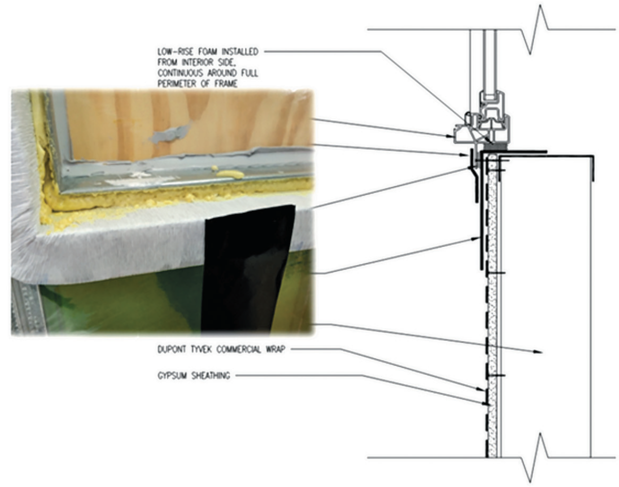

Figure 6. Mock-up 4, round 1 testing, mechanically fastened WRB system. Note: WRB = water-resistive barrier.

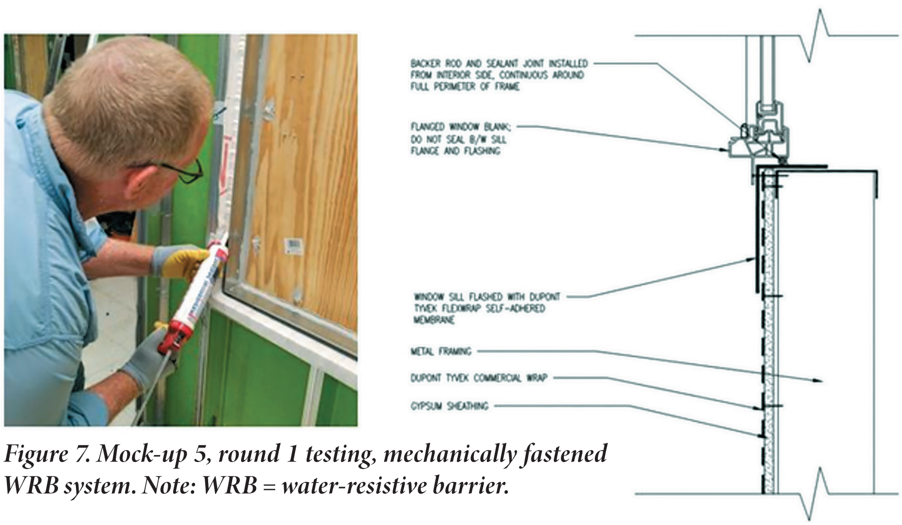

Figure 7. Mock-up 5, round 1 testing, mechanically fastened WRB system. Note: WRB = water-resistive barrier.

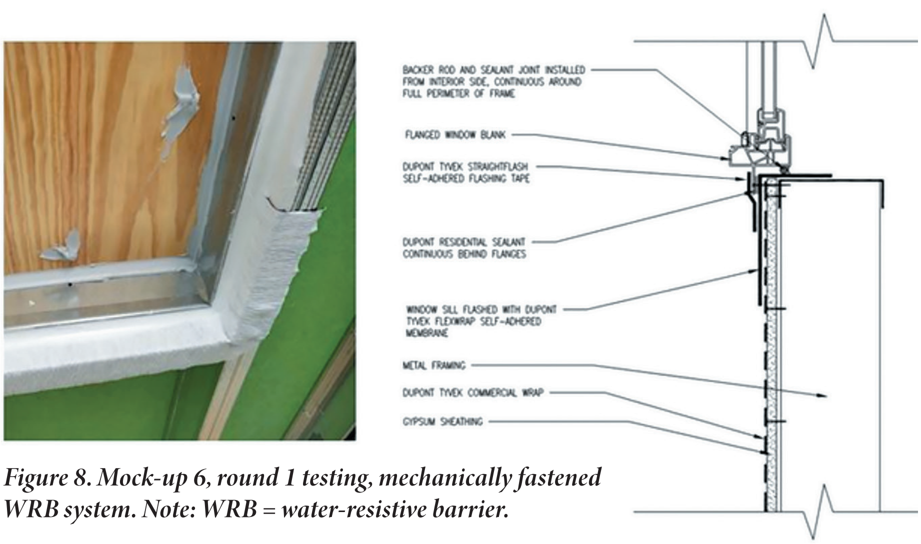

Figure 8. Mock-up 6, round 1 testing, mechanically fastened WRB system. Note: WRB = water-resistive barrier.

Window "blanks" were constructed from 24-gauge metal with soldered corners. The goal of the blanks is to simulate flanged windows and to prevent air or water penetration through the blank itself. The air- and water-resistive barrier was installed on mock-ups by a manufacturer's representative in accordance with the manufacturer's installation instructions (round 1 testing with a mechanically fastened WRB system and round 2 testing with a fluid-applied WRB system). While the window blanks were designed not to allow any air leakage, the blanks typically measured a negligible amount (typically 0.1 cfm of air leakage, but results ranged from 0.0 cfm to 0.2 cfm). The window blanks were then installed by the authors in general accordance with ASTM E2112 Method A1 but with specific sill modification details designed by the research team:

- Mock-up 1: open at the sill, no interior air seal (**Fig. 3**)
- Mock-up 2: barrier at sill, no interior air seal (**Fig. 4**)
- Mock-up 3: open at sill with low-pressure foam installed from interior side (**Fig. 5**)
- Mock-up 4: barrier at sill with low-pressure foam installed from interior side (**Fig. 6**)
- Mock-up 5: open at sill with backer rod and sealant installed from interior side (**Fig. 7**)
- Mock-up 6: barrier at sill with backer rod and sealant installed from interior side (**Fig. 8**)

Figure 9 shows a summary of the mock-up constructions. The jamb and head conditions were kept consistent (excluding the foam/sealant installed from the interior). Only the sill condition was detailed differently on each of the mock-ups. A 4 ft × 8 ft test chamber was built from dimensional lumber, sheet vinyl, and tape sealed to the backside of each mock-up. A vacuum was attached with an airflow meter, along with a manometer to read pressure differentials. Each mock-up was tested for air leakage in general accordance with ASTM E783 (round 1 testing) or ASTM E283 (round 2 testing). The air-leakage tests were performed at both 75 Pa and 300 Pa pressure differential per the standards noted previously. For each mock-up, three air-leakage tests were performed:

Mock-up no.	Installation method	Interior air seal
1	Open at sill	Nothing
2	Barrier at sill	Nothing
3	Open at sill	Foam
4	Barrier at sill	Foam
5	Open at sill	Sealant
6	Barrier at sill	Sealant

Figure 9. Summary of mock-up construction.

Figure 10. Mock-up 3, round 2 testing during blank isolation air-leakage testing.

Figure 11. Air-leakage testing equipment (manometer, airflow meter, commercial vacuum).

1. Air test 1: Fully isolated—a 3 mil sheet of plastic was taped over the entire front face of each mock-up.
2. Air test 2: Blank isolated—a 3 mil sheet of plastic was taped over the window blank only (**Fig. 10**).
3. Air test 3: No isolation (Fig. 3).

Subtracting the results of air test 1 from those of air test 3, the resulting value determined air leakage through the air-barrier assembly. Subtracting the results of air test 3 from those of air test 2, the resulting value determined air leakage through the window blank.

After the air-leakage testing (**Fig. 11**), the mock-ups were tested for water-penetration leakage in general conformance with ASTM E1105 (round 1 testing) or ASTM E331 (round 2 testing) utilizing custom-built spray racks. The pressure differential used during the testing was 10 psf for the ASTM E1105 field round 1 testing (**Fig. 12**), and increasing pressures up to 25 psf were used for the ASTM E331 laboratory round 2 testing.

RESULTS

Test results are summarized in Table 2 and Table 3. The air test procedures were repeated on each mock-up typically at least three times, resulting in a significant margin of error for the measured results. However, a relative hierarchy for airtightness was clear:

1. For the round 1 testing (mechanically fastened WRB system) at 75 Pa, mock-ups 3, 4, 5, and 6 exhibited zero air leakage. Mock-up 2 leaked 1.4 cfm and mock-up 1 leaked 2.0 cfm.
2. For the round 1 testing at 300 Pa, mock-ups 4 and 6 exhibited zero air leakage. Mock-up 3 leaked 0.9 cfm and mock-up 5 leaked 0.7 cfm. As expected, mock-ups 1 and 2 exhibited the most air leakage (8.2 cfm and 2.1 cfm, respectively).
3. For the round 2 testing (fluid-applied WRB system), all air-leakage testing at both 75 Pa and 300 Pa resulted in negligible values close to zero.

While water-penetration testing is typically used as a pass/fail method, a test pressure of 10 psf was selected for the round 1 testing with the intent of determining a hierarchy of water- penetration resistance.

Round 1 testing (mechanically fastened WRB system):

- Mock-up 1: Water infiltration was observed within 10 seconds.
- Mock-up 2: Water infiltration was observed at approximately 9 minutes. Upon retest, water infiltration was observed at 19 minutes.

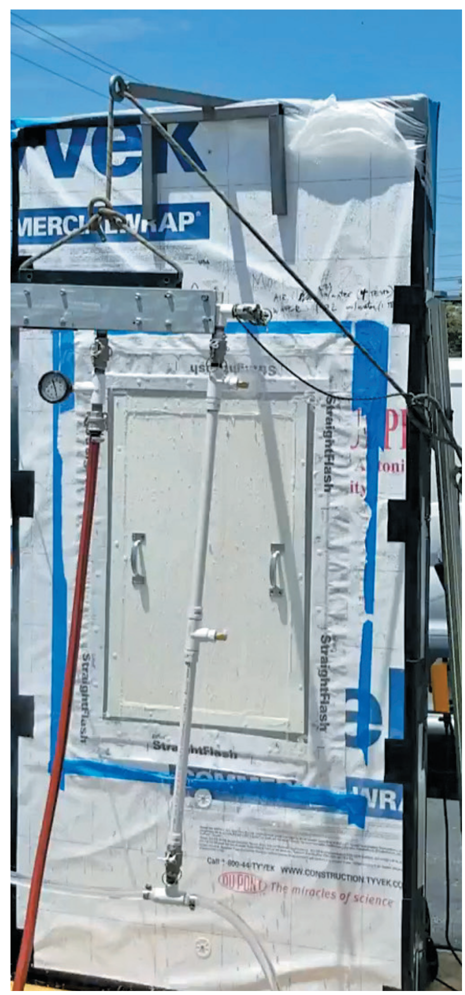

Figure 12. ASTM E1105 water testing of mock-up 2, round 1 testing.

Mock-up information			Mechanically fastened WRB		
Mock-up no.	Installation method	Interior air seal	Air leakage through specimen, ASTM E283, cfm/sf	Air leakage through specimen, ASTM E283. cfm/sf	Water leakage through specimen, ASTM E331
			300 Pa	75 Pa	Summary
1	Open at sill	Nothing	0.005	0.002	860 Pa
2	Barrier at sill	Nothing	0.015	0.015	75 Pa
3	Open at sill	Foam	0.049	0.019	Pass (1200 Pa)
4	Barrier at sill	Foam	0.015	0.015	300 Pa
5	Open at sill	Sealant	0.005	0.002	Pass (1200 Pa)
6	Barrier at sill	Sealant	0.017	0.015	Pass (1200 Pa)
			(0.04 is pass)	(0.04 is pass)	(No water observed is pass)

Note: WRB = water-resistive barrier.
Table 3. Summary results of round 2 testing (fluid-applied WRB system)

- Mock-up 4: Water infiltration was observed after completion of the 23-minute test when the testing chamber was removed.
- Mock-up 6: Water infiltration was observed at approximately 13 minutes.
- Mock-ups 3 and 5: No water infiltration was observed during nor after completion of the 23-minute test.

Figure 13. Commercial flanged window installation.

Round 2 testing (fluid-applied WRB system):

- Mock-up 1: Passed testing through 15 psf, water infiltration observed at 18 psf.
- Mock-up 2: Water infiltration observed at 1.57 psf.
- Mock-up 3: Passed testing through 25 psf.
- Mock-up 4: Passed testing through 1.57 psf, water infiltration observed at 6.2 psf.
- Mock-up 5: Passed testing through 25 psf.
- Mock-up 6: Passed testing through 25 psf.

CONCLUSION

A common flanged window installation (**Fig. 13**) often used on multifamily construction is ASTM E2112 Method A1 with low-pressure foam installed from the interior. However, Method A1 with a barrier modification at the sill is being used more frequently due to increasing airtightness requirements. For high-rise construction, the industry is seeing more and more flanged aluminum window systems with little guidance for installation best practices. The following lessons learned were gleaned from our research:

- Test results for both low-rise (round 1 testing) and high-rise (round 2 testing) construction show that the low-pressure foam or backer rod and sealant installed around the full perimeter of the windows from the interior side is very important for both increased air-leakage and water-penetration performance. The research team was not able to determine any increased performance from foam as opposed to sealant, but at least one of those strategies is always recommended. It should be noted that architectural drawing sets frequently omit the low-pressure foam (or backer rod and sealant) in the window section details, despite the importance of this component. Note that our research methods do not account for the relative abilities of foam and sealant to withstand long-term building movement, which may be a reason to consider backer rod and sealant instead of low-pressure foam, as the foam will shrink and may lose adhesion to the substrates, decreasing system performance over the long term.
- Test results indicate that the open at sill approach generally appears to manage water better than the barrier approach for both low-rise (round 1 testing) and high-rise (round 2 testing) construction. This recommendation is clear for low-rise construction, but more testing would be required to clarify recommendations for specific high-rise construction conditions, such as hurricane-force winds or coastal areas. It should also be noted that the open at sill approach plans for drainage from windows that may fail in the future and allows for more installation error on the part of the installer.
- Testing indicated that the barrier approach is generally more airtight than the open at sill method. However, the open at sill method can be very airtight (due to the foam or sealant installed from the interior side). At 75 Pa (low-rise construction, IBC requirements, PHIUS requirements), the open at sill approach is sufficient for airtightness (zero or negligible air

leakage measured). For most high-rise conditions, the open at sill approach (with an interior air seal) is sufficiently close to zero air leakage when a fluid-applied WRB system is utilized.

- Based on our test results, the recommendation for low-rise construction with vinyl flanged windows and a mechanically fastened WRB is the open at sill approach with either low-pressure foam or backer rod and sealant. More testing is required to clarify recommendations for specific high-rise construction conditions, such as hurricane and coastal zones.
- Test results indicate that the change from a mechanically fastened WRB system to a fluid-applied WRB system demonstrated a marked performance improvement in terms of both air- and water-leakage performance (i.e., the same or less air leakage and the same or less water infiltration for all mock-ups). All projects should consider the change from a mechanically fastened WRB system if possible. However, this change/upgrade becomes significantly more critical for high-rise construction and the associated increase in pressures from wind, rain, and sun.

The research team intends to test the following in future rounds of testing:

- Variation: backer rod and sealant at the sill and only 6 in. up the jamb.
- Traditional head detail with mechanically fastened WRB flapped up versus reverse-lapped head detail (window head flange sealed outboard of WRB, but then taped and sealed at the top edge with compatible sealant).
- Repeat all tests with a self-adhered membrane WRB system.
- Repeat all tests with a mechanically fastened WRB system, but per test methods used in round 2 testing (ASTM E283 and ASTM E331).
- Repeat all tests with a board stock WRB system.
- All future testing will follow ASTM E331 and E283 to facilitate comparison of metrics and results as well as to utilize greater pressure differentials.

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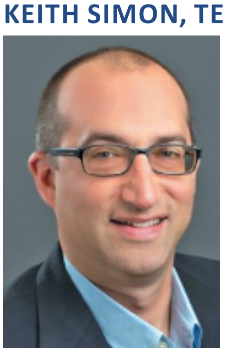

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Keith Simon joined Building Exterior Solutions Inc. (a division of Terracon) in April 2014. He has over 15 years of experience in architectural design and building enclosure consultation, including peer review, design assistance, durability analysis, construction administration, testing, and forensics of building enclosure issues. Simon was the founder of the Austin Building Enclosure Council (BEC: Austin). He currently serves as a board member for BEC: Austin as well as the Passive House Austin Chapter, and he is secretary of the national executive committee for the Building Enclosure Technology and Environment Council. Simon serves as Terracon's subject matter expert for hygrothermal modeling and building enclosure commissioning.

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John A. Posenecker joined Terracon in March 2015. A registered mechanical engineer, he is on the Building Enclosure Council National Board and is a board member and Technical Committee cochair for the Air Barrier Association of America. His experience includes the design, construction, testing, and forensic investigation of building enclosure systems. Posenecker has participated in a wide variety of projects associated with enclosures, including containment systems for commercial nuclear power plants, noise control systems for commercial and institutional projects, and waterproofing systems for a wide variety of commercial high-rise and low-rise buildings.

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