Water Penetration Resistance at Terrace Doors Hinges on the Details

By Kelly Cronin, PE; Suzanne Thorpe, PE; and Emmett Horton, EIT

Ask any building engineer, management company, or property owner and they will tell you that one or more of the terrace doors at their property has leaked at some point during a rain event. This is a common occurrence, and one that industry professionals will tell you is "to be expected." Exterior doors that experience water infiltration often result in property damage and can potentially require expensive or disruptive repairs. Damage can include minor puddles and stains, buckling of high-end interior floor finishes, or even active water leakage into occupied spaces around and below the door.

While water infiltration at terrace doors can lead to significant in-service challenges, it is often a risk that is not given enough consideration during the design and construction phases. Even when the design team focuses on door performance requirements and the contractor establishes quality control programs during installation, water leakage may still occur at terrace doors, particularly at in-swing doors. Although water leakage cannot always be eliminated, there are preventive measures that can limit the amount and frequency of water ingress at and around terrace doors.

This article focuses primarily on side-hinged architectural terrace doors[1] located at upper-level terraces, balconies, or penthouses as these door assemblies are typically exposed to more direct rainwater and higher winds compared with ground-level doors. However, many of the topics discussed in this article can be applied to all exterior doors throughout a building.

THE "INS AND OUTS" OF DOORS

There are many types of doors; they run the gamut from all-glass to hollow metal doors with no perimeter gasketing or weatherstripping to those with more robust, thermally broken aluminum frames, complete with gaskets and multipoint locking mechanisms. Doors can be hinged to open in or out. Often, the architect of record has a specific aesthetic for a terrace or amenity area, and the sightlines of the door play a key role in how the area is perceived or enjoyed because it serves as the gateway into and out of the space. For example, an all-glass door with minimal framing may be desired to allow a more seamless visual transition between the interior and exterior environment.

The overall type of door, and the operational requirements should be carefully considered when developing specifications during the design phase. Building code requirements dictate the direction of operation of the door (in-swing or out-swing) for occupant egress. Additionally, performance requirements associated with, but not limited to, structural capacity, thermal resistance, air leakage, and water penetration should be evaluated. For example, doors that are located at a penthouse-level, corner terrace with no screen walls or canopies will experience higher wind loads than doors that may be positioned at a third-floor terrace, mid-elevation, under a soffit setback.

Doors can be given a performance rating by the Fenestration and Glazing Industry Alliance (FGIA), formerly known as the American Architectural Manufacturers Association (AAMA). In AAMA/WDMA/CSA 101/I.S.2/A440, *North American Fenestration Standard/Specification for Windows, Doors, and Skylights*,[1] doors are assigned a performance class (Residential, Light Commercial, Commercial, or Architectural) and performance grade. Performance grades are assigned to a unit based on structural performance, water penetration resistance, air infiltration resistance, uniform load deflection testing, forced-entry resistance (if applicable), and operating force (if applicable). These tests dictate the design pressure of the unit. It is important to note that not all doors are created equal, and many are not rated to resist water penetration.

Door Ratings Explained

As outlined in the AAMA 101 Standard,[1] there are four performance classes for windows and doors: Residential (R), light commercial (LC), Commercial (CW), and Architectural (AW). Each of these performance classes has a minimum design pressure that the door or window must meet to be certified.

When evaluating a window or door, the laboratory testing parameters for structural performance and water penetration resistance start with what is referred to as the performance grade, also known as the minimum design pressure. The minimum design pressure is increased by a factor of 1.5 for testing for structural performance. This factor applies to all four performance classes. For water penetration resistance, windows and doors in the R, LC, and CW performance classes are tested with a pressure differential that is 15% of the minimum design pressure. The pressure differential is the difference between the air pressure on the exterior and the air pressure on the interior for the purposes of simulating wind-driven rain. For the AW performance class, the water penetration resistance test pressure is increased to 20% of the minimum design pressure.

There are also minimums for resistance to air leakage. These minimum values are a function of the door type and seals, and whether they are compression or sliding style units.

R performance-class ratings begin at performance grade (PG) 15, LC performance-class ratings begin at PG25, CW performance-class ratings begin at PG30, and AW performance-class ratings begin at PG40, with the performance grade representing the minimum design pressure, measured in pounds per square foot (lb/ft^2) for each performance class and grade. Because water penetration resistance ratings are measured as pressures, the ratings can be converted to values representing the height in inches of water that a door can manage. For example, a door is designated AW-PG60, it is an architectural-class door with a design pressure of approximately 60 lb/ft^2 (2.9 kPa). The minimum water penetration resistance pressure is then approximately 12 lb/ft^2 (0.6 kPa) or, when converted, approximately 2.31 in. (59 mm) of waterhead.

PERFORMANCE TESTING

As stated previously, there are various styles of doorframes, gasketing, and thresholds, which all combine to determine how effective a door assembly is against water ingress and whether it can be rated by AAMA/WDMA/CSA 101/I.S.2/A440.[1] Rated assemblies are tested in the laboratory using a pressurized test chamber to determine their maximum performance capabilities. They can also be tested in situ within 6 months of installation to confirm field performance as part of a project's quality assurance program, typically using a reduced air pressure difference in the testing chamber when compared with the laboratory evaluation.

When door assemblies are tested in the laboratory to obtain the water penetration resistance rating, there are generally two test standards that are followed:

- ASTM E331, *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference*[2]
- ASTM E547, *Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference*[3]

When rated door assemblies are tested in the field as part of a project's quality assurance program during construction, the following test standards are typically implemented to evaluate an assembly's ability to resist water penetration:

- 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*[4]
- AAMA 502, *Voluntary Specification for Field Testing of Newly Installed Fenestration Products*[5]

The tests described by ASTM E1105 includes a grid of nozzles providing a horizontal spray of 5 gallons (20 liters) of water per square foot per hour in a cascading effect. This equates to a vertical rainfall of roughly 8 in. (200 mm) per hour. In reality, a typical door assembly would likely not be exposed to this quantity of water during an average rainfall, but it might experience similar intensity during the peak of an extreme rain event.

When performing diagnostic testing of an in-service door more than 6 months after initial installation, the following testing standards are typically used:

- ASTM E2128, *Standard Guide for Evaluating Water Leakage of Building Walls*[6]
- AAMA 511, *Voluntary Guideline for Forensic Water Penetration Testing of Fenestration Products*[7]

Terrace doors that are not rated to resist water penetration are common (except along hurricane-prone coastlines and in localized high-wind areas), and many terrace doors will experience at least one wind-driven rain event while they are in service that results in water penetration to the interior. When this occurs in residential or commercial spaces, tenants report water leaks and building management is left to clean up the mess. Manufacturers will not guarantee that these types of unrated doors will resist rainwater; therefore, such doors cannot be evaluated using formal AAMA 502 or ASTM E1105 standards. However, evaluating these installed doors in the context of ASTM E2128 and AAMA 511 with a modified, zero air pressure differential, ASTM E1105 water penetration test can be valuable (**Fig. 1**). When used as a diagnostic tool, the modified ASTM E1105 test, where water is allowed to sheet down the full height of the door assembly, can be very informative in assessing the rainwater resistance performance of the door assembly and can help identify sources or points of entry for reported water infiltration. An understanding of these points of entry can inform the selection of after-market accessories that may improve performance of the door in wind-driven rain events, reducing the volume of water leakage.

It is worth noting that when diagnosing water entry points for terrace doors (and operable windows), a handheld spray nozzle is not recognized by FGIA as an appropriate tool, per AAMA 502.1, Note 1, which states, "This field check method is not appropriate for testing of operable components such as operable windows and doors." If the testing agency elects to use a handheld nozzle for informational purposes only to re-create a known water leak, care should be taken to only use the nozzle under low pressure and never direct the water spray at a gasket or threshold. Best practices for diagnostic testing are outlined in ASTM E2128 and AAMA 511.

CHALLENGES RELATED TO ACCESSIBILITY AND EGRESS

Aesthetics and performance requirements are only a part of the equation when specifying a

Figure 1. ASTM E1105 spray rack assembly positioned above the head of a terrace door, allowing water to sheet over the door assembly at zero pressure differential.

terrace door assembly. Applicable building codes must be consulted to determine accessibility and egress requirements. Accessibility and egress requirements have a direct impact on water management capabilities of the door assembly.

Accessibility

Americans with Disabilities Act (ADA) requirements[8] can pose a challenge when aiming to ensure that exterior egress doors remain watertight. Thresholds at doorways cannot exceed ½ in. (13 mm) in height for nonsliding doors, or ¾ in. (19 mm) for exterior sliding doors. Also, landings with a slope are not to exceed 0.25 units vertical in 12 units horizontal (approximately a 2% slope).

In addition to ADA, accessibility is governed by the *International Building Code* (IBC),[9] the Fair Housing Act,[10] and various local standards, codes, amendments, and ordinances. A threshold with a ½-in. vertical rise can only manage 2.6 lb/ft^2 (0.1 kPa) of pressure, which is less than the lowest AAMA 101-rated door assembly (that is, a Residential performance class, performance grade 15 [R-PG15] door with a laboratory water penetration resistance rating of 3 lb/ft^2 [0.14 kPa]).

Egress

Egress requirements for entrance/exit doors are governed by the applicable building code based on building use, occupancy load, and door type (swing, sliding, revolving). Per IBC[9] Chapter 10, "Means of Egress," a means of egress must be provided for all outdoor areas, including patios and terraces. The number of egress doors is based on occupancy and use of the space. The code stipulates egress requirements, which include minimum door dimensions, maximum door panel width, panic hardware, step-down dimensions to the exterior, requirements for threshold geometry, door swing direction, illumination, operating force, signage, and more. All designated "egress doors shall be of the side-hinged swinging door, pivoted doors, or balanced door type" and "shall swing in the direction of egress travel." Doors are required to swing in the direction of egress travel only if any one of the following three conditions exists:

- The door serves a room or area with an occupant load of 50 or more.
- The door assembly is used in an exit enclosure.
- The door opening services a high-hazard contents area.

Typically, upper-level terrace egress doors satisfy the second condition, where in an emergency, it would be undesirable for an occupant to take time to pull the door open in the direction they are moving from.

All door opening forces should be applied to the latch side of the door, and egress doors should include exterior, surface-mounted latch-release hardware. Egress doors must also be accessible and shall not exceed "½ inch [13 mm] above the finished floor or landing for other doors."

These egress requirements result in the use of in-swing doors with low-profile thresholds for terrace applications. This can pose challenges for managing water under storm conditions with sustained positive wind loads that decrease compression at the operable components of in-swing doors. The reduced compression increases the potential for air and water infiltration around perimeter gasketing between the door panel and frame, resulting in the threshold managing excess water with only a ½-in. (13-mm) vertical rise. It should be noted that under storm conditions, doors will be exposed to changing positive and negative pressures.

Water Management

High-performance terrace doors rated for water penetration resistance by AAMA/WDMA/CSA 101/I.S.2/A440[1] are designed to prevent exterior air infiltration and water penetration to the building interior. As briefly noted previously, out-swing doors will typically resist air infiltration and water penetration better than in-swing doors because exterior positive wind pressures tend to compress the door panel against the weather stripping and the upturned leg of the threshold is on the interior side of the door, acting as a dam for water ingress. With an in-swing door, the positive wind loads acting on the door panel will result in the door releasing compression against the frame, allowing more water to pass the perimeter gasketing and travel the door jambs vertically to the sill and threshold. Often, the profile of a threshold for an in-swing door will contain either a flat threshold or one with a vertical gasket toward the exterior that can potentially trap water and direct it inward.

The key to designing and installing a watertight terrace door is to understand the most common points of water entry. These common sources of water leakage at terrace doors include, but are not limited to, flashing; perimeter sealant; hardware; weatherstripping, gaskets, shoes, and sweeps; glazing; and thresholds.

Flashing

The position of the door within the rough opening affects the flashing that surrounds the door. The door assembly must be integrated into the adjacent air/water barriers and terrace waterproofing. While some door assemblies include perimeter flanges that can be integrated into the air/water barrier with flashing membrane, this is not always the case. If a door assembly does not contain a flange, a full-height cavity closure flashing may be needed to isolate an adjacent rain screen cladding from the wet/dry line of the door assembly and prevent water migration behind primary seals. At the head of the rough opening, there should be sufficient setback of the door assembly from the facade or a drip-edge flashing to promote water drainage away from the top of the operable door panel.

Perimeter Sealant

The placement of the primary perimeter sealant joint is critical. The joint should be located between the doorframe and the surrounding air/water barrier. A door could have as many as three lines of sealant at its perimeter: an exterior seal from the doorframe to the cladding, the primary exterior seal between the doorframe and the air/water barrier, and an interior air seal between the doorframe and the air/water barrier. Some doors (such as hollow metal doors or those with an open extrusion profile) require a cap or filler element to be installed at the perimeter of the frame to provide a sufficient substrate "bite" for perimeter sealant (that is, most sealant manufacturers require a minimum ¼-in. [6-mm] bond of the sealant to the substrate) (**Fig. 2**).

Hardware

Handles, locks, hinges, and other hardware can be locations of water entry if they are not watertight. Often, doorframes are modified to include handles and latches, resulting in reduced water penetration performance of the doorframes. Hardware can also inadvertently cause leaks if penetrations in doorframes or door panels are not properly sealed, or if the hardware does not operate as intended (for example, the door does not fully latch and properly engage the door panel to the doorframe).

Figure 2. Vertical masonry cavity closure flashing installed at the jamb of a terrace door to provide a substrate for the perimeter sealant.

Weatherstripping, Gaskets, Shoes, and Sweeps

Protecting and limiting the air gaps between the operable door panel and the perimeter frame and threshold are critical to the door assembly's water penetration performance. Minimizing this gap and promoting engagement of the door with the frame through adequately sized gaskets, shoes, and sweeps will reduce the volume of water the door assembly is required to manage. The gaskets should compress appropriately around the door panel, even during wind events, which will impart negative or positive pressure on the door depending on direction of operation. Door shoes and sweeps should engage the selected threshold and not ride above it. Without engagement with the threshold, water that is running down the jamb gaskets or sheeting over the floor toward the threshold may manifest over top or at the ends of the threshold, resulting in a leak.

The gaps between the operable door panels and the frame, or between dual door panels, typically contain weatherstripping. There are various types, sizes, and shapes of weatherstripping.

Glazing

Operable door panels may include glazing (**Fig. 3**). Some doors contain wet-glazed lites whereas others rely on a gasketed interface between the glass and the frame. Water that enters the glazing pocket must be managed effectively by fully sealed frame joinery and directed to the exterior through weeps in the system, outboard of the threshold gaskets.

Thresholds

Perhaps the most definitive element in determining the performance of in-swing terrace doors with regard to water penetration is the threshold (**Fig. 4** and **5**). Typically, the water resistance performance of door thresholds can be improved by increasing the threshold height. However, as stated previously, the vertical height

Figure 3. Active leak at the lower corner of a glazing unit installed within a terrace door assembly.

Figure 4. Thermally broken door threshold with saddle profile containing vertical element with gaskets that integrate with jamb gasketing.

Figure 5. Flat door threshold, meeting Americans with Disabilities Act requirements, with no gasketing.

is limited on accessible swing doors to ½ in. (13 mm) by ADA. There are numerous sizes and shapes to thresholds, including, but not limited to, flat, saddles, half saddles, offset saddles, and latching panic saddles. Designers may select a certain threshold profile to aid in covering an exterior waterproofing or cavity condition or to transition onto an adjacent hardscape. These elongated flat profiles can promote lateral migration of water under the door panel. Similarly, latching panic saddles contain a small, vertical upturned leg with a gasket that engages the in-swing door panel; if this gasket and the vertical element of the threshold are not fully compressed, they will allow water to enter over the threshold into interior spaces. Thresholds that are not level can also inadvertently pitch water inward.

In addition to the profile of the threshold itself, there are conditions beneath the threshold that can affect water penetration. Door thresholds should be set in a full bed of compatible sealant to the underlying waterproofing assembly (**Fig. 6**); metal flashings may be necessary to ensure compatible substrates for sealant installation and to conceal waterproofing materials that may not be designed for exposure to ultraviolet light (**Fig. 7**). If the ends of thresholds are not sealed to the doorframe, that can create an avenue for water to enter beneath the threshold (**Fig. 8**).

Additionally, the presence of door pivot boxes, unsealed or erroneous fastener penetrations through the threshold, and/or discontinuous waterproofing beneath the threshold can all lead to water entry under a door threshold.

POSSIBLE SOLUTIONS

Once the door aesthetics, performance requirements, and applicable code requirements are evaluated for operation and an assembly is specified, the design and construction teams should shift their focus to detailing and construction parameters that will limit water infiltration at the door. The typical components of a door assembly are the frame, gaskets, door, hardware, threshold, sealants, and fasteners. The interactions of these components, as well as the preparation of the door rough opening, are critical to the success of the door.

As established previously, water leakage at terrace doors generally occurs when design accommodations for egress or accessibility are overcome by in-service, pressure-driven rain events.

With only a ½-in. (13-mm) threshold height allowed, it is not reasonable to expect that an accessible door will remain watertight in all storms, whether it is a rated assembly or not. Knowing that tenants and building owners do not want to see water ponding on interior floors adjacent to terrace doors, there are options to consider that will improve terrace door performance. Although the following options may not entirely mitigate interior water penetration during heavy, wind-driven rain events, these options, both individually or when combined, have significantly limited water infiltration when implemented on recent projects. These options can be implemented during the design phase as well as during remediation of in-service doors.

- Confirm positive slope of the adjacent exterior slabs to drain. Positive slopes away from thresholds specified in the design phase can become flat spots or even negative slopes due to construction tolerances and slab distortion. Pedestal pavers or drainable hardscape located outboard of doors can minimize this effect.
- Provide a curb or slab depression between the exterior and interior beneath the door assembly.

Figure 6. A door with a threshold that meets Americans with Disabilities Act requirements set atop concrete infill at a terrace. Waterproofing on terrace beneath pedestal pavers was not extended up and onto the concrete fill prior to placement of the threshold. In addition, threshold is not bed sealed.

Figure 7. Exposed terrace waterproofing outboard of threshold is not designed for exposure to ultraviolet light and direct foot traffic.

Figure 8. Door threshold is notched around frame at the jambs and is not sealed to the door frame. There is potential for water ingress at the joint between the jamb and threshold. Additionally, the presence of door pivot boxes, unsealed or erroneous fastener penetrations through the threshold, and/or discontinuous waterproofing beneath the threshold can all lead to water entry under a door threshold.

- Install surface-mounted diverters at the base of the door panel. Some diverters contain rubber sweeps that can improve engagement with the threshold. There are multiple sizes and styles of surface-mounted diverters on the market that range in color and material (**Fig. 9**).
- Construct the doors under cover (canopies, awnings, overhangs) or in alcoves to dramatically decrease the amount of water that reaches the doors. If locating the door assembly in a recessed setback from the facade is not possible in the design, a surface-mounted diverter or drip-edge flashing can also be added above the head of the door panel, applied to the frame, to help direct water sheeting down the wall above away from the door panel (**Fig. 10**).
- Select a threshold that will engage the door panel and fully seal it to the jambs of the doorframe. The door threshold should also be fully bed-sealed to the flashing/membrane beneath the assembly. Ensure that the flashing/waterproofing outboard of the door extends into the door rough opening to promote continuity of primary seals. Consider using stainless steel flashing over any waterproofing membrane flashing at the sill of the rough opening to provide UV protection.
- Install trench drains across doorways to

Figure 9. Door accessories mounted to the base of a terrace door panel. There are multiple sizes and styles of surface-mounted diverters and sweeps on the market that range in color and material.

Figure 10. Drip edge installed at the head of a doorframe located at a roof-level terrace.v

help drain water that could potentially accumulate against the threshold. The trench drains will generally require heel-proof grates. Trench drains can be installed at either the exterior (to limit ingress) or interior (to manage leakage). The trench drain should be sized to be slightly wider than the doorframe and be properly piped to storm drainage.

- Install recessed, waterproofed interior walk-off mats, particularly at locations where the interior finishes inboard of the door are highly susceptible to moisture-related damage (warped wood flooring, stained stone flooring, etc.). Walk-off mats can be evaporation pans or drained assemblies.
- Install larger perimeter gaskets at the full perimeter of the operable panels or doorframe to promote engagement of the panels and frame. Care must be taken to size each gasket such that it engages the door panel and is compressed enough to restrict air infiltration, but not so large as to inhibit proper closure of the door or require increased operable force.
- Provide a door shoe that engages the bottom of the door panel with the threshold.
- Review glazing installation to ensure that glazing gaskets are compressed or glazing seals are continuous. If gaskets are compromised, consideration may be given to the installation of a wet seal (cap seal) over the glazing gaskets, although it should be noted that this seal will require routine inspection and maintenance for continued performance.
- Ensure that perimeter sealants at the interior and exterior of the door assembly are installed continuously. Cap the ends of vertical extrusions, particularly on hollow metal doorframes, to install continuous perimeter sealant at corners of doorframe.
- If a dual, out-swing door is used, consider adding an astragal cover to provide additional protection to the meeting gaskets.

CONCLUSION: GETTING A HANDLE ON TERRACE DOORS

In summary, there are many types of terrace doors. During design, a door should be selected that complies with the owner's performance requirements, with appropriate attention given to the detailing of the door assembly with surrounding construction. If an in-service door is not meeting the expectations of the owner or tenants with respect to water leakage, after-market accessories can be considered to limit water ingress and improve the overall performance of the door assembly.

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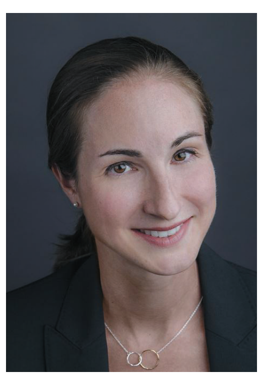

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