Feature

Finding the Leak

By David A. Rash, RRC

WITH THE INCREASING complexity of modern building techniques, it is important for all members of the project team to understand how the various materials and systems being utilized are to be incorporated into the completed building. This was illustrated with a new-construction project in downtown Seattle, Washington, where an apparent roof leak developed while construction was underway. After the building was occupied, the leak recurred at irregular intervals for several years. Identifying and resolving the leak required an extended series of investigative techniques involving the use of water testing, infrared thermography, and electronic leak detection (ELD). The source of the roof leak was unexpected as it was associated with the side laps of the field roofing membrane, but once it was identified, there was some logic behind its occurrence.

BUILDING PROJECT BACKGROUND

The building, where the long-recurring roof leak happened, was constructed to be a corporate headquarters. As such, the building was viewed by the developer and building owner as a long-term asset, and team members were selected on the basis of expertise rather than cost. This was true not only on the design side but also on the construction side.

The building has seven full stories with a partial eighth, or penthouse, story that was originally intended to house amenity spaces for the building's occupants. The structure is reinforced concrete, while the cladding is brick veneer with unitized curtainwall glazing. The roof slab has a two-way slope directed to the center of the slab, although the roof drains are located midway down the slope, resulting in the need for a tapered roof insulation layout to direct rainwater to the drains. The main roof at the eighth-floor level was designed as an extension of the amenity spaces in the penthouse. Precast concrete pavers were laid to create patio areas. Pavers were also placed around the perimeters of the penthouse and the roof parapet (**Fig. 1**), and these paths were used for walking and jogging by employees. The remaining roof areas were covered with vegetation. During occupancy of the building, the south recreational lounge of the penthouse was repurposed as the corporate boardroom (**Fig. 2**), reinforcing the importance and desirability of the garden roof, which was visible from the boardroom.

For reference, the installed roofing assembly is, from the roof deck upward:

- Primer on concrete deck
- Styrene-butylene-styrene (SBS)-modified membrane as an air/vapor barrier and temporary roofing membrane, torch applied
- Tapered polyisocyanurate roof insulation to achieve *R*-38, adhered
- Gypsum-based coverboard, adhered
- Two-ply SBS-modified roofing membrane with granular cap sheet, torch applied

At the patio deck areas, the overburden was specified (from roofing membrane upward):

- Asphaltic protection board, loose laid
- Adjustable pedestals
- Hydraulically pressed precast concrete pavers, typically 24 in. (610 mm) square in size

At the vegetated areas, the overburden was specified (from roofing membrane upward):

- Drainage composite, loose laid
- Extruded polystyrene (XPS) insulation, loose laid
- Growing medium and plants

A RECURRING LEAK

As the building approached completion and occupancy in 2016, the building experienced roof leaks. The first involved poorly detailed conduit penetrations, which were quickly resolved. More troublesome was a leak that became evident at the ceiling level of the seventh-story office space at the south end of the building, in the general proximity of the centerline of the roof slab. At the time, the roofing contractor found some minor deficiencies in the roofing membrane under the precast concrete paver area at the south end of the main roof, which were repaired. In addition,

Figure 1. *Southern view from company boardroom with paved patio area and vegetative roof areas (2/17/2019).*

Figure 2. *View of eighth-floor green roof with pavers and south end of penthouse structure with glazed wall of company boardroom (2/17/2019).*

the investigation team performed tests on both the inside and outside face of the south parapet using a calibrated spray wand (**Fig. 3**), based on the American Architectural Manufacturers Association's AAMA 501.2 testing standard.[1] The water tests did not replicate the leak, and the initial repairs made by the roofing contractor appeared to address the leak issue.

Over the following 3 years, the initial roof leak recurred with sufficient frequency that the roofing contractor installed four inspection ports near the roof drains and the centerline of the main roof slab in 2017. Although the leak recurred with some frequency, there did not appear to be a consistent correlation between weather events and the roof leak. A limited number of exploratory openings were made, which indicated that water was collecting at the level of the air/vapor barrier (**Fig. 4**), but no breaches were discovered in the air/vapor barrier. The inspection ports (**Fig. 5**) were an attempt to monitor water volume during rain events to see if there was some correlation between water volume and recurrence of the leak, but they were ultimately not useful in understanding the source(s) of the roof leak.

Due to the expense of removing sufficient portions of the vegetated roof assembly to access the roofing membrane underneath, as well as the potential harm that this would cause the plants, no leak investigation occurred in any of the vegetated roof areas during this time. Also, there was no direct evidence that pointed to the vegetated areas as being the source of the recurring leak. For the first several years, there was no direct evidence of where the leak was located other than the existence of water stains and other damage on the ceiling below the roof deck and on the floor finishes at the approximate center of the south end of the building.

THE HUNT FOR THE LEAK

From approximately September 2018 to September 2019, the building experienced no apparent leaks, which gave hope that the previous attempts to resolve the leaks had been successful. Even when a severe thunderstorm had occurred on September 7, 2019, with 0.59 in.

Figure 3. *Eighth-floor parapet water tested with a calibrated spray wand shortly after the building was occupied with metal panel cladding removed to identify potential leak path(s) (2/11/2016).*

Figure 4. *Exploratory opening revealing water at the level of the roof air/vapor barrier, but no breaches (2/02/2017).*

Figure 5. *Inspection port installed under pavers on pedestals at south patio area of eighth-floor green roof (2/17/2019).*

(15 mm) of rainfall during roughly an hour and sustained winds of 12 mph (19 km/h), the leak had not recurred. When the leak returned, it was after 3 consecutive days with precipitation: rainfall was 0.49 in. (12.5 mm) on September 17, 2019, 0.26 in. (6.5 mm) on September 18, 2019, and 0.03 in. (1 mm) on September 19, 2019.

Since the leak had not occurred when the roof had recently experienced more severe weather, the possibility existed that the leak of September 19, 2019, was a new leak even though it appeared to be a replication of the prior leaks. Because the building had gone for nearly a year without a recurrence of the leak, the roofing contractor had removed the inspection ports on September 19, 2019, and when the leak recurred within a month, concern was expressed that the repair patches at the inspection port locations might be at fault for the leak's recurrence, even though the patching material was polymethyl methacrylate (PMMA) flashing membrane. Adhesion issues were discovered with the PMMA patches, and new, larger patches were installed; however, this did not resolve the issue.

Still, the building owner wanted a resolution to the problem and requested that an investigation plan be developed to find the leak.

In developing the investigation plan, the client requested that all potential sources for the leak be investigated even if previous testing of some locations was repeated. For the south end of the main roof, this would include

- the south roof parapet,
- the south end of the penthouse structure, including the base flashing transition from the field membrane onto the roof curb supporting the exterior walls, and
- the south end of the main roofing assemblies.

Testing techniques would ultimately include infrared thermography, ELD, calibrated spray wand water testing, continuous water flow testing, and a limited flood test.

Although a flood test of the affected roof area was initially considered, the roofing materials manufacturer indicated that this test would invalidate the extended roofing warranty.[1] The manufacturer reminded the testing team that the roofing system was not intended to be subjected to the hydrostatic pressure that would result if approximately 5½ in. (140 mm) of water was allowed to stand on the roof for the 24 hours that the test would normally be expected to last. This objection eliminated the need to have the structural engineer of record determine if the building structure was capable of supporting the weight of a flood test.

The first component of the leak investigation was an infrared thermographic survey of the underside of the concrete roof deck, which was performed on March 2, 2020. Some minor thermal anomalies were identified; however, none were indicative of significant water absorption into the concrete deck (**Fig. 6**).

The second component was an ELD test performed on the base flashing membrane at the south end of the level 8 penthouse. No breaches were found in the base flashing membrane, although several anomalies suggestive of potential breaches were identified (**Fig. 7**); these were mainly small portions of side lap edge conditions that did not appear to be fully sealed.

The third component was a water test of the three vegetated roof areas at the south end of the building, which involved running the irrigation system continuously without blocking the roof drains (**Fig. 8**), eventually saturating the vegetated assembly. Prior to initiating the water test, the roofing contractor reinstalled one of the inspection ports to determine whether water from the testing was infiltrating down to the vapor barrier and collecting in the roofing assembly in conjunction with the roof leak; the inspection port was located near the central valley line of the roof deck. The inspection port was a short piece of polyvinyl chloride piping that extended several inches above the roofing assembly and down to the vapor barrier; it allowed the investigation team to confirm whether water was infiltrating down to the vapor barrier, but it did not allow one to ascertain through which layers of the assembly that the water might be percolating. This water test replicated the leak for the first time, although

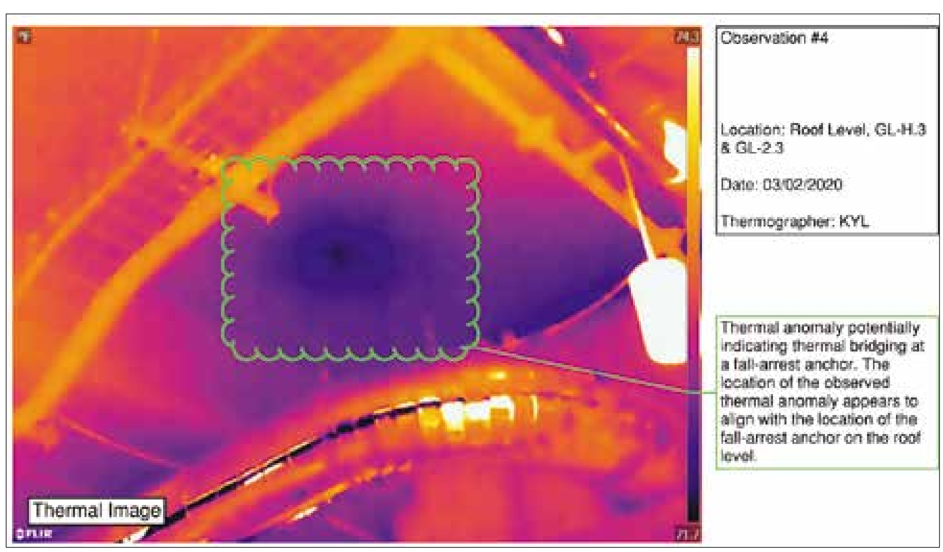


Figure 6. *Interior thermographic survey confirmed no excessive moisture accumulation in concrete deck, while also identifying minor thermal bridging from fall-arrest anchors attached to the deck (3/02/2020).*

Figure 7. *Electronic leak detection was used to confirm no breaches in base flashing membrane along the base the penthouse structure (3/02/2020).*

Figure 8. *The three vegetative roof areas at the southern end of the eighth-floor roof were saturated with water from the irrigation system, which replicated the leak for the first time (3/16/2020).*

it did not identify which roof area might be the source of the leak or if all three areas were contributory; water was also observed in the inspection port.

The fourth component was a water test of only the southeast vegetated roof area (**Fig. 9**). This water test replicated the leak for the second time; replication took less time to occur than during the prior (third) component of the investigation.

The fifth component was a water test of the southwest vegetated roof area (**Fig. 10**), running water continuously so that the vegetated assembly became saturated. This water test did not replicate the leak, nor was further water observed in the inspection port.

During the testing of the southwest vegetated roof area, a review of the perimeters of the vegetated areas found that the southeast vegetated assembly was installed with expanded polystyrene (EPS) insulation directly over the roofing membrane (**Fig. 11**), while the southwest vegetated area had EPS insulation installed above the drainage composite. The change from XPS insulation to EPS insulation was presumably a cost-saving measure during construction.

At this point in the investigation, the roofing installer elected to repair some of the roofing anomalies by applying PMMA flashing membrane over the anomalies, primarily seams where the laps did not appear to be fully sealed adjacent to the southeast vegetated roof area, expressing the concern that standing water around the vegetated roof area might be the source of the leak. After the repairs were completed, the southeast roof area was retested (**Fig. 12**). Although it took longer, the leak was replicated for a third time, suggesting that the PMMA repairs may have resolved contributing breaches in the roofing membrane, but the primary cause of the leak was still unresolved.

Figure 9. *The southeast-corner vegetative roof was saturated with water, replicating the leak for the second time (3/17/2020).*

Figure 10. *Saturating the southwest vegetative roof separately did not replicate the leak (3/18/2020).*

Figure 11. *Southeast vegetative roof area was discovered to have expanded polystyrene (EPS) insulation resting directly on the roofing membrane, with the drainage composite installed over the EPS insulation (3/18/2020).*

Figure 12. *Minor deficiencies patched with polymethyl methacrylate membrane, after which the southeast vegetative area was separately tested, resulting in a third replication of the leak (3/19/2020).*

The sixth component was a water test of the glazing assembly of the south elevation of the penthouse (**Fig. 13**). For this test, a spray rack was utilized without a pressurized chamber on the interior side of the glazing, as the test was to determine whether water penetration was at the interface between the glazing assembly and the base flashing membrane at the concrete support curb at the perimeter of the penthouse structure. The roof leak was not replicated, nor was water observed in the inspection port.

In late March 2020, the state of Washington imposed a moratorium on nonessential construction activities due to the COVID-19 pandemic, which was not lifted until mid-May 2020. Once the moratorium was lifted, the seventh component of the investigation was instigated. This included testing of the inside face of the south parapet at its base, midsection (cladding), and coping. Water was directed at the various levels of the parapet using a calibrated spray wand in general conformance with the AAMA 501.2 testing standard,[1] testing 5 ft (1.5 m) sections of the parapet laterally for a period of 5 minutes. This was performed initially at the base flashing membrane at the bottom of the parapet, then the lower half of the metal siding, followed by the upper half of the metal siding, and finally the metal plate coping (**Fig. 14**). At no point during this testing was the roof leak replicated, nor was water observed in the inspection port.

The eighth component was a water test of the outside face of the south building parapet (**Fig. 15**). For this test, a spray rack was utilized to apply water to the metal plate coping and the brick facing above the uppermost window heads. Each section of the parapet was tested for 15 minutes, with the middle third of the

Figure 13. *A spray rack was used to determine if the interface between the glazing assembly of the penthouse and the base flashing membrane of the roofing system contributed to the roof leak (3/23/2020).*

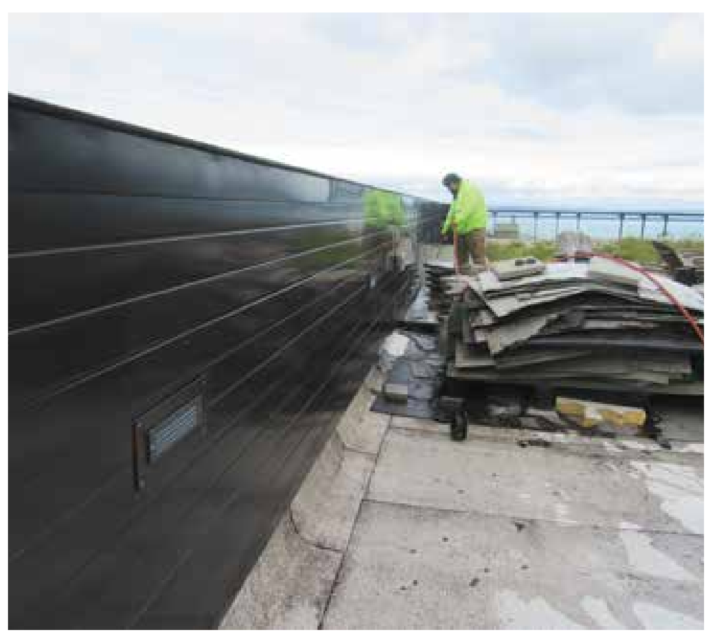


Figure 14. *The south building parapet was tested using a calibrated spray wand at the base of the parapet, the metal cladding of its interior face, and the coping, in sequence from bottom to top (5/19/2020).*

Figure 15. *Spray rack was used to water test the exterior face of the south building parapet (5/20/2020).*

Figure 16. *South-central vegetative area was also water tested separately, but it did not replicate the leak despite having expanded polystyrene insulation resting directly on the roofing membrane (5/22/2020).*

south elevation being tested (centered at the interior leak location). The roof leak was not replicated.

The ninth component was a water test of the small south-central vegetated roof area (**Fig. 16**), running water continuously so that the vegetated assembly became saturated. Even though the installed vegetated assembly of this roof area was similar to the southeast vegetated roof area in that there was EPS insulation directly on the roofing membrane with the drainage composite above the EPS insulation, there was significantly less growing medium due to its location straddling the peak in the tapered roof insulation of the roofing assembly. This water test did not replicate the leak, nor was water observed in the inspection port.

At this point, the preliminary leak investigation was complete insofar as testing to identify the likely location of where the leak was entering the building. Since water testing had replicated the leak at only the southeast vegetated roof area, the general contractor agreed to have the vegetated assembly removed at this location. This allowed the roofing membrane to be visually reviewed, after which time decisions could be made about further investigation of the roof leak.

After the vegetated assembly had been removed, the exposed roofing membrane was reviewed in company with the roofing contractor (**Fig. 17**). Some minor roofing anomalies were observed, such as minor loss of granules from the cap sheet and lack of bitumen bleed-out along portions of the side laps, but none appeared to be obvious breaches in the membrane that might allow water intrusion. Plant roots were also evident on the surface of the roofing membrane, but these were sufficiently small as to be considered inconsequential for possible water intrusion, as none had breached the cap sheet.

After discussion with the project team, a water test of the exposed roofing membrane was conducted. The irrigation system for the southeast roof area was allowed to run for more than 6 hours, which had previously been

Figure 17. *Vegetative assembly removed from the southeast corner of the main roof. Minor root growth was discovered to have penetrated the root barrier but without evident damage to the roofing membrane (7/14/2020).*

sufficient time for the roof leak to become manifest when the vegetated assembly was in place. Without the vegetated assembly, the roof leak was not replicated.

In hope of better understanding how water might be infiltrating the southeast roof area, an infrared thermographic survey was performed (**Fig. 18**). Some minor thermal anomalies were identified that did not appear to be large enough to indicate that they were part of the water path but were marked on the cap sheet of the roofing membrane. Six exploratory openings were performed by the roofing contractor at locations chosen by the investigation team and the chief building engineer. At four locations south of the roof drain, the top facer of the roof insulation was wet, but the polyisocyanurate core was dry. At two locations north of the roof drain, the roofing assembly was dry.

Despite the infrared thermographic survey and exploratory openings, no obvious sources of water entry were evident from a review of the exposed roofing membrane. After an inspection of the roofing membrane, a T-lap approximately 12 ft (3.7 m) inboard of the south building parapet was selected for a targeted flood test. A temporary box dam, approximately 2 ft (0.6 m) square in size, was constructed and sealed to the cap sheet (**Fig. 19**). Approximately 5 in. to 6 in. (12.7 cm to 15.2 cm) of water was allowed to accumulate inside the dammed area. After approximately 1.5 hours, water was observed seeping out of two other adjacent cap sheet T-laps, as well as at the cap sheet edge of one exploratory opening (**Fig. 20–22**). All locations were upslope from the flood test location and more than 20 ft (6.1 m) from the roof drain. Once the water test was removed, water migration ended.

Based on these observations, it was concluded that the roof seams were allowing water ingress when under hydrostatic pressure, as occurs when the vegetated assembly becomes fully saturated and becomes increasingly heavy and exerting pressure on the cap sheet similar to what would occur during a flood test. This allowed water to migrate laterally through the roofing assembly until a penetration, like a fall-protection anchor, allowed the water to migrate vertically to the roof deck and subsequently to the south edge of the roof deck and materialize on the interior of the south exterior wall.

LEAK RESOLUTION

In discussing repair options with the roofing contractor, one option was to simply have the

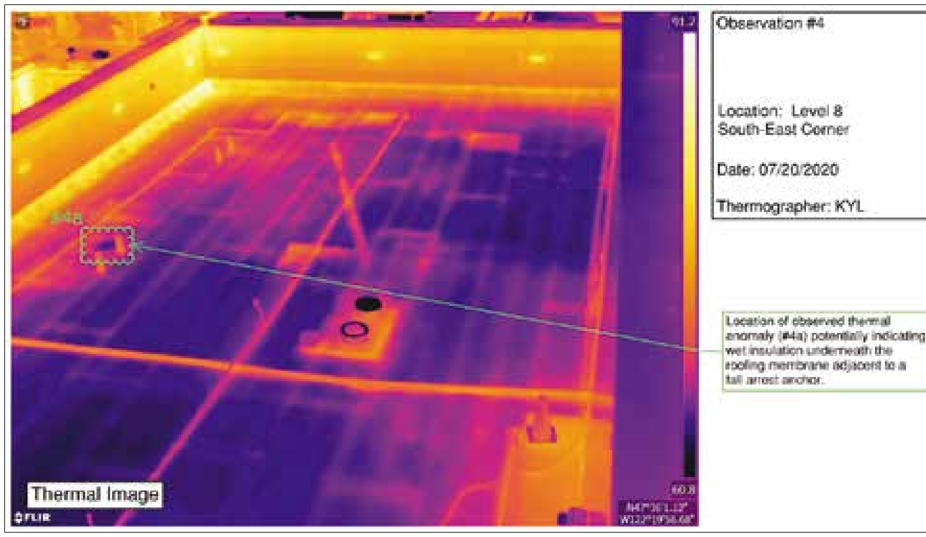


Figure 18. *Infrared thermographic survey identified a few thermal anomalies, but none proved to be the "smoking gun" for the roof leak (7/20/2020).*

Figure 19. *Flood test performed at a T-lap location suspected of being compromised (7/29/2020).*

Figure 20. *General view of roofing membrane upslope of flood test location with water visibly seeping out of the T-lap seam (yellow circle) (7/29/2020).*

Figure 21. *Close-up view of water seeping out of the roofing seam (7/29/2020).*

Figure 22. *Additional water seepage from the roofing seam subsequent to the time recorded by Figure 20 (7/29/2020).*

vegetated assembly reinstalled as originally specified, which was the responsibility of a separate contractor, after the necessary repairs to the exploratory openings were completed. Considering that the roof leak had been occurring for approximately 4 years, the possibility existed that the roof seams might have been compromised. Compromised seams might allow the leak to recur if the vegetated assembly became sufficiently saturated and hydrostatic pressure developed, such as during a severe weather event. Thus, despite the presence of the drainage composite directly above the roofing membrane, leaks could still recur. There was also the consideration of the expense of removal and reinstallation of the vegetated assembly should there be any future need to access the roofing membrane should a leak reoccur. Even though the building was then unoccupied due to the COVID-19 pandemic, a recurrence of the leak after the building was again occupied would be impactful for the occupants and building owner.

Ultimately, the roofing contractor chose to apply a PMMA reinforced flashing membrane at all the roofing membrane seams of the southeast vegetated roof area. This was likely the most conservative corrective action that could be taken, but it was also the option that minimized the potential for a recurrence of the leak. A 4 in. (100 mm) wide strip of PMMA membrane was installed, centered over the leading edge of the roofing membrane seams (**Fig. 23**). When the seam stripping was approximately two-thirds complete, an adhesion pull test of the PMMA membrane was conducted, which indicated that good adhesion was being achieved. In addition, a technical representative of the roofing materials manufacturer also reviewed the corrective work prior to the reinstallation of the vegetated assembly.

After the vegetated assembly was reinstalled, a water test utilizing the irrigation system was performed at the southeast roof area. Since all previous tests that replicated the leak lasted less than 6 hours, the confirmation water test was run for slightly more than 6 hours, during which time the leak (fortunately) was not replicated. The roof is now approaching some 5 years without a replication of the leak.

Figure 23. *Polymethyl methacrylate flashing membrane being applied to all roofing seams in the southeast vegetative roof area (8/05/2020).*

LESSONS LEARNED

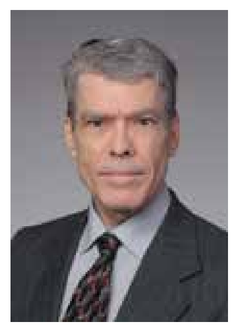
Although there was a requirement for the roofing contractor and a representative from the roofing materials manufacturer to attend the preinstallation meeting for the vegetated assembly, the installation of the vegetated assembly was essentially treated as separate tasks. To a degree this was true, as there was one installer for the roofing assembly and a separate installer for the vegetated assembly, and the only interface between the two assemblies was the top surface plane of the roofing membrane. Installation review of the vegetated assemblies was not part of the scope of work for the building envelope consultant,[i] nor was attendance at the preinstallation meeting for the vegetated assembly. Presumably, if review of the vegetated assembly had been part of the building envelope consultant's scope, the inadvertent error of installing EPS insulation below the drainage composite and in direct contact with the roofing membrane would have been caught and corrected during original construction.

More generally, the roof leak and its cause raise the question of how prudent it might be to install a roofing membrane, as opposed to a waterproofing membrane, at locations where access to the membrane intended to keep water at bay is difficult once construction is complete. For this project, having a continuous membrane to manage rainfall drainage was highly beneficial, as it allowed for refinements in the layout of paved areas and the vegetated assemblies as construction was in progress. It would have been possible to install a two-ply SBS waterproofing membrane in lieu of the two-ply SBS roofing membrane, but at a higher cost. In retrospect, for this project, the higher cost would have been justified, as a membrane capable of being subjected to hydrostatic pressure would have been in place and the leak would not have occurred.

REFERENCE

1. American Architectural Manufacturers Association (AAMA). 2009. *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing Systems.* AAMA 501.2. Schaumburg, IL: Fenestration & Glazing Industry Alliance (FGIA).

ABOUT THE AUTHOR



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