Online exclusive

Mysterious Moisture Marks: Assessment of Water Stains at Window Glazing

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EVERY YEAR, APPROXIMATELY 1 in every 50 homeowners in the United States claims water damage.[1] During extreme weather events such as hurricanes and tropical storms, the claimed damage to the interior contents due to wind driven rain can range from 50% to 100% of the overall damage claims.[1] Moisture intrusion is a substantial concern because biological growth may potentially cause structural deterioration, serviceability disruptions, and damage to the interior contents. Even during normal weather conditions, condensation deposits can affect the performance of buildings by affecting the overall heat, air, and moisture (HAM) transfer phenomenon and energy consumption.[2] There are also life-safety concerns. Too much moisture within the building enclosure can lead to forms of biological growth that are detrimental to human health. It is critical to mitigate moisture through proper building management that maintains acceptable indoor air quality.

When an anxious homeowner or other stakeholder discovers staining around windows, a qualified building investigator can assess the situation and provide guidance. A thorough assessment of the reported area of staining should include evaluations of all likely causes of moisture intrusion.

According to the US Environmental Protection Agency (EPA), the only way to eliminate mold and mold spores in an indoor environment is by controlling the moisture entering into the building.[3] Mold and other types of organic growth are often on the surfaces of a window assembly ("sweating") and affects the overall HAM of the building. Compared with the rest of the building enclosure, openings such as these are the most susceptible to condensation, which transfers excessive moisture to adjacent finishes.

There are multiple building codes and standards available for wind-driven-rain testing during extreme weather events (**Table 1**).[4-14] In contrast, fewer codes and standards address moisture intrusion under normal weather conditions.

Building enclosure issues related to moisture can be briefly classified into three categories, design, construction, and maintenance.

- Design-related problems may include improper specification of insulation or improper window design. Examples of poor design include an exterior sill with no slope or improperly designed drainage mechanisms.
- During the construction phase, improper installation of an air/vapor barrier, a lack of rain penetration tests, and improper flashing tend to lead construction defects and potential water and moisture intrusion.
- Inadequate maintenance and a lack of operational awareness can lead to premature failures and reduced life-cycle performance for building enclosure components and systems. Failure to perform timely inspections, deferred maintenance, and an insufficient preventive maintenance plan all increase the risks for an array of water and moisture intrusion opportunities.

WINDOW TYPES

Windows are a critical part of a building enclosure, but they are vulnerable to age- and weather-related damage. Because water intrusion within a building enclosure can cause aesthetic and structural problems, the appearance of water stains on the interior surfaces of the window glazing system may raise alarms for the unit owner or building stakeholders. However, not all water stains are the same.

Table 1. Items to consider before implementing unconventional masonry wall repair strategies

Standard	Type of load	Specified load	Specified number of cycles	Notes
ASTM E283[4]	Static	299 Pa	N/A	Laboratory test Infiltration must be less than 0.06 CFM per square foot of glazing and 0.09 CFM/ft^2 of projected window.
ASTM E330[5]	Static	Design wind pressure (DP)	N/A	Laboratory test Interstory drift and deflection must be within serviceability limits for an applied 10-sec load. No gasket disengagement or structural failures.
ASTM E331[6]	Static	Largest of 20% DP or 718 Pa	N/A	Laboratory test When a rain spray rate of 3.4 L/m^2.min (5.0 U.S. gal/ft^2.h) is used for 15 minutes, no water infiltration must be observed.
ASTM E1105-05(A)[7]	Static	Largest of 20% DP or 718 Pa	N/A	Field test When a rain spray rate of 3.4 L/m^2.min (5.0 U.S. gal/ft^2.h) is used for 15 minutes, no water infiltration must be observed.
ASTM E1105-05(B)[7]	Cyclic static	Largest of 20% DP or 718 Pa	Minimum of 3	Field test When a rain spray rate of 3.4 L/m^2.min (5.0 U.S. gal/ft^2.h) is used for 15 minutes, no water infiltration must be observed.
ASTM E547-00[8]	Cyclic Static	137 Pa	Unspecified	Laboratory test When a rain spray rate of 3.4 L/m^2.min (5.0 U.S. gal/ft^2.h) is used, no water infiltration must be observed.
BS EN 12155[9]	Static	Depends on rating pressure	N/A	Laboratory test When a rain spray rate of 2 L/m^2.min is used, no water infiltration must be observed.
BS EN 13050[10]	Dynamic	37.5% of design pressure	Unspecified	Laboratory test When a rain spray rate of 2 L/m^2.min is used, no water infiltration must be observed.
BS EN 13051[11]	Static	No loads; Annex B suggests the use of BS EN 12155 loadings if air pressure is required	N/A	Field test When a rain spray rate of 5 L/m^2.min is used, no water infiltration must be observed.
BS EN 12865[12]	Pulsating load	Incremental steps of 150 Pa	As many as needed	Laboratory test (limit of watertightness) When a runoff rate of 1.2 L/m^2.min and a driving rain rate of 1.5 L/m^2.min are used, no water infiltration must be observed.
AAMA 501.1-17[13]	Dynamic	300.0 Pa, 380.0 Pa, 480.0 Pa, 580.0 Pa, and 720.0 Pa	One 15-min cycle at a time	Laboratory test/ field test When a rain rate of 3.4 L/m^2.min (5.0 U.S. gal/ft^2.h) is used, no water infiltration must be observed.
CSA A440[14]	Static	150 Pa, 200 Pa, or 250 Pa	Four cycles of 5 min, each with air pressure, and 1 min with no pressure	Field test When uniform water film on the outside of the window is used, no water infiltration must be observed.

Note: N/A: Not applicable, 1 L/m^2 = 0.0245 US gal/ft^2; 1 Pa = 0.000145 psi; 1 CFM = 1 ft^3/min = 0.028 m^3/min.

ASTM: American Society for Testing and Materials, **AAMA:** American Architectural Manufacturers Association, **BS EN:** British Standards European Norm, **CSA:** Canadian Standards Association

When evaluating water staining, it is important to begin with an understanding of window types and performance expectations. Each window type discussed herein serves a distinctive purpose, and the distinct styles and configurations require specific approaches toward investigation and repair.

Single-Hung Windows

Typically, a single-hung system consists of two glass panels (sashes). Single-hung windows open vertically, with one window panel or sash moving up and down and the other sash remaining stationary. Thus, when you open the window, the upper sash is covered on the inside. How these sections move is the major difference between single-hung and double-hung windows. If the operable sash of the window is impeded from functioning properly, that could lead to gaps and seams that allow water intrusion. Field consultants who perform or oversee water penetration field-testing procedures such as ASTM E331[6] should be knowledgeable at the vulnerability of each window type. ASTM E331 diagnostic water intrusion testing or a field modified version (based on site conditions), delivers water via spray nozzles near perimeter openings such as windows and doors. This growth may be related to poor insulation practices, which lead to a buildup of condensation within a grid pattern, with the water uniformly sprayed and directed at the vulnerable areas. Within properly installed single – hung windows, vulnerable areas likely include exposed fasteners, gaskets, and the operable sash. There are many other deleterious conditions at window bases that impede watertightness (**Fig. 1**).

Figure 1. *Base of sliding window was previously blocked and allowed water accumulation.*

Double-Hung Windows

Like a single-hung window, a double-hung window has two sashes; however, in a double-hung system, both the lower sash and the upper sash can move up and down, and the sashes usually tilt out for easy cleaning and maintenance. A double-hung system has twice the moving parts of single-hung system, and if one or both of the operable sashes of the window are impeded from functioning properly, that could lead to gaps and seams to allow water intrusion. During ASTM E 331 testing,[6] water is applied to the exterior of the test window while the pressure inside is lowered by means of an air chamber built on the inside or opposite side of the test window. The vulnerable areas should be observed. If water intrudes within the vulnerable areas, the test can be redirected, recalibrated, and refocused to pinpoint the source of origin. Within properly installed double-hung widows, vulnerable areas likely include exposed fasteners, gaskets, and one or both of the operable sashes.

Casement Windows

Casement windows swing out to the side or up to open. This mode of opening allows the window to be constructed of solid glass; therefore, compared with a single- or double-hung window, a casement window offers a less-obstructed view overall. Casement windows usually come with one casement windowpane on the left and one on the right. Defects at any screws, bolts, springs, or hand crank could impede the casement from functioning properly, creating gaps and seams that allow water intrusion.

Since casement windows operate differently than the sliding mechanisms of other window types, they require a slightly different verification testing method. When preforming ASTM E331[6] testing, the investigators must ensure that the hand crank or locking mechanism is completely engaged during the time that the calibrated spray apparatus is applying water and uniform static pressure is simultaneously applied to opposite sides of the test area.

Awning Windows

Awning windows are ideal for climates with a lot of rain because the windows create water-resistant awnings when opened. Awning windows swing open on the outside by being pushed outward with the latch or handle. This design makes awning windows more weatherproof, but they are not invulnerable. If an awning window is left open, updrafts or wind-driven rain could lead to moisture accumulation within the interior space.

Sliding Windows

Sliding windows have a minimum of two sections or sashes, and one of the sections slides horizontally outside/inside of the other to open or close. Similar to double-hung windows, if one or both operable sashes of the window are impeded from functioning properly, that could lead to gaps and seams that allow water intrusion. Debris, long-term wear, or distortion of the track may impede the window from closing or sealing properly. Water may drain off the base of the track during rain events or when other water accumulates from the outside environment. Sliding windows and other window types may have drainage systems or weep holes to keep water out of the window, but the following factors can impede any water entrapment precautions:

- Improper installation: If the window frame, track, or base is misaligned, that can prevent water from flowing toward or out of drains.
- Impeded drainage: Debris on the lower track can cause obstructions.
- Lack of coordination among trades: Paint contractors, stucco installers, or other vendors may unintentionally apply construction materials that cover or obstruct the weep holes.

Fixed Windows

Fixed windows include arched, picture, and geometric-shaped windows that do not open or close. These types of window are often installed above standard windows that provide ventilation. Some fixed windows can open the same way that a casement window does. They can also be installed in a multiarch structure with square or rectangle windowpanes on the side and arched curved windows. Picture windows are fixed windows that are inoperable, but they are often paired with operable windows. They are large window types that do not have any breaks or visible frames. Fixed windows have no operable sashes, panels, or mechanisms with no potential for gaps, seams, or misalignments that create ideal paths for water intrusion. Therefore, if there is water intrusion, attention should be focused on the condition and construction of the window frame.

The condition of the window frame material is a significant concern during the evaluation of water intrusion, and forensic water testing may be warranted. Deterioration or distortion of the window frame can be the source of the mysterious water stains.

In window frames made wood, deterioration from rotting or warping is a commonplace culprit in water intrusion. Absorbed moisture causes wood rot and creates ideal conditions for further rot, biological growth, and pest infestation. Termites and other wood burrowing insects can further damage the wood and create additional pathways for water intrusion.

When the window frame is made of untreated wood, moisture can become trapped and long-term cycles of expansion and contraction can lead to permanent bends in the frame that distort the window's appearance, making it look crooked, twisted, cupped, or bowed. In addition to the aesthetic effects, such distortion can adversely affect the window system's operation or weathertightness.

PERFORMANCE EXPECTATIONS

The industry standard specification for evaluating fenestration products is AAMA/NWWDA 101/I.S. 2-08 *Voluntary Specification for Aluminum, Vinyl and Wood Windows and Glass Doors.*[22] It establishes the following performance requirements for a window assembly:

- Structural ability to resist wind loads or wind pressure standards
- Resistance to air leakage
- Resistance to air infiltration
- Resistance to forced entry

Products that with the certification under AAMA/NWWDA 101/I.S. 2-08 are designated by a four-part code that denotes the type of window, the performance class, and performance grade. For example, the code C-R15 indicates a casement window (C) recommended for residential applications (R), with a performance grade of 15. How well a window performs when subjected to heavy rains and high wind pressures reflects its performance grade and design pressure. The window design pressure (lb/ft^2) is typically provided based on the structural rating only. However, a strong structural assembly prevents the risks of component displacement and further water intrusion. In addition to this design pressure, the performance grade indicates that a window has met the water resistance and air infiltration standards for that grade.

The minimum recommended design pressure for residential windows is 15 lb/ft^2 (73.24 kg/m^2). A design pressure of 15 lb/ft^2 means a window has been tested to withstand sustained wind pressures of 22.5 lb/ft^2 (109.85 kg/m^2), roughly equivalent to a 95 mph (42.5 m/s) wind (depending on the pressure coefficient), applied to either side of the window, simulating either positive or negative wind pressures. The test pressure is always 150% of the rated design pressure to provide a safety factor. To earn a performance grade of 15, a window must also pass a water pressure test of 2.86 lb/ft^2 (13.96 kg/m^2), which simulates rainfall of 8 in. (203 mm) per hour with a wind speed of 34 mph (15.2 m/s).

In coastal areas or other areas prone to intense rain events or hurricanes, higher-performance-grade windows exceeding minimum code requirements are recommended. Window design pressure ratings combine the window's resistance to (a) water leaks, (b) air leaks, and (c) actual structural loading. Points are assigned for the window's ability to resist each type of force and then a total window performance grade rating number is calculated. Higher ratings indicate better performance in preventing common causes of water intrusion. Thus, a high rating describes a window that is significantly more resistant to water and air leaks than the threshold performance criteria.

A consideration when setting performance expectations and investigating window conditions will be the perimeter conditions. All window systems, regardless of their condition at the time of assembly, are susceptible to the passage of time and exposure. Sealants that are vulnerable to age can dry and crack, leaving passageways for water to enter the wall structural enclosure (**Fig. 2**). Unpainted areas of the exterior wood window frame components will retain moisture, potentially subjecting the frame to accelerated rot and decay. Over time, framework for both wood and aluminum windows can expand and contract with temperature changes, thus creating space at the perimeter of the window system where water intrusion can occur. Fluctuations between daytime and nighttime temperatures cause repeated movement of window glass that expands in warm weather and contracts in cool weather. This movement can cause glass to fracture to allow water intrusions. In double-paned windows, flexing motion can cause the seals between the panes to fail, resulting in window condensation fog.

Figure 2. *Aged sealant conditions around a window.*

Figure 3. *Improper assembly at the joining of window systems.*

On rare occasions, windows assemblies have defects due to their original manufacture. For example, newly fabricated window frame materials may exhibit cracks or splits either at the manufacturer or after transport to the site.

Although defects may be difficult to observe in an installed window system (**Fig. 3**), exposed defects may be noted during a visual inspection. Outside the wall, gaps and unsealed elements might be noted in the exposed window joinery and miter joints. Separation and other defects tend to occur at the 90-degree angles of the corner miter joints. The lack of a firm seal at mull bars or at the joining of window assemblies may also allow water intrusions.

Water stains may occur early if windows are improperly installed and allow water intrusion through gaps, voids, and separations. When evaluating window installations, investigators should assess whether corrosion-resistant flashing and the watertightness methodology are sufficient to divert water away from the building enclosure and prevent water intrusion within the wall cavity and frame components of the structure. The investigator should be familiar with the window assembly and associated building construction and be capable of recognizing whether fasteners are missing, components are misaligned, or waterproofing is improperly installed.

Recent weather history at the site is also an important influence on the assessment. Different types of severe weather events can affect window components in different ways. Hail can cause physical damage to not just window frames and glass but also the surrounding exterior cladding. Hail can break glass panes, allowing water intrusion during and after a rain event. Impact dents from hail on the window frames may affect the way that the window operates, thus compromising the watertightness. The impact of windborne debris adjacent to window openings can also create openings for water to intrude through the building enclosure.

TYPES OF STAINING

Water stains on windowsills and at the perimeter of the openings can be a source of anxiety for building owners and occupants. The cause of a stain might be a simple drop or splash from watering a nearby plant, or the stain may be the tip of the iceberg, indicating a larger structural issue. This is why it is so important to determine whether stains are the sign of a major leakage problem or not.

Water Accumulation–Clear

The appearance of standing or pooling water around or at the base of a window is often reported as a leak. It is important to investigate and figure out where the moisture is coming from. If the window is open, you should be able to close the window, mop up

Figure 4. *Red stains reveal compromised conduit not window assembly.*

the mess, and not worry much further. But if a closed window allows water infiltration, that suggests faulty installation or failure of materials. Such situations warrant further investigation.

Stains and Discoloration–Amber

Another sign of a window leak is the appearance of stains or discoloration. The area could be dry or wet, and the stains may be copper, yellow, or brown residue. Growth of the stain over time is a likely sign of a leak. Reddish staining can also be a sign of corrosion of metal fasteners or structural rebar reinforcement (**Fig. 4**).

Biological Growth–Green or Black

Biological growth often occurs in areas of excess moisture such as bathrooms, kitchens, and basements. If it appears on or around windows in an area without any plumbing fixtures or any obvious sources of running water, the cause is likely a leaky window. Biological growth can look spotty and fuzzy (**Fig. 5**). In addition to being an eyesore, airborne spores can adversely affect health and well-being or produce musty odors. The odor often stems from areas where moisture has been accumulating for long periods. Interior finishes such as drywall are absorbent when saturated with moisture, and as low-air-circulation environments, they can serves as petri dishes for biological growth and detectable odors.

Finish Distortion–Fading

When drywall absorbs water, this can cause paint to fade and wallpaper to lose adhesion. Therefore, if the interior finishes adjacent to the window assembly begin to distort and peel away from the wall surfaces, leaks in the window assembly should be suspected. Water intrusion through the window assembly can also lead to fading or flaking of the window finishes. Distortions of the window frame such as warping will also compromise the window integrity (**Fig. 6**). Walls around the windows may also exhibit signs of significant separation gaps as the materials warp. Soft spots and spongy materials will sag because of the weight of entrapped water and as building materials deteriorate. The buildup of biological growth, wood rot, and pest infestation can add mass beneath the surface. Extensive warping could be the result of structural damage. These conditions merit additional review and are expensive to investigate and repair.

Figure 5. *Example of bio growth.*

Figure 6. *Distortion at window.*

Window Sweating

The fundamentals of window sweating are simple. When the air within the building enclosure forms a convection current cycle against the cold surfaces of a window, the colder air sinks and warm air replaces it. As warm, moist air encounters the colder interior glass surface, the air drops below dew point, depositing moisture on the glass. As the convection current process continues over time, additional moisture leaves deposits on the glass. Adjacent surfaces may eventually become stained as built-up condensation on the surface of glass drips onto the windowsill and other surfaces. If an individual is not present to witness this process, the cause of staining may be a mystery.

When investigating "sweating" windows and related staining, it is important to keep in mind that condensation on windows within an enclosed occupied space may not necessarily be a sign of water infiltration. Human activities such as showering, cooking, and simply breathing can affect the dew point and convection current cycles, leading to condensation on glass.

Understanding the types of window glass installed in the building enclosure is important to assess the appearance of water and its significance. Single-paned windows are less energy efficient and less insulated than their double-paned counterparts. Therefore, the use of single-pane glass can lead to more condensation on the window surface, increasing the risk for water staining of the window trims, surrounding walls, and floor surfaces below.

Condensation can be the result of poor thermal bridging design. Thermal insulation acts as barrier to regulate temperature as per the design intent. When thermal insulation is interrupted by a window, condensation can build up, resulting to areas of water staining and distortion.

The window assembly material may further affect the risk for moisture condensation buildup and staining. High-conductivity materials such as aluminum have low thermal resistance relative to insulated materials, which means they allow heat to bypass the thermal barrier. Investigators should understand which window materials carry higher risks that may factor in the assessment and mitigation strategies going forward. Guidelines such as *Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections* (AAMA 1503-09)[23] can be used to evaluate certain window elements and provide expectations for condensation resistance. The AAMA condensation-resistance factor (CRF)[23] indicates the magnitude of the temperature-driven vapor that can take the form of condensation. That type of condensation can potentially mislead an observer to conclude that the window is defective. Determining a window's CFR and taking note of the surrounding environment are key to a proper assessment of the source of water stains.

FACADE ASSESSMENT

In addition to window condensation, other causes of moisture stains can range from steam from a teapot to more serious causes such as an underperforming HVAC system. Properly maintained and balanced mechanical ventilation systems are needed to control the moisture levels within the enclosure. Depending on the airtightness of a design and the performance of operable natural ventilation, the rate of moisture may fluctuate dramatically and result in dew point moisture accumulation and staining of surfaces at the window area.

With recent advancements in technology, several noninvasive methods have been developed to gain insight to mysterious moisture stains near the window. These innovative methods can be employed to analyze a variety of construction defects, wall coating failures, and potential structural issues that can be hidden behind moisture stains.

An investigator's initial observations of the exterior facade may involve the use of long-range binoculars or a high-power camera lens. These tools are beneficial when you have a direct line of sight. However, there are times when the target area of concern is in an obscured location and costly mobilization of equipment would be required to gain a clear vantage point.

Commercial unmanned aerial vehicles (drones) can be used to avoid the need for lift booms and scaffolding as staging equipment. When equipped with a high-quality camera lens, a drone may help the investigator visually note deviations in the facade (**Fig. 7**). Deleterious facade conditions may correlate with the moisture staining, water-related distortion, or biological growth witnessed within the building enclosure. The photographic survey performed by the drone can document from a variety of angles, positions, and heights any threats of structural failure, loss of facade elements, and other potential issues responsible for the water stains.

As discussed earlier, failures of installed window sealant (or other building components) can take the form of distortions,

Figure 7. *Example use of aerial drone.*

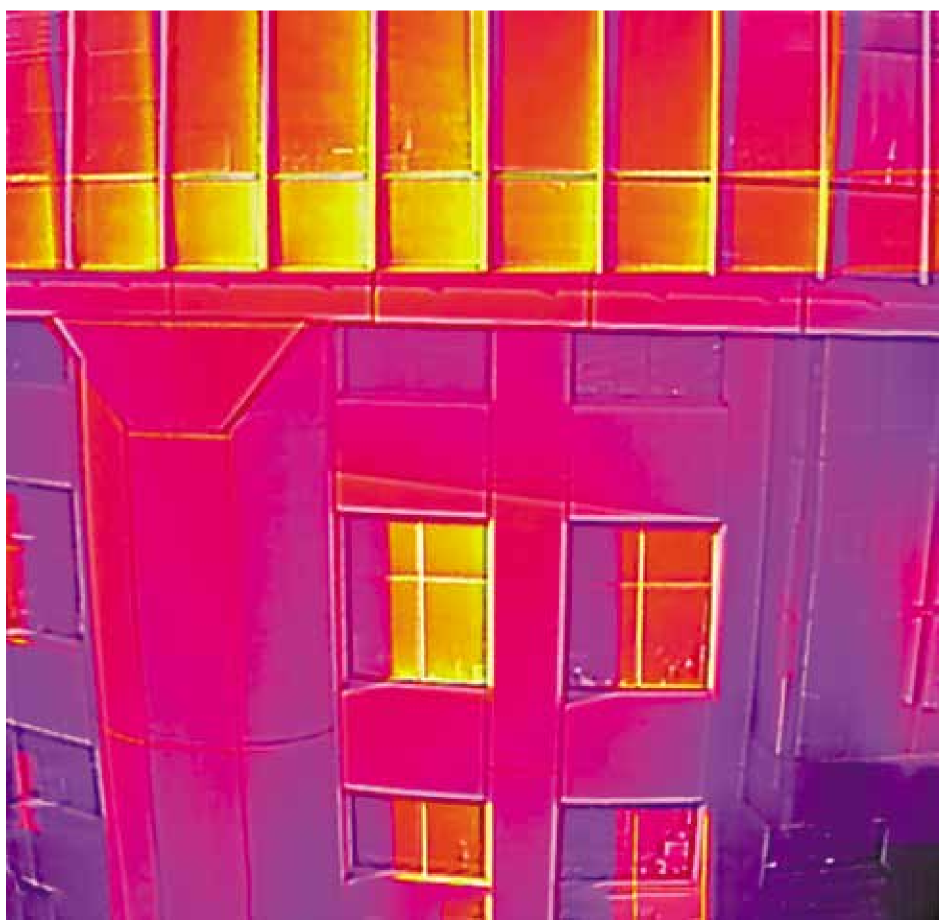

Figure 8. *IR facade survey via drone.*

voids, and displacements that allow water intrusion and lead to interior staining. Sealant failures may be due to insufficient sealant adhesion, incorrect sealant cure times, or sealant joint discontinuities. In some cases, inconsistent quality control measures or improper product specifications for the sealants may be the likely cause of water stains. Visual inspection may narrow the universe of potential causes to sealant issues instead of window assembly defects. If so, the costly and unnecessary endeavor of building permitting and purchasing and installing window assembly replacements can be avoided.

Not all defects are visible to the seasoned investigator's naked eye or via the ocular lens of a typical drone camera. It is therefore fortunate that not all cameras are the same. Specialized drones with dedicated cameras with infrared (IR) thermography capabilities are available. The IR thermography can capture the temperature distribution on surfaces and relay that information on a visual spectrum. The drone can be maneuvered across the facade and over large areas in the search of abnormalities. It can also focus on specific areas that may correlate with locations of reported interior water staining. IR imagery may identify discontinuities of the building enclosure's facade that are not visible by standard methods (**Fig. 8**). The speed of the IR assessment via drones allows the investigator to view "invisible" conditions within inaccessible areas in an expedited manner, thereby preventing future water damage. Thermal modeling of the facade while using fixed-measure temperatures as point of calibration can be ideal to understand, analyze, and provide recommendations for mitigation.

CONCLUSION

When investigating mysterious moisture stains, an effective strategy is to determine the logical steps of the investigation based on facts, reasonable expectations, and precedents based on scientific research. The investigation should include the following:

- Identifying the physical evidence around the window system without first making presumptions about the source or causality of the staining
- Gathering and documenting the visual information from both the interior space and the exterior environment about the window system and adjacent conditions
- Interviewing owners, tenants, and other stakeholders about the installation, use, and maintenance of the window system
- Reviewing past and present information about neighboring window systems and similar adjacent conditions

Often, the goal of a moisture distress assessment is to determine whether the concerns are justified, identify the sources of identified problems, determine the causality, and assess any life-safety risks. After the initial assessment and observations, investigators should communicate their findings, risks, and recommendations to the stakeholders. The assessment should be used to determine whether interior staining indicates detrimental water intrusion or superficial surface condensation and then form an appropriate plan of action to mitigate and address the sources of water stains. The action plan may involve a systematic approach of targeted water testing as established in AAMA 511[24] or ASTM E2128.[25] Test protocols vary based on specific conditions and components. An alternative approach to water testing involves selective demolition to investigate the water stain areas and repair the issues discovered. These approaches vary in terms of costs, durations, and interruptions, which is why it is important to conduct a preliminary assessment before choosing what actions to take. Poor workmanship, failure of window systems, and simple user error require different approaches and resolutions. Simple reasoning can shed light to the mysterious appearance of moisture stains and provide proper direction. **Figure 9** provides an overview of typical moisture stain assessment by a building investigator and future steps.

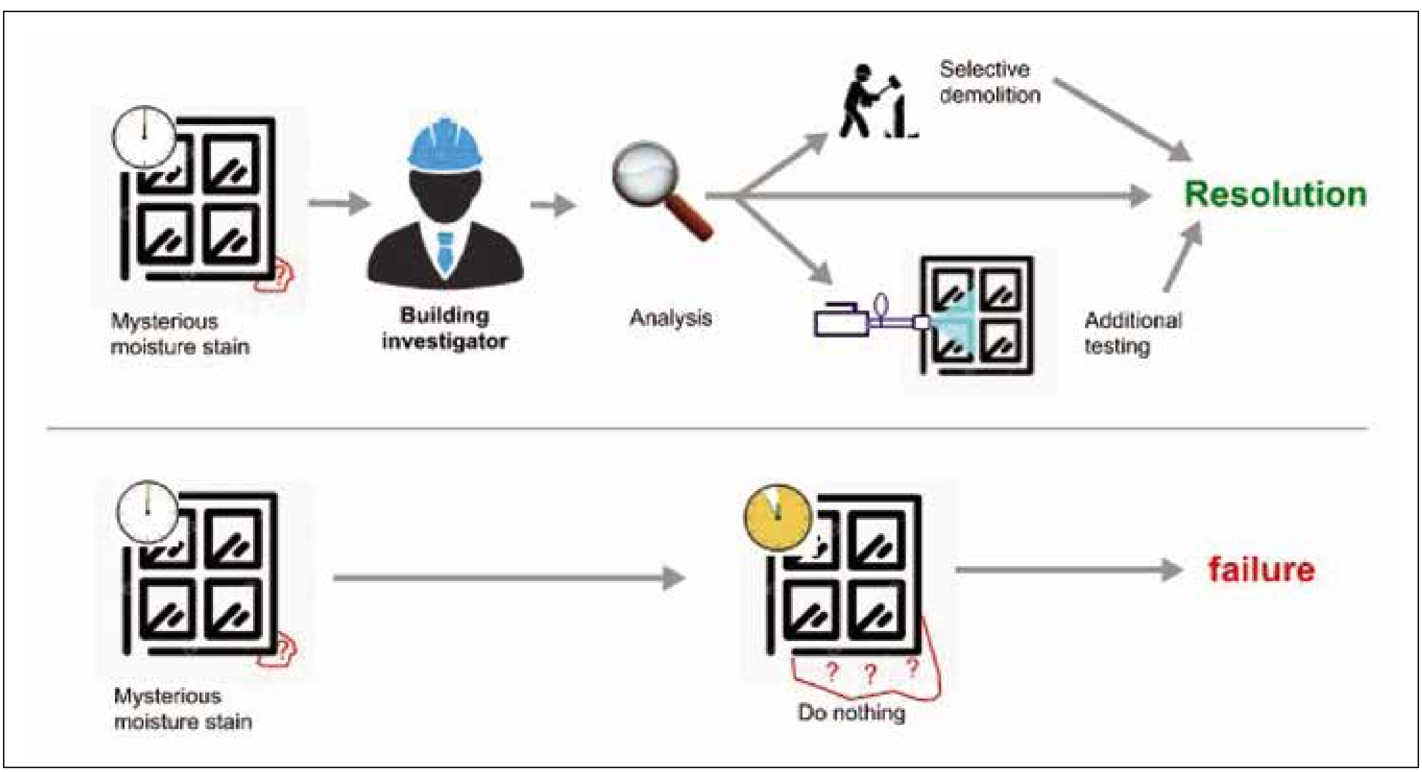

Figure 9. *The path of assessment.*

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