Infrared Applications in the Fields of Forensic & Construction Defect Engineering

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ABSTRACT

This paper outlines the use of infrared thermography in forensic and construction defect engineering in the mountainous State of Colorado. The building envelope case studies explored in this paper include the use of infrared thermography in the analysis and solution of problems including cold roof ventilation, ice damming, roof ice melt systems, in-floor radiant heat systems, exterior insulation and finish systems/stucco, stone veneer, plaza decks/balconies, flat roof and at-grade foundation clearance failure analysis and building envelope system performance.

Keywords: forensic, construction defect, building envelope, infrared, thermography, failure analysis

THE BENEFITS OF INFRARED THERMOGRAPHY IN FORENSIC ENGINEERING & CONSTRUCTION DEFECT INVESTIGATIONS

In forensic engineering and construction defect investigation, a visual illustration of an envelope system or specific component failure that resulted in damage or the likelihood for damage is just as important as knowing how and why the system or component failed to begin with. Infrared thermography has proved itself as a successful tool in providing lucid, intuitively understandable illustrations of damage that not only assists engineers in failure analysis, but can be readily understood by adjusters, attorneys, arbitration panels, judges and courtroom jurors.

The application of infrared thermography can be utilized in many areas of forensic engineering and construction defect investigations. One of the primary driving factors behind these types of cases or projects is often the inability of a structures building envelope to prevent incursion of moisture and other outdoor elements. The building code indicates the construction of a building is to be “weather tight.” The so-called waterproofing or water shedding characteristics of a building’s envelope is vital for ensuring long-term structural integrity along with reducing the nuisance of leaks, interior damages and the likelihood for an environment that will foster and support mold or other biological growth.

The intent of this paper is not to address all of the different types of building envelope components and systems and the variety of reasons that they can fail. However, it will provide a general overview of where the technology of infrared thermography can be utilized to provide a more accurate and cost-effective assessment of the failure mechanisms along with the types and extent of damages that can occur and be better identified through infrared.

INFRARED APPLICATION EXAMPLES

The following list of examples provides a general overview of the types of forensic engineering studies or construction defect investigation work in which infrared can be utilized as an invaluable tool to confirm deficient installation and assess problematic conditions and subsequent damages with structures:

Cold Roof Ventilation & Ice Damming

In central Colorado and other mountainous regions, ice damming is an epidemic problem that results in not only damage to the interior and exterior of structures, but is a safety issue that can be life-threatening for pedestrian and vehicular traffic. To effectively combat ice damming, multiple design and construction factors must be considered and implemented to prevent this phenomenon from occurring.

Ice damming is the result of snow or ice that melts at upper roof sections and re-freezes when it flows to the cold eave sections. While there are several different approaches to reducing or eliminating ice damming altogether, the approach that has proven to be the most effective through our studies has been the cold roof design. A cold roof is designed to provide a uniform and consistent cross-flow ventilation path from the eave to the ridge of a roof resulting in a more uniform temperature equilibrium across the roof's sheathed surface. By maintaining a roof temperature of the closer to equilibrium to the outside ambient air temperature, ice damming is significantly reduced because the eave surfaces are now in equilibrium with the up slope roof surfaces (no hot spots). Another roof design concept for mountainous regions to control ice damming is that of the super-insulated roofing system. In theory such a system will work effectively; however the incorporation of 100% vapor barriers at the ceiling level, control of ceiling penetrations such as chimneys, and recessed can lights must be eliminated or designed and detailed properly in order for the system to achieve the desired performance. Solar gain must be considered in both designs, as it may circumvent any roof system.

Infrared thermography can be utilized to evaluate deficient conditions in cold roof or super-insulated roofing systems for the purpose of measuring temperature differentials due to heat loss that can result in heated sheathing surfaces that allow snow melt and subsequent ice damming.

Ventilation of a roofing system is also vital to minimize the possibility that condensation may form within the attic space, resulting in conditions that can encourage mold and other biological growth on the underside of the roof deck sheathing and framing components. These conditions are often found in residences and multi-family dwellings where and ice and water protection membrane has been used on the entire roof and adequate ventilation is not present. The ice and water protection membrane acts as a vapor barrier and does not allow the drying of building components on the roof. The removal of humid air through the attic is a necessary aspect in the design and construction of the roof component, and even more so if the vapor barrier is installed on the cold side of the assembly.

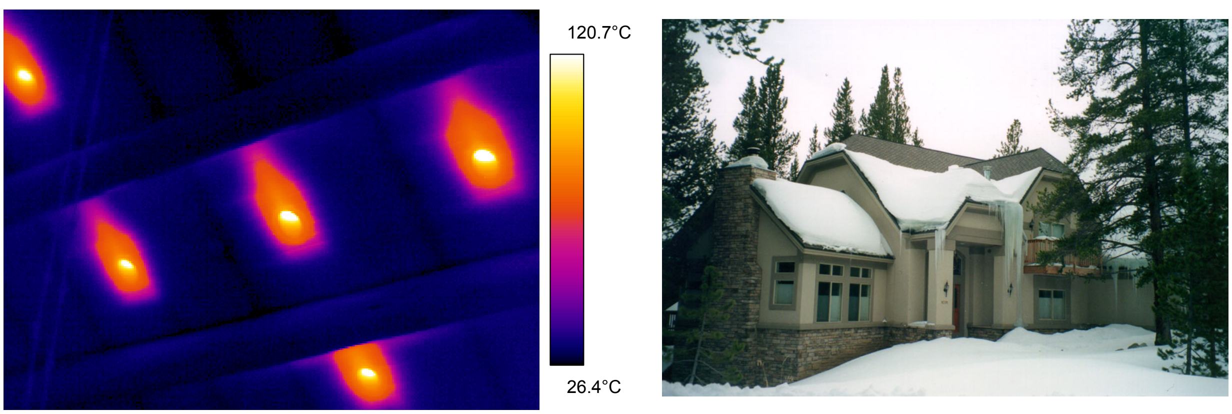

Figure 1. *Heat transfer patterns from recessed can lighting in the cathedral ceiling of single family log home in Steamboat Springs, Colorado resulted in significant ice damming (left). Such conditions can result in ice damming on either super-insulated or inadequate cold roof systems as shown on this home in Blue River, Colorado (right).*

Roof Ice Melt System

While roof ice melt systems will not replace a well designed and constructed cold roof or other appropriate designs for reducing ice damming, they can be an effective addition to assist in ice dam control at difficult venting locations and in areas where unwanted solar exposures and shading are the dominant cause of ice damming. Some of the most common ice melt systems seen today are a heat tapes or cable systems that are woven across a roof eave or valley in a "zigzag" pattern. While these are the most prevalently seen ice melt systems, they are probably the least effective. The effective heat zone in heat tape or cables is only 1" to 3" resulting in cave or tunnel melt patterns that do not provide a continual warming to prevent freezing along the entire length of an eave or valley. The more effective systems on the market incorporate an extruded metal rim plate cover along the entire length of the eave and valley in which the heat cable is covered. The metal extrusion and plate cover conduct the heat to provide a uniform melt section across the entire length of the eave or valley. This is similar in action to a bun warmer (the entire surface is heated).

Infrared thermography is an effective measure of determining heat effective zones, dead spots, insufficient coverage, and proper operating temperatures of all ice melt systems used to control ice-damming conditions and freezing of gutters and downspouts. The use of the infrared camera is extremely beneficial to the maintenance of the property, as the systems can be turned on and checked with the camera prior to the first snowfall.

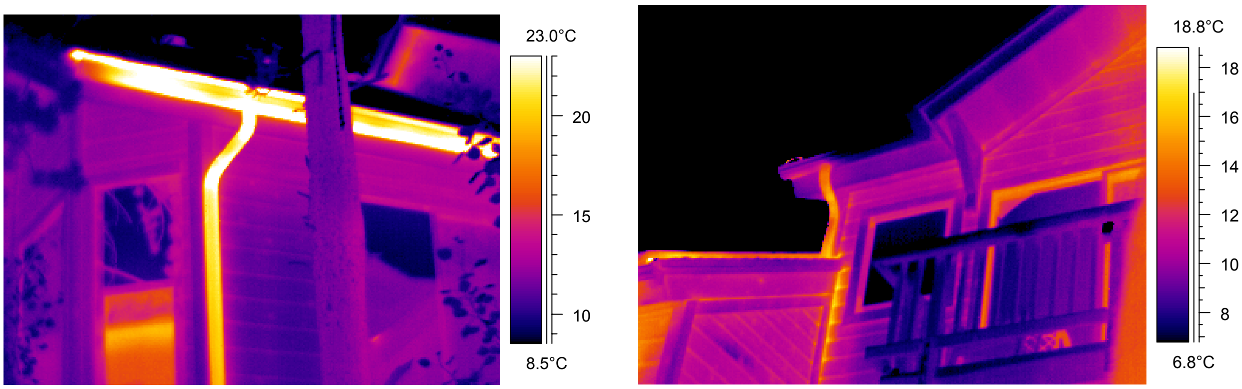

Figure 2. *Ice melt/heat cable system investigation on multi-family property in Breckenridge, Colorado (left). Note active system in gutter and downspout in Image 1 and partially non-operating gutter system in Image 2. This inactive heat cable section was found to be the result of a damaged cable and connection (right).*

In-Floor Radiant Heat Systems

In-floor radiant heat systems (both electrical and fluid) can be effective for heating both interior and exterior floor or slab structures. On interior floors, they provide a cost-effective heating solution while in exterior applications they can eliminate the need for shoveling snow and significantly reduce if not eliminate ice build-up that can result in a slip and fall safety hazards, as well as reduction in maintenance and aid when snow storage space on the site is limited, or to prevent snow from being piled against the buildings.

Similar to roof ice melt system analysis, infrared thermography can be used to evaluate or investigate in-floor radiant heat systems to locate effective/ineffective heat zones, breaks or ruptures in the lines, improper line placement and proper design operating temperatures. In investigations of line failures, or subsequent determination of repair areas, the value of the infrared camera can not be overstated.

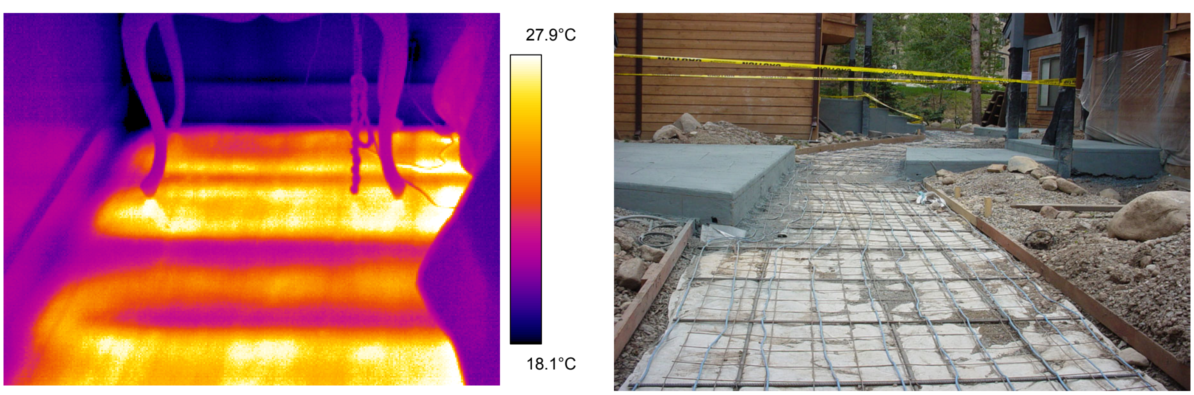

Figure 3. *In-floor radiant heat system investigation at single family home in Wolcott, Colorado (left). Electrical heat system for snow melt in exterior walkway at townhouse complex in Breckenridge, Colorado (right). Note that IR can be utilized both prior to the pouring of the concrete as a quality assurance procedure or long after the concrete is poured to identify heating malfunctions.*

EIFS (Exterior Insulation and Finish Systems) & Stucco

While the topic of EIFS is commonplace in today's construction defect arena, a short explanation on the history of EIFS would assist with understanding why it has received all the publicity. Per the EDI (Exterior Design Institute) EIFS 3rd Party Inspector Certification Course, EIFS systems were originally invented in Europe in 1947 and were introduced into the U.S. commercial market in 1969. Throughout the 1970s and 1980s, EIFS systems in the U.S. were primarily targeted at commercial projects where the architect and engineer involvement was not only in the design, but also in the quality assurance process to a greater degree than that on a residential project. Due to the downturn of the U.S. commercial market in 1991, EIFS manufacturers, distributors, and contractors began to target the residential market. In 1996 problems with “barrier” EIFS systems were headlined in the Wilmington, North Carolina, area due to a lack of flashings, missing, or improperly installed sealants, and water infiltration resulting in mildew, rot, insect infestation, and sometimes structural damage due to water infiltration behind the EIFS at faulty and improperly detailed windows. Shortly thereafter in 1996, “drainage” EIFS systems were introduced into the U.S. market to address applications of EIFS where water may enter the wall from improper or missing flashing, leaking windows, inadequate sealants, etc.

In both “barrier” and “water-managed” EIFS systems, moisture intrusion into the façade is most often the result of missing, insufficient or improper detailing (i.e. flashings and sealants). Similar to other facades, without the attention to detail these systems are prone to water entry and failure.

Similar to the uses of infrared with low-slope or commercial roofing systems, infrared thermography has proven to be invaluable in the assessment of moisture infiltration into EIFS and stucco clad structures. Being able to provide a physical illustration of the moisture migration paths is much more conclusive than extrapolating moisture meter probe locations and more cost effective than large intrusive test cuts.

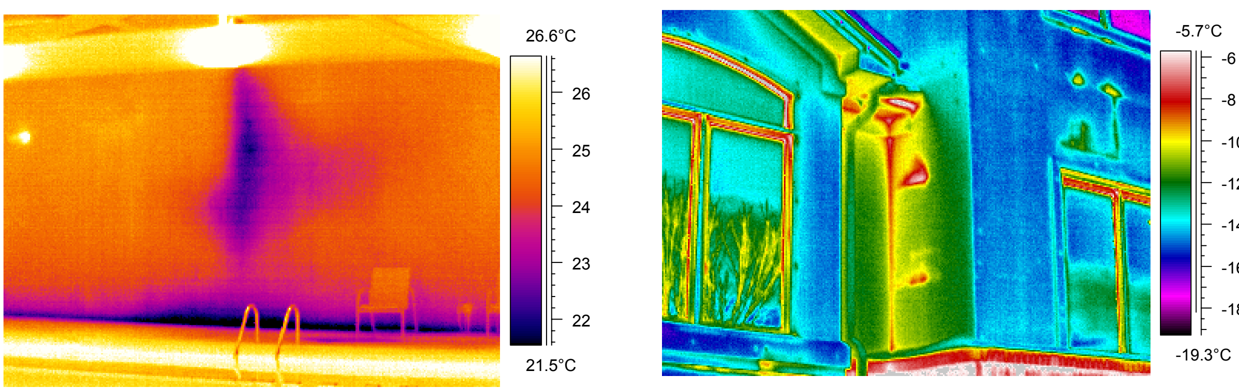

Figure 4. *:Interior moisture (left). Missing sheet metal “kicker” flashing at a roof-to-wall interface has resulted in moisture infiltration behind the EIFS façade of a single family home in Parker, Colorado (right).*

Stone Veneer

Stone veneer (similar to other facades such as brick, stucco, siding, etc.) is a common cladding material in both single family and multi-family construction in Colorado. While the majority of these products provide sound weatherproofing characteristics or systems, it is often the detailing that is overlooked or improperly installed that allows moisture to infiltrate the wall assembly. Often that insufficient detailing entails either missing or improperly installed flashings and/or backer rod and sealant joints at terminations between the façade and dissimilar materials.

Infrared thermography provides a valuable means of not only detecting or verifying moisture infiltration due to missing components or faulty construction, but also monitoring and tracking moisture migration paths within the wall cavity.

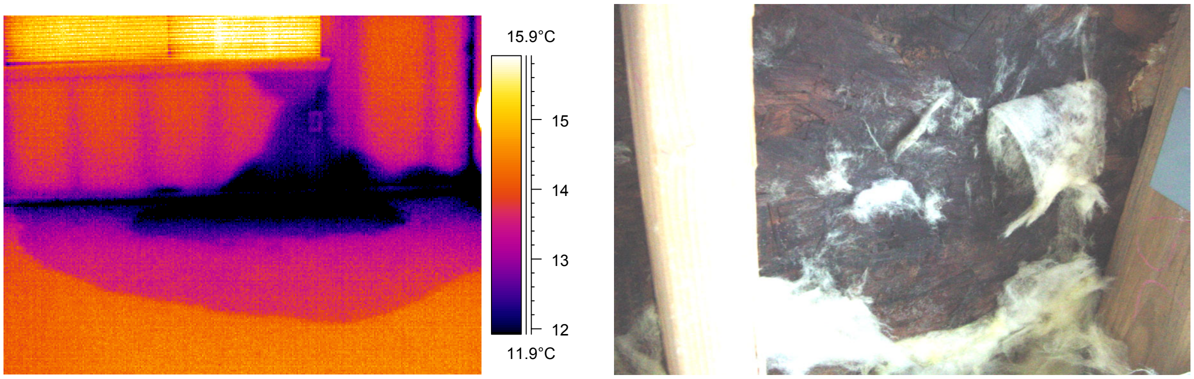

Figure 5. *Improperly terminated / sealed stone veneer to window frame and missing flashings resulted in moisture infiltration into the wall cavity and interior living space in a multi-family apartment building in Greeley, Colorado (left). Water infiltration into a wall cavity can result in deterioration of the sheathing and the possibility for biological growth or mold as seen here on this single family residence in Windsor, Colorado (right).*

Plaza Decks and Balconies

When not properly designed or installed, plaza decks and balconies provide opportunities for water entry into occupied spaces below the deck or balcony and also into structural components and members. Plaza deck and balcony waterproofing defects are common in multi-family dwellings where individual unit decks and below-grade parking structures are present. Failure to provide proper flashings, composite drainage media, and perimeter or internal drainage systems often allows moisture intrusion into not only the deck or balcony, but the supporting structure and adjacent walls as well. This water entry can result in a structural degradation of the supporting elements and an environment that will foster and support mold and other biological growth.

Infrared thermography can be utilized to determine or verify potential leak locations and moisture migration paths without the large expense of removing overburden.

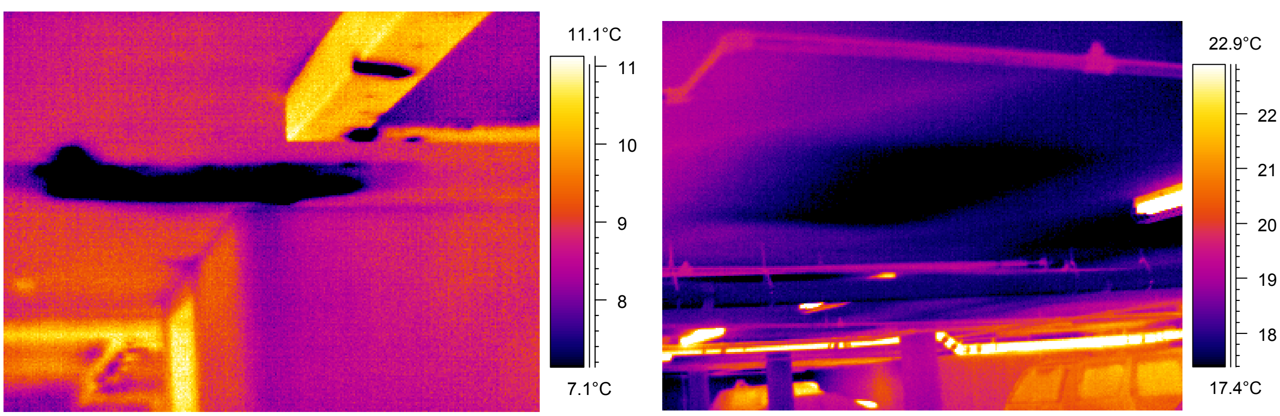

Figure 6. *Improper flashing at balcony-to-wall connections and missing perimeter drainage system resulted in moisture intrusion into the wood framing support structure of the exterior walkway balcony of a loft complex in Denver, Colorado (left). A missing composite drainage plane or medium on a below-grade parking garage plaza deck structure in Cherry Creek, Colorado resulted in standing water between the structural concrete deck and the plaza wearing surface (right).*

Low-Slope / Commercial Roof Structures

Low-slope or commercial roofing systems are a valuable asset to any building owner because they protect a majority of a company's in-house assets. Therefore, the overall weather tight integrity along with the energy efficiency of a low-slope roofing system are vital components that if jeopardized could result in damage, loss of production, and excessive heating and cooling costs.

While infrared thermography has been widely used in roof moisture and heat loss surveys in low-slope or commercial roofs for years, it should be noted that this is still one of the most effective non-intrusive test methods for determining moisture intrusion and relevant heat loss in these systems.

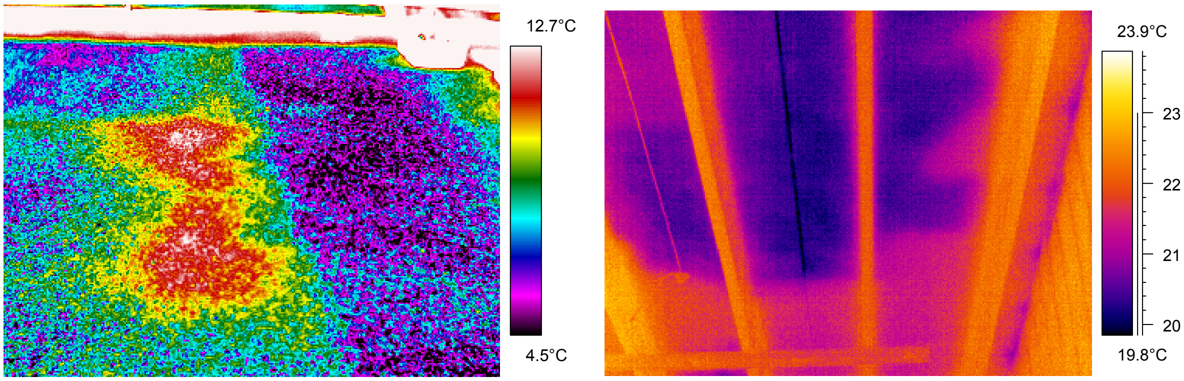

Figure 7. *Moisture infiltrated BUR (Built-Up Roof) assembly on a low slope manufacturing facility in Cheyenne, Wyoming (left). Water-damaged roofing components and insulation identified from infrared scan from the underside of the built-up roof on a structural concrete tee deck (right).*

At-Grade Foundation Clearance

Clearance of not only the foundation, but façade materials (EIFS, stucco, siding, brick, stone, etc.) from at-grade soil and concrete flatwork is an important construction practice that if not followed can result in significant moisture infiltration into not only the façade materials, but the interior of the structure as well. Infrared thermography has proven itself as a valuable tool in the non-intrusive investigation of moisture intrusion problems that lead to not only interior finish damage, but also structural deterioration of the sheathing, sill plate and framing along with the identification of mold and biological growth inside wall cavities.

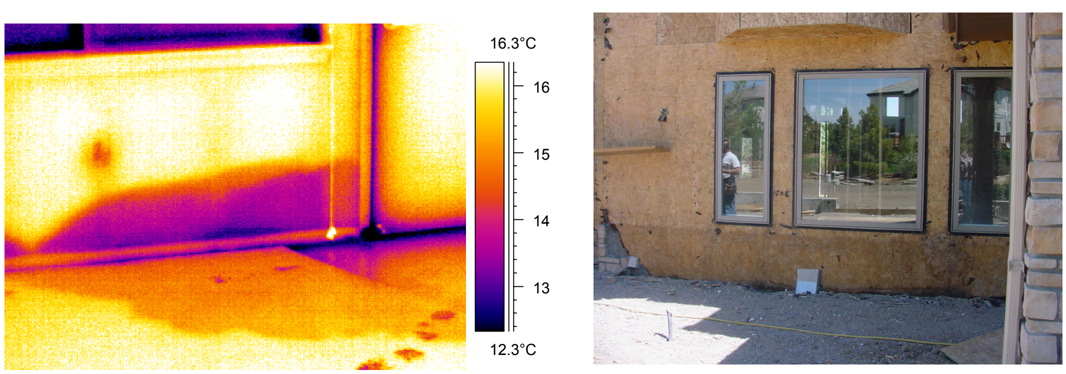

Figure 8. *Moisture migration into drywall from capillary drive and interior finish components from inadequate clearance and slope of grade from vinyl siding façade on an apartment complex in Loveland, Colorado (left). Example of where OSB sheathing and façade materials had begun to deteriorate because they were not withheld above the at-grade soils (right).*

Plumbing Breaks / Inadequate Insulation – Product Defects

One of the common occurrences in Colorado is the freezing of water in pipes or plumbing lines. These events can lead to physical damage to the premises, but often spawn subsequent mold claims due to insufficient remediation of wet or water damaged components and materials. Frozen pipes or plumbing lines are usually the result of inadequate insulation or placement of the lines; however occasionally product defects are found involving valves or connections that result in similar type damage.

Infrared imaging can accurately locate water damaged components or materials that require remediation. Furthermore, infrared imaging can often provide a far better understanding of the leak source than can be discovered with the naked eye.

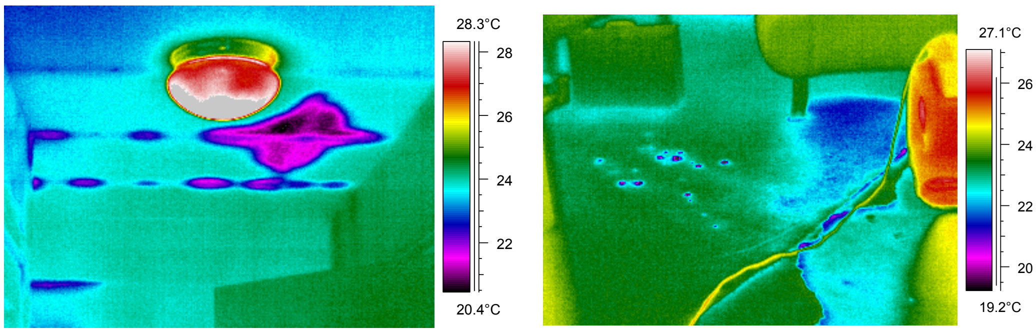

Figure 9. *Moisture migration tracking along steel joist channels inside ceiling of a single family home where a plumbing line had ruptured in Morrison, Colorado (left). Water from plumbing leak was found to have migrated farther than originally anticipated by the contractor during remediation techniques of cutting back carpet and installing dehumidifiers – note wet carpet under chair that was not removed (right).*

ASTM E 1105 Water Testing

One of the common test procedures utilized to determine moisture infiltration into windows or between windows and adjacent façade materials is the ASTM E1105 water test. This test is comprised of applying a controlled spray to a specimen while a uniform or cyclic negative pressure chamber is maintained on the interior of the specimen.

While this test in itself is an excellent means of identifying the sources of moisture intrusion, often infrared thermography can provide an added benefit to the testing by identifying migration paths between the sheathing and façade materials, where otherwise they may have gone undetected from a standard visual observation in the wall cavity.

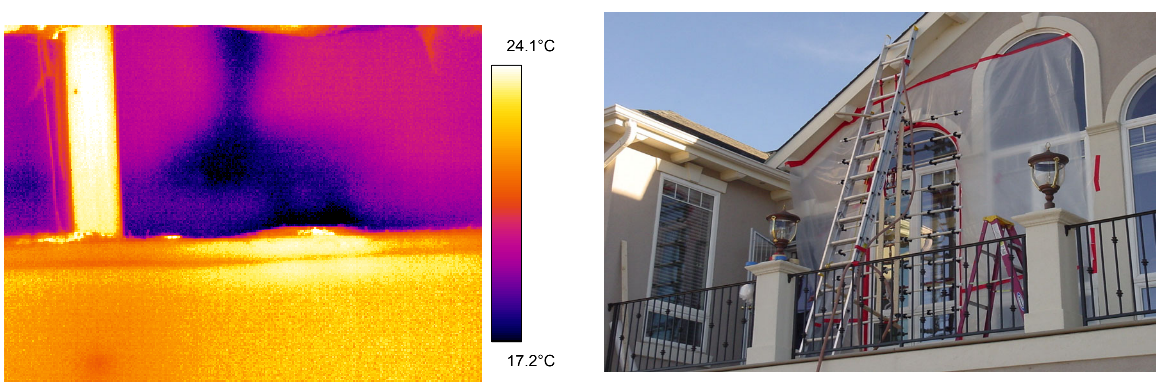

Figure 10. *Moisture migration path detected between exterior gypsum sheathing and EPS (expanded polystyrene) insulation component of EIFS system at intrusive test cut under window sill on high rise loft complex in Denver, Colorado (left). Overview of an ASTM E-1105 water spray test (right) for investigating leaks in windows and different façade types.*

CONCLUSION

Infrared thermography provides an invaluable service to forensic engineering and construction defect investigations in that it allows the engineers a non-destructive method to substantiate their visual findings or other means of testing with an illustrative test to indicate what is happening behind or inside the building envelope component.

While infrared technology can provide a valuable asset to an investigator, more often than not it cannot be used as a sole source for determining deficiencies in a building envelope. Knowing what you are looking for and where to look are extremely important when investigating building envelope type issues with infrared technology. Verifying infrared readings with moisture probes and / or small intrusive test cuts or other test methods is a wise recommendation to minimize the possible misinterpretation of infrared images.

Infrared thermography has been and will continue to be an asset too engineers and other investigative professionals that are in search of alternate methods of identifying distress or substantiating / providing further evidence to confirm or support failures and deficiencies in the fields of forensic and construction defect engineering.

REFERENCES

1. Exterior Design Institute (EDI), EIFS 3rd Party Inspector Certification Course Reference Manual, Norfolk, Virginia