INFRARED THERMOGRAPHY FOR ROOF INVESTIGATIONS

BY SCOTT WOOD

ABSTRACT

Infrared thermography is an excellent investigative tool used for a multitude of building-specific applications, including roof investigations. Since its introduction in the 1970s, lower prices and technology advances have allowed thermography to expand, becoming an indispensable tool for roof investigators. For roofing applications, thermography is typically used for condition assessment and forensic studies of the low-sloped roof. Since many papers have been written on this subject, this article will summarize the discussions on how infrared thermography works as a tool for roof investigations.[1-6]

INTRODUCTION

Infrared has been around long enough that many professionals use infrared analysis for building applications, including low-slope roof inspections. Before the use of infrared, roofing professionals had to go to great lengths to detect leaks caused by moisture intrusion, though electrical methods were available for determining roof leaks. The use of infrared imagers in detecting roof leaks has provided the roofing industry with a tool that has become essential to low-slope roof leak inspections.

In the past, time and resources were used to carefully inspect all areas of the roof, below and above, to determine if it was leaking or to locate an intrusion site. For the trained roof thermographer, now a roof overview can be as simple as a quick flyover, though onsite inspections are important to confirm any flyover findings.[7-9] For building owners, advances in technology have made infrared imagers one of the most cost-effective ways to detect and locate damaging roof leaks and to provide corrective measures.

In 1990, ASTM C1153, *Standard Practice for Locating Wet Insulation Using Infrared Imaging*, was published and is still in use with very few changes today.[10] Unfortunately, while imagers have improved dramatically, the approaches to roof inspections have not, as demonstrated by the minor changes of the current version (i.e., 2010) of ASTM C1153. One neglected aspect of this standard is that it only describes night investigations. It is clear from many years of experience that the laws of physics apply to day surveys as well.[4]

Understanding and using thermography to detect a roof leak or wet insulation is much more difficult than just pointing and shooting a thermal imager. Experts need to spend many months as active thermographers and go through many hours of training to achieve competency. In the hands of a trained professional, though, roof leaks can be detected in a variety of ways using infrared thermography.

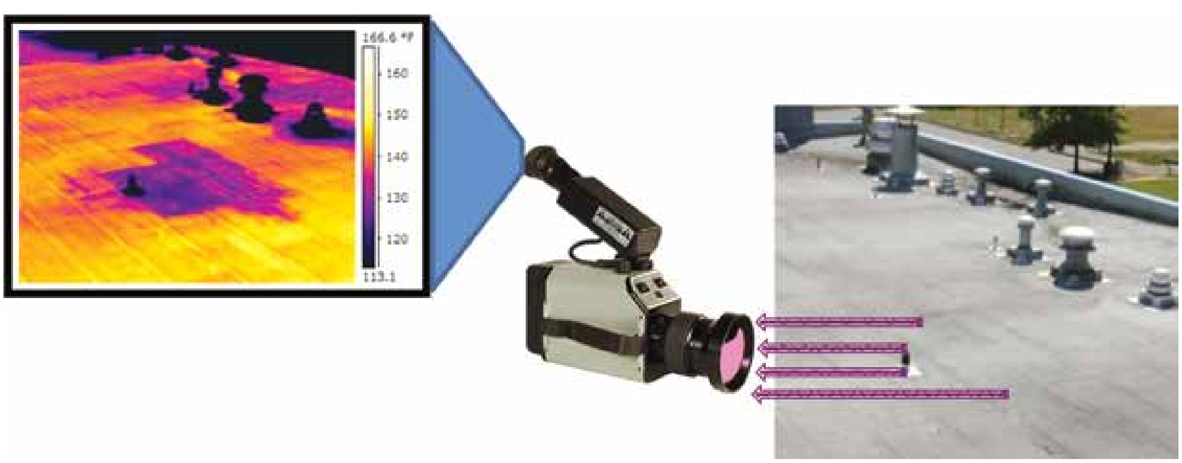


Figure 1 – Infrared radiation is emitted from the roof surface and detected by the infrared imager that converts the invisible infrared to a visible image.

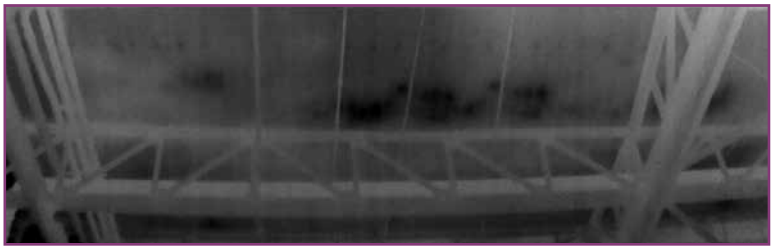


Figure 2 – Wider-angle, multiple-image view.

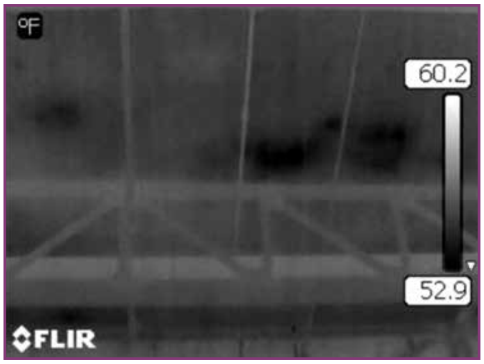


Figure 3 – Narrower, single-image view.

HOW DOES IT "SEE" THE LEAK?

The roof emits infrared radiation, according to the laws described by Planck, Stefan-Boltzman, and Kirchhoff. An infrared imager converts invisible infrared radiation into a visible image by detecting the incoming infrared electromagnetic energy and intensities from the roof with its detector.

Just as in visual photography, the infrared electromagnetic energy is focused with a lens onto a detector, which then processes the information into a visual image displayed onto the viewfinder as shown in *Figure 1*. The intensity of the radiation, coupled with the imager's electronics, can yield thermal patterns on the surface of the roof being inspected.

IMPORTANT IMAGER SPECIFICATIONS[11]

In order to capture and interpret the thermal image, it may not be necessary to fully understand how the imager's internal components work or the need to adjust the parameters for correct temperatures. However, when purchasing, it is important to understand some of the basic specifications of the infrared imager. The two most important specifications are image resolution and thermal sensitivity. Image resolution is very important when observing the roof from a distance, as when performing a flyover or from an adjacent building, to provide clear images to the client. Thermal sensitivity is important when little temperature variation is present and a higher contrast is needed.

Most infrared imagers applicable for roof inspections have an image resolution of at least 320x240 (76,800 pixels or 0.07 megapixels), though lower resolution can still provide the majority of details to resolve moisture locations, provided one is close enough. Unfortunately, 0.07 megapixels is much less than the digital cameras we use to visually document the inspection. Higher resolutions are needed when greater distances are are involved in observing the roof, such as in a flyover. For this application, to compensate for a lower-resolution imager, a telephoto lens is sometimes used, and images are stitched or merged together. One way to increase resolution as well as wider viewpoint is to stitch multiple images together. In *Figure 2*, three images were stitched together to show a wider viewpoint and higher resolution as compared to the single image shown in *Figure 3*.

For on-roof thermography, where close distance observation is performed, some thermographers use a wide-angle lens. This, like stitching, increases viewing angle, facilitating a larger instantaneous viewing area of the roof surface. The wide-angle lens can minimize the scan area and the need for multiple images.

The thermal sensitivity or noise-equivalent temperature difference (NETD) for an infrared imager is measured in degrees Celsius (°C) or milliKelvins (mK). It is the measurement of the smallest temperature difference that a thermal imager can detect in the presence of electronic noise. A 50-mK (0.05°C) sensitivity is two times as sensitive as a 100-mK (0.1°C). The NETD can be as important as resolution when deciding what imager to purchase. An experienced thermographer can usually distinguish thermal images having as little as a 10 mK NETD difference. The lower the thermal sensitivity, the more detailed and less noise present on the thermogram. This is especially evident in the case when using small thermal spans. Highly sensitive (low-NETD) thermal imagers will show more temperature differences, and thus more patterns.

The thermograms in *Figures 4* and *5* were taken with the same infrared imager but tuned to different temperature spans. The thermogram in *Figure 4* has a span of 3°F, which is narrower than *Figure 5*, with a span of 36°F. *Figure 4* is grainier than *Figure 5*. If the imager has 256 dis-

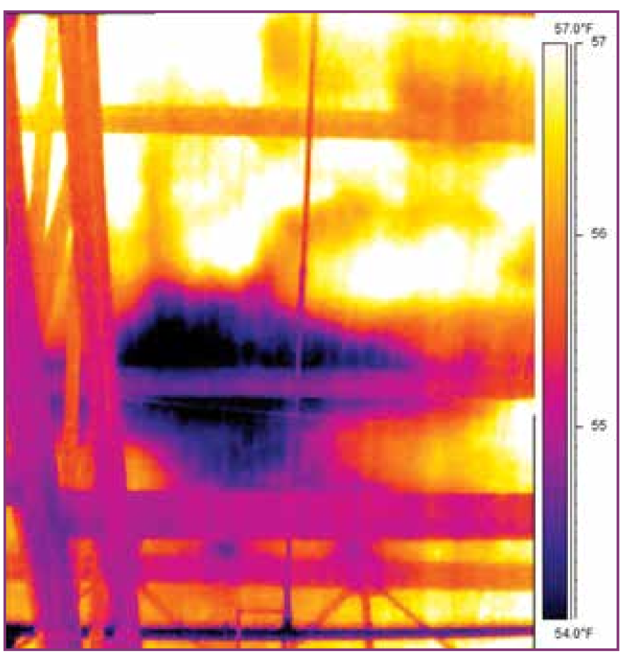


Figure 4 – A narrow, 3°F (1.7°C) span.

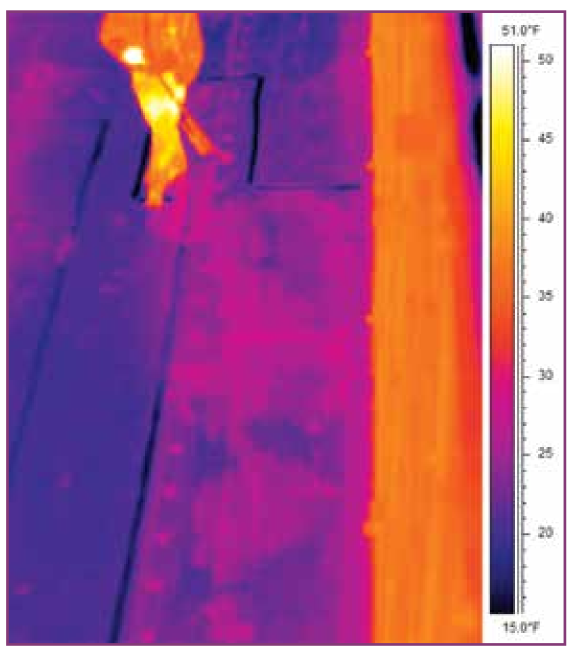


Figure 5 – A wider, 36°F (20°C) span.

crete color levels, then for the narrow span in *Figure 4*, each color level would represent 0.011°F or 0.006°C (6 mK). This is far more sensitive than the 50-mK (0.05°C) NETD specification for this imager, causing increased noise in *Figure 4*.

The infrared imager's frame rate or capture rate may be an issue if the stabilization of the imager is difficult. A low-frame rate (9Hz) makes it difficult to stabilize or freeze the image for capture. This is very important if the imager is bouncing due to turbulence during a flyover (especially helicopter flights) or from a thermographer's hands after too many cups of coffee. A 30-Hz or better frame rate should be considered—especially for flyover applications.

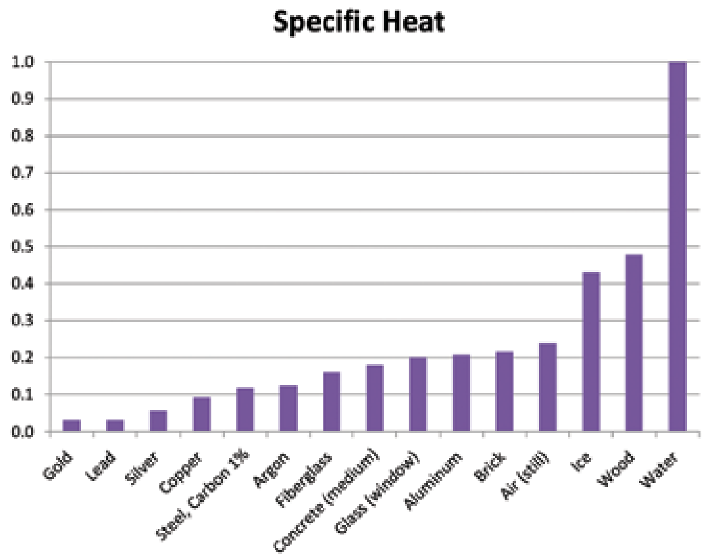


Figure 6 – Heat capacity of various materials in Btu/lb. °F.

Material	Specific Heat Capacity (Btu/lb °F)
Bitumen	0.59
Rubber membranes	0.48
Fiberboard	0.32
Asphalt singles	0.30
24ga Steel	0.30
½" Plywood	0.29
Gypsum	0.26
Stone	0.20
Concrete lightweight	0.20
Fiberglass	0.16
Concrete	0.16

Figure 7 – Heat capacity of various roofing materials in Btu/lb. °F.

Another imager specification for roof investigation is detector wavelength. Midwave detectors (3-5µm) can provide less cold-sky reflection (*Figure 18*) than the long-wave band of 8-14 µm. More of the midwave band is absorbed by the atmosphere than the long-wave wavelengths of 8-14 µm. This reduces the radiation from the cold sky when using midwave imagers, resulting in an attenuated component of the energy reflected (originating from the sky) by the roofing material. This is especially useful for low-emissive roofing, such as reflective roof coatings.

WHY DOES THE WET INSULATION SHOW A PATTERN?

The thermal patterns observed on the roof where wet insulation is present are due to material differences in "thermal capacity" or "heat capacity." This is the amount of heat (energy) required to raise a unit mass one degree in temperature. The chart in *Figure 6* provides a graphic representation of specific heat of various materials, from gold to water. It is clear that water has the highest heat capacity of the materials listed. In fact, it has such a high-heat capacity that it takes water almost ten times longer to heat than steel. Once materials with a high specific heat are heated, they stay warmer longer or cool more slowly.

When it comes to roofing, the heat capacities of various roofing materials have at least half the heat capacity of water (1 Btu/lb. °F) as shown in *Figure 7*. In the morning, when the sun heats the roofing material, the water heats at a slower rate (than the roofing material), conveying a cooler thermal pattern for the trapped water or wet insulation. As the sun sets, the heat capacity of the water keeps the water pattern warmer longer, providing a heated thermal pattern for the wet insulation.

The thermographer can observe thermal patterns both in the evening, just after sunset; or in the morning, just as the sun is

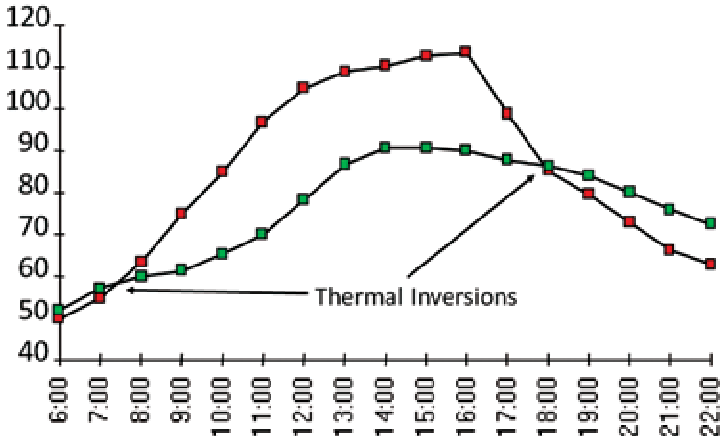


Figure 8 – Graph showing the temperatures of wet insulation (green points) and dry roof deck (red points).

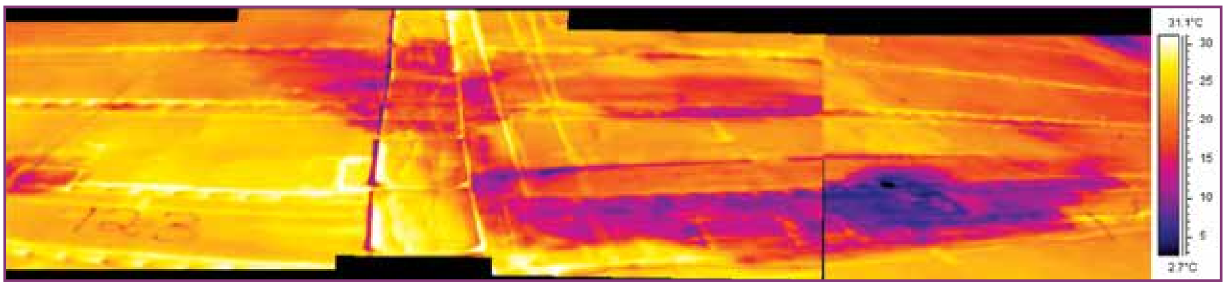


Figure 9 – On-roof viewing of multiple stitched images, showing a wide view.

rising, due to the thermal capacity differences of water and roofing material. The temperature data shown in *Figure 8* indicate temperature differences of wet or dry insulation during the day and evening.

ROOF INSPECTING

Walk-on inspections may require a wide-angle lens or the stitching of multiple images to provide a wide angle of view shown in *Figure 9* as compared to the standard lens shown in *Figures 10* and *11*. Additional thermal patterns may be confused for trapped moisture. The small hot spots in *Figure 10* are due to the high conductivity of the fasteners. Whenever there is a concern, moisture meter testing (*Figures 12-13*) or nuclear radioisotopic thermalization[12] (*Figures 14-15*) should be used to confirm the patterning observed by infrared thermography. If following the ASTM C1153 standard, coring must be performed to confirm the results of the thermography inspection.

Whenever possible, on-roof viewing will benefit from a wider-angle lens or from a higher vantage point, such as an adjacent roof

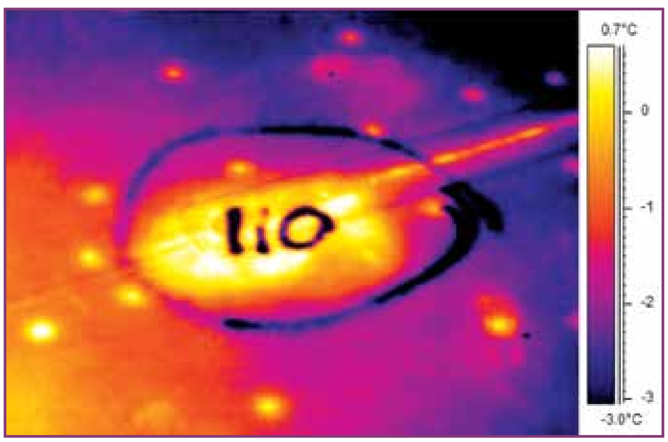


Figure 10 – Thermogram of an on-roof viewing.

Figure 11 – Visual image of an on-roof viewing.

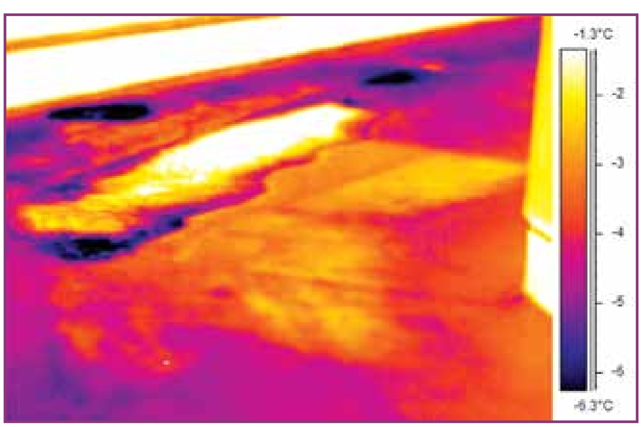


Figure 12 – Thermal pattern visible outside of the frozen puddle.

Figure 13 – Visual image showing frozen water and a roof capacitance moisture meter (Tramex RWS moisture meter roof and wall scanner).

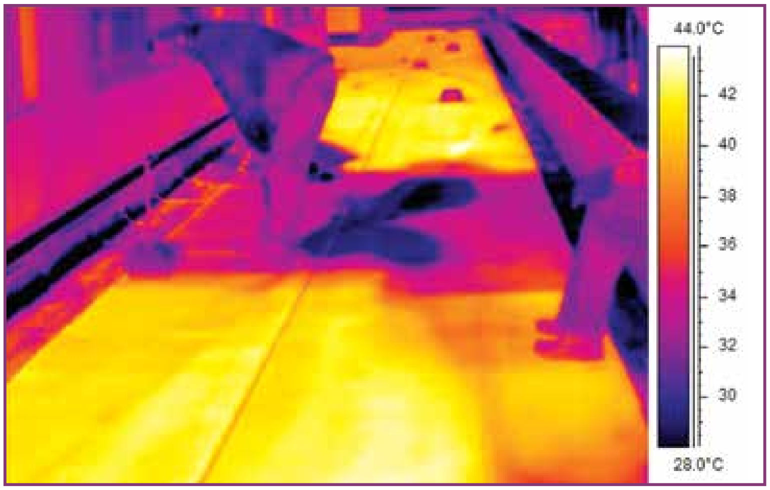


Figure 14 – Wet insulation visible as a cool thermal pattern.

Figure 15 – Technician performing nuclear moisture testing.

as shown in *Figures 16* and *17*, especially when roof access may be difficult or unsafe. In addition, a bird's-eye view provides the thermographer a much better overview than walking on the surface. The same building observed in the roof inspection shown in *Figures 16* and *17* is observed in a flyover in *Figure 18*. Roof flyovers provide opportunities to investigate difficult-to-access roofing, as well as multiple roof systems, in minutes. More area is observed in a single frame from the vantage point of an aircraft above; however, image resolution is important as shown in the difficult-to-interpret image of *Figure 19*.

Unfortunately, ASTM Standard C1153 does not provide guidance for daytime roof thermography. But since the physics do not change, thermal patterning can be observed during the day as well as the evening. The graph in *Figure 8* clearly shows that temperature differences appear throughout the day, as well as in the evening. Day thermography may be more difficult than evening thermography due to high daytime temperatures overwhelming the cool patterns of the wet insulation with hot spots or shadowing, as shown in *Figures 20-21*. The comparison of an evening inspection (*Figure 18*) and morning inspection (*Figures 16-17*) of the same area shows the dramatic temperature differences, in part due to solar insolation differences of day and night, shadowing, and night radiation heat transfer.

EMISSIVITY AND ANGLE

Thermal inspections of low emissive surfaces are limited due to the increase in reflection. This is also apparent for on-roof inspections due to the low angle necessary to observe distant areas as shown in *Figures 22* to *24*. Based on the Lambert's cosine law, the radiant intensity observed is directly proportionate to the cosine of the angle (see *Figure 25*).

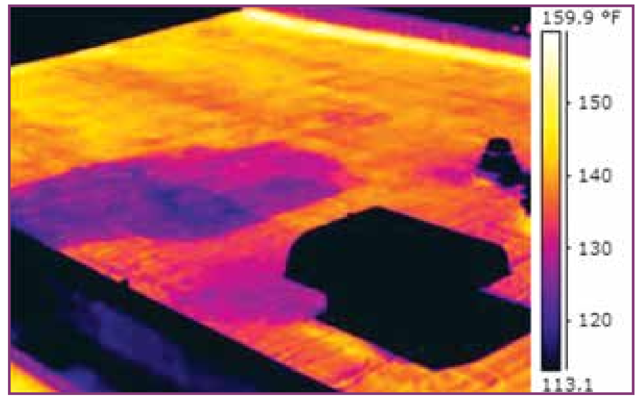


Figure 16 – Viewing from an adjacent roof.

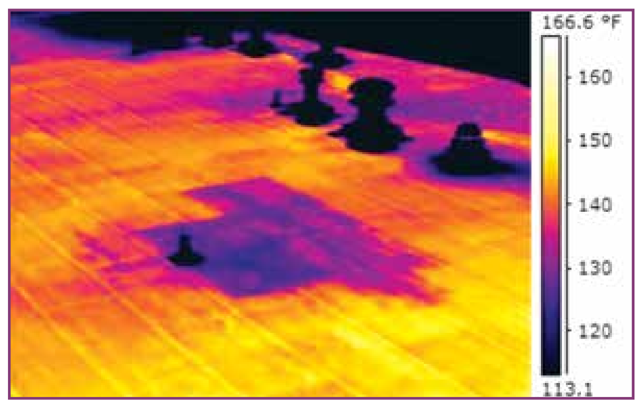


Figure 17 – Viewing from an adjacent roof.

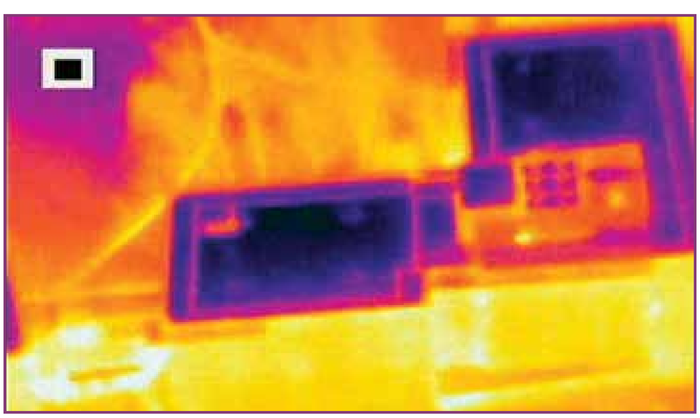


Figure 19 – Flyover using low-resolution imager digitally zoomed.

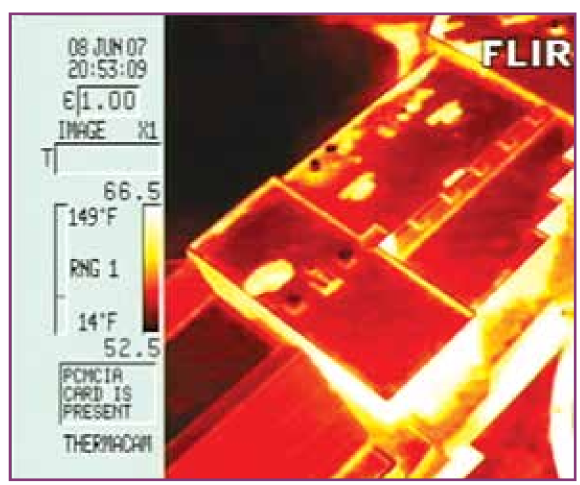


Figure 18 – Flyover of area shown in Figures 16 and 17.

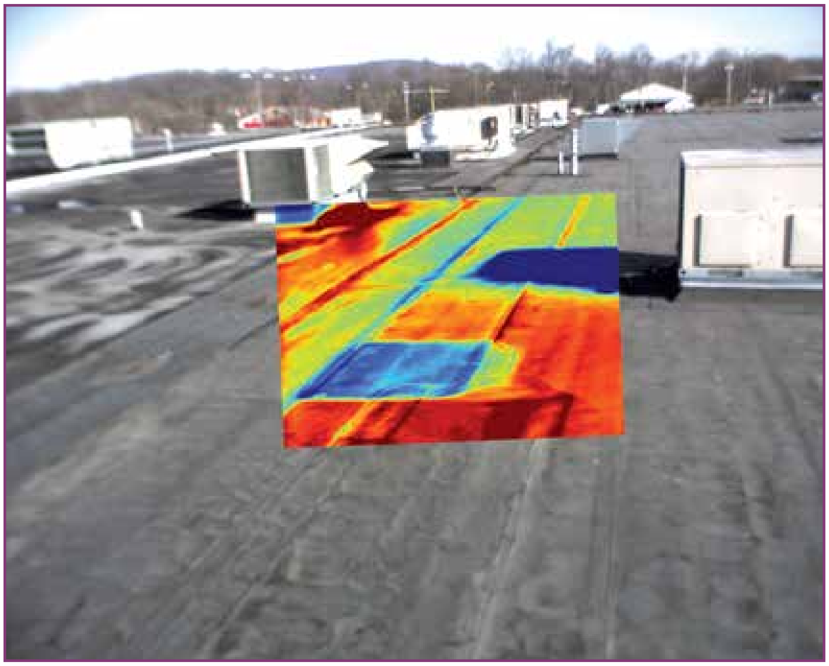


Figure 20 – Cooler patterns may be due to shadowing.

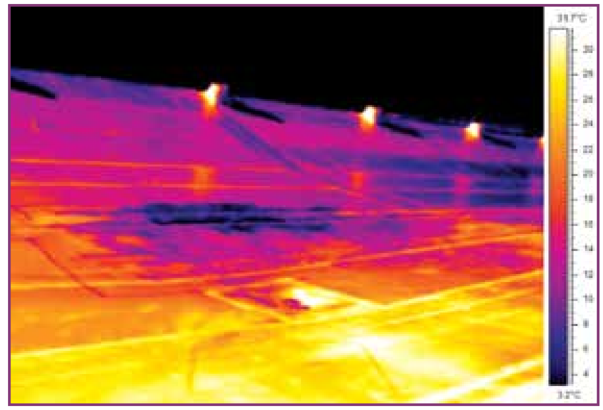


Figure 21 – Thermal patterns from reflection and shadows.

Fronapfel, in his 2006 InfraMation article, determined the emissivity of various building materials and the changes that were induced by adjusting the observation angle.[13] For roofing membranes made of ethylene propylene diene monomer (EPDM), the emissivity was observed to change from 0.95 to 0.85 when viewed at a 75-degree angle. Care should be taken when observing low-emissive roofing or roof coatings. The observed thermal patterning may be due to reflections and not temperature differences of the material.

Underdeck inspections can be problematic due to low-emissive coatings such as radiant barriers, but direct view is usually more of an issue since the underdeck is typically concealed from view. When direct observation can be performed, the underdeck results can be dramatic, as shown in *Figure 26*.

Figure 22 – Reflection due to high angle obscures the roof.

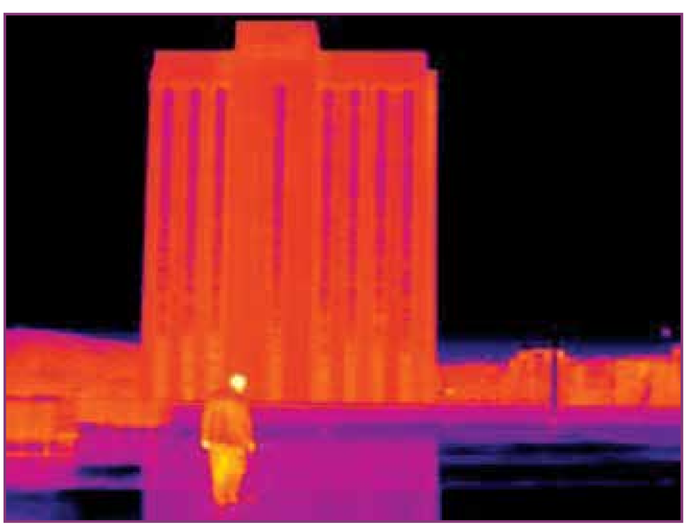


Figure 23 – Heat reflecting from the building.

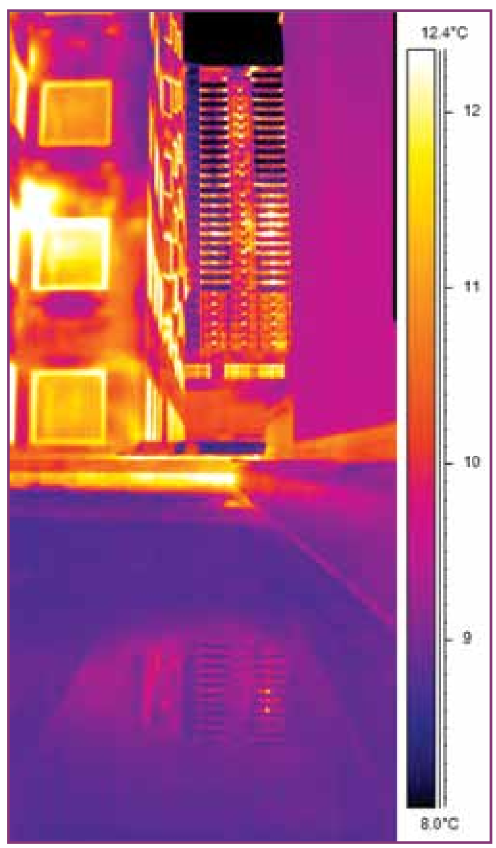


Figure 24 – Reflection from water on the roof surface due to angle and the spectral (smooth) surface of the water.

REPORTING RESULTS

Roof replacement can be very costly for the building owner. By locating a leak or damaged area, the cost of repair is considerably less than a new roof. Infrared thermography can easily locate and document the leaks, providing a clear map to correct the issues without replacement of the whole roof (see *Figures 27-29*). In addition to the savings of postponing roof replacement,

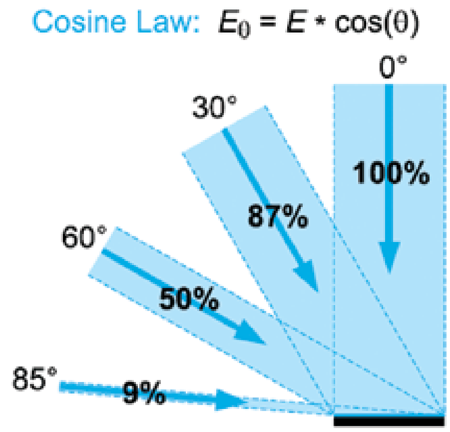


Figure 25 – Reflection due to high angle obscures the patterns radiating from the roof.[14]

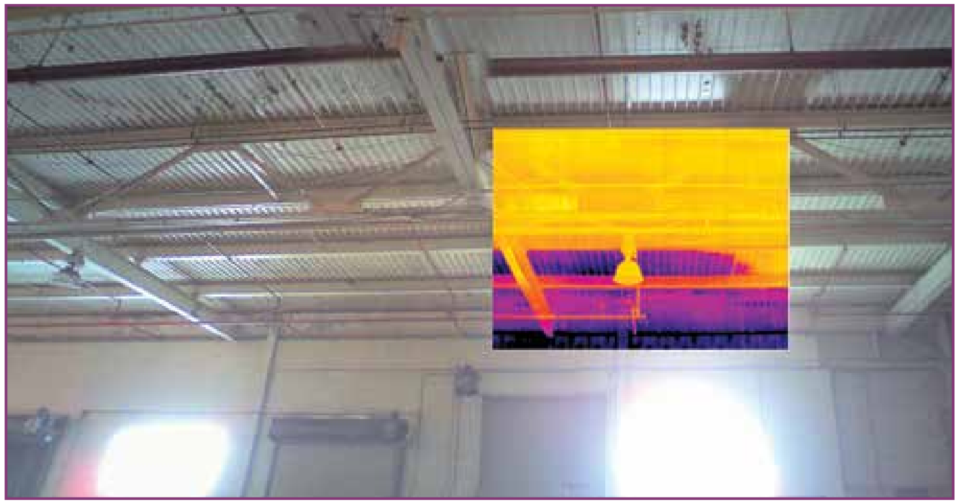


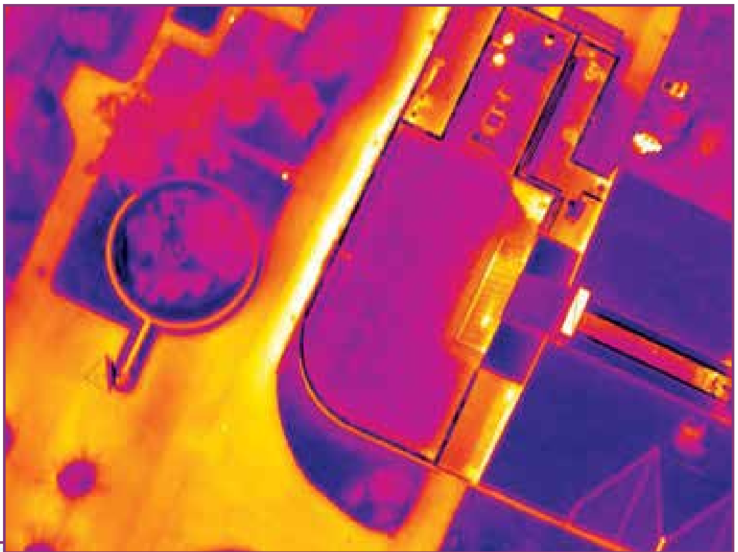
Figure 26 – Thermal pattern visible at the underside of the deck.

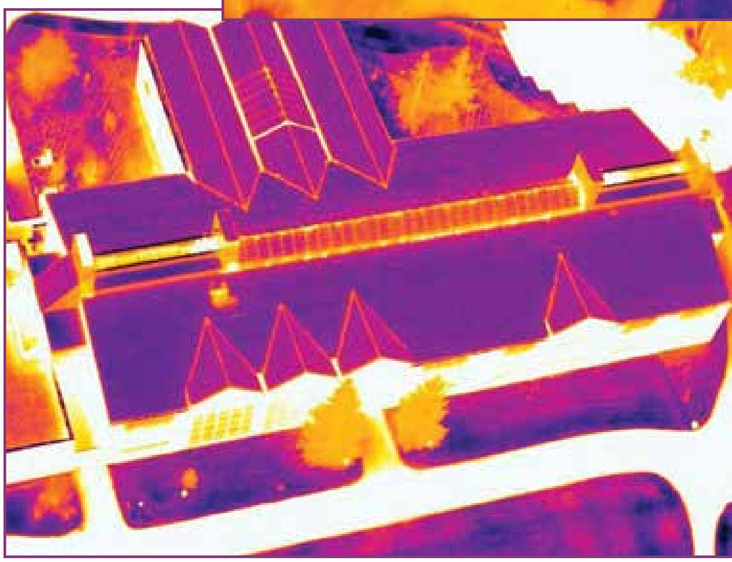
energy costs will be reduced. Wet fiberglass insulation is 14 times more conductive than dry insulation. Locating the wet insulation and replacing it will save heating and cooling costs for the building. Because of these effective cost-saving measures and ease of mapping wet insulation, infrared imagers are the best method available today to locate a roof leak.

IMPORTANT CONSIDERATIONS WHEN INSPECTING

The foremost consideration for a roof investigation is safety for the personnel. Climbing onto the roof presents a clear safety hazard of falling. In my personal communications with building investigators, I've heard from many survivors falling from ladders and through decayed roofing, many becoming physically disabled due to the falls. We all believe it will not happen to us, but it is a reality for many. Below is a simple (but not all-exclusive) list of important safety considerations:

- Always use proper restraints and proper safety equipment during inspections.
- Always inspect the underside of the





Figures 28 and 29 – Thermal images locate the wet areas.

useful at providing qualification levels and experience requirements, it tends not to provide enough guidance for the complex, specific thermography applications such as buildings or roofing. Both require extensive background in building sciences and construction to provide competence for this application of thermography.

The Canadian National Master Specification (NMS) is providing a new approach to the complex certification requirements for thermography by developing specifications for electrical, mechanical, roofing, and building envelope industries.[16] Others are working on international standards that provide more guidance on application-specific qualifications and certification requirements for thermography. It is clear that proper equipment, training, and experience are important for competency in the application of roof thermography.

The ASTM C1153 standard notes the following very important environmental parameters:

- No appreciable precipitation for the previous 48 hours. Infrared cannot see through water.
- No standing water.
- Wind less than 25 km/h (15 mph) to prevent convective heat loss of the thermal patterns.
- Direct sunshine on the roof during the day.
- At least 18˚F (10˚C) between inside and outside of the roof if there is little sun.

Not all thermographers are competent to perform roof inspections. Training is important for all thermographers, with most U.S. training organizations using the American Society for Nondestructive Testing, Inc. (ASNT) Recommended Practices ASNT SNT-TC-1A as a guide.[15] Though this guide is universally cited for training guidance and

SUMMARY

Infrared thermography is the conversion of invisible infrared electromagnetic radiation into a visible image. It is important to understand image resolution and thermal sensitivity in order to choose the right imager for an application. Lens types, such as wide-angle, normal, or telephoto, are also considerations. The high-heat capacity of water provides the means for observing thermal patterning of trapped moisture within the roof system.

ISO 6781:1983 (Thermal insulation – Qualitative detection of thermal irregularities in building envelopes – infrared method) and the similar ASTM C1153 standard are currently the only available standards, but are outdated due to fast-paced technological advances in thermal imagers. These standards provide good guidance for the roof thermographer but little guidance for daytime thermography. New or updated standards are needed, as it is clear that proper equipment, training, and experience are important for competency in the application of roof thermography.

Locating wet insulation will save the building owner the cost of a total roof replacement. Energy savings are also achieved by replacing the highly conductive wet insulation, thereby saving on heating and cooling costs. Because of these effective cost-saving techniques, infrared imagers are the best method available today to evaluate, map, and locate roof leaks.

Major advantages of an infrared roof moisture survey are:

- Locates water-damaged insulation quickly and accurately
- Identifies small problems before they become serious and more costly to repair
- Eliminates unnecessary replacement of good roof
- Documents problems before the warranty expires
- Greatly extends the life of the roof

A roof moisture survey should be carried out:

- Prior to acceptance of a new roof system or during a building's commissioning process
- Before any existing warranties expire
- Before acquiring a new building
- Before roofing over existing roofing
- For planned maintenance purposes

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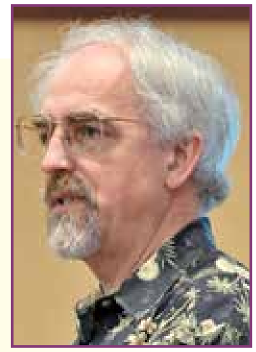

Scott Wood, president of Scott Wood Associates, LLC, is an Air Barrier Association of America (ABAA) auditor and a Level III thermographer. Starting in 2003, he created building science thermography classes that he has since taught to thousands. He is a founding member and treasurer of the International Association of Certified Thermographers (IACT); company advisor for ēssess, inc.; an active voting member for ASTM International C16 committee; and a member of the National Association of Commercial Building Inspectors and Thermographers (NACBI), National Institute of Building Sciences (NIBS), and the Seattle Building Enclosure Council (SeaBEC).

Inquiry Continues Into Elliot Lake Mall Collapse

A provincial government inquiry into the deadly June 23, 2012, collapse of the Algo Centre Mall in Elliot Lake, ON, which killed two and injured more than 20, began in March and is expected to conclude in September.

Robert Wood, principal owner and president of engineering firm M.R. Wright & Associates, Inc. (MRW), Sault St. Marie, wrote a report based on a visual inspection of the mall, stating that the mall's roof was sound only seven weeks before it collapsed. He has since been charged under the Occupational Health and Safety Act with providing negligent advice that endangered workers. He faces up to a $25,000 fine and a year in jail.

Wood and Gregory Saunders, his engineering partner who signed off on Wood's report, had previously had their engineering licenses suspended for designing a bridge that did not meet code. Saunders had regained his license after remedial exams, but Wood had not. Saunders gave testimony that the partners were aware of ongoing leaks, mold, and severe rusting of steel beams from a 2005 report by their own firm. Even so, they wrote in their May 2012 inspection report (contracted by mall owner Robert Nazarian to obtain new mortgage financing for the mall) that the "members" were "still structurally sound."

A class-action lawsuit into the collapse is ongoing, as leaks, mold, and water damage had been reported at the mall since its construction in the 1970s. At a press conference announcing the lawsuit, it was noted that some residents had placed bets on when the building would collapse.

NORR, an architectural and engineering company, has produced a 142-page report commissioned by provincial police and released to the public in March 2013. The report states that leaking occurred because an "intrinsically flawed" waterproofing system installed in 1980 failed from the start and prompted years of complaints. "The fact that the roof was allowed to leak for 32 years is perplexing," the report states. Two companies—Pinchin and M.R. Wright—issued reports attesting to the soundness of the structure during that time.

According to NOOR's analysis, the collapse occurred when a weld between a support column and beam failed in two stages because of corrosion caused by years of water and road-salt penetration (part of the roof was used as a parking deck). NORR also alleges that Coreslab, the company that supplied the precast concrete for the roof deck; and John Kadlec, the structural engineer, misled the mall's original owner about the capabilities of the product. The substrength hollow-core slabs did not play a direct role in the collapse, but their deficiency later thwarted proper waterproofing solutions, NOOR claimed.

—Compiled from CBC News, CTV News, and *ENR* reports