Building Enclosure Design

Using Infrared Thermography in Flat and Low-Sloped Roofing Systems

By Gregory R. Stockton

Roof maintenance is one of the most expensive and complicated challenges facing building owners and facility managers today. As part of a roof asset management program, however, roof moisture surveys that use infrared thermography can help save substantial dollars. Thermal imaging can narrow roofing areas that contain moisture to a finite and targeted amount, thus ensuring that maintenance staffs or contractors need only replace these wet areas. Similarly, building commissioning professionals can use thermal imaging results to see problems with design and/or construction defects during and after construction.

While many infrared applications have been developed over the years, infrared roof moisture surveying remains one of the most difficult for thermographers to understand. This is due, in large part, to the many different roofs, roof types, roof waterproofing, roof insulations, roof substrates and roof decks. A thermographer must understand the thermodynamic characteristics for each individual type of roof and each combination in the substrate—all of which can vastly differ, depending on such factors as weather over the past 48 hours, solar insolation during the preceding 24 hours, ambient conditions at the time of the survey and thermal activity under the roof. As a best-practice, condition-monitoring, predictive-maintenance technique and commissioning tool for roofs, however, infrared thermography often is performed incorrectly.

Flat roofs, as the name implies, have no pitch (slope); therefore, mechanical drain piping systems remove water from the roof. Low-sloped roofs have a pitch of less than 3/12 (14.04°).

In general, roof assemblies fall into two categories: warm and cold. A warm, or compact, roof assembly is designed so its layers are set on top of one another, allowing no space for ventilation. For a cold, or ventilated, roof, insulation below the roof deck results in ventilated space, and both the deck and membrane temperatures are close to outside temperatures. The result is much less heat transfer from the building to the outside—and more opportunities for better thermal images. Some roofs and insulation types and combinations do not absorb water at all, or do not exhibit a good infrared signal, primarily for two reasons: the roof's surface is too reflective or the roof's ballast is so dense that daytime radiation is not absorbed into the roof substrate. As a result, this radiation cannot be emitted back into the atmosphere at night and seen with an infrared camera.

Conducting Non-Destructive Moisture Testing of Roofs

Three types of equipment are used to find moisture in flat or low-sloped roofs:

1) Nuclear density gauges, which count slowed neutrons.
2) Dielectric capacitance meters, which measure differences in dielectric constants.
3) Thermal infrared cameras, which measure heat differences.

Meter surveys are used primarily on roof types that do not readily gain or lose solar energy, or do not lend themselves to infrared. Both nuclear gauges and capacitance meters take spot readings on either a 20- by 20-foot, 10- by 10-foot or five- by five-foot grid on a roof. Measurements extrapolate the location

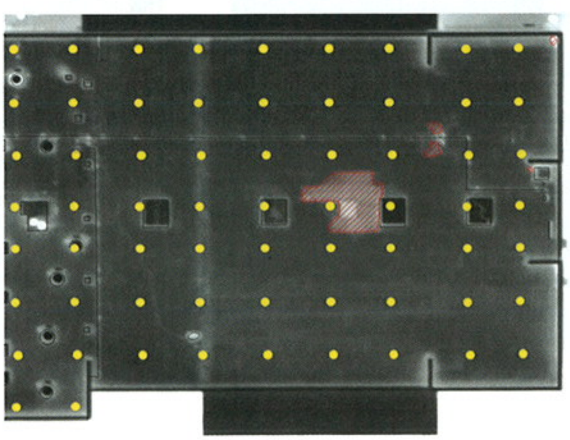

Figure 1: Eighty (80) square feet of wet insulation were found with infrared thermal imaging (red shapes) of a 5,000-square-foot roof section. None of these wet areas were found using a 10- by 10-foot grid pattern (65 readings, noted with yellow marks).

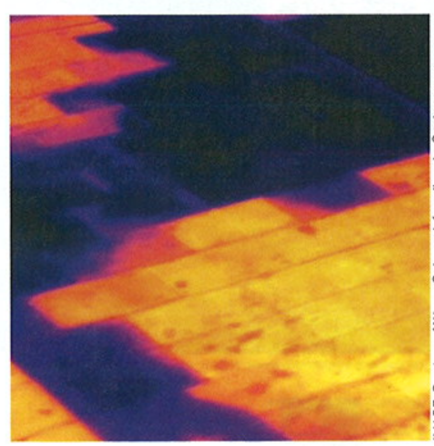

IMAGE: Courtesy of Wayne Swirnow, InfraredImagingServices.com

Figure 2: This thermal image of a flat insulated roof shows a clear delineation of wet insulation below the membrane as warmer, lighter-colored areas.

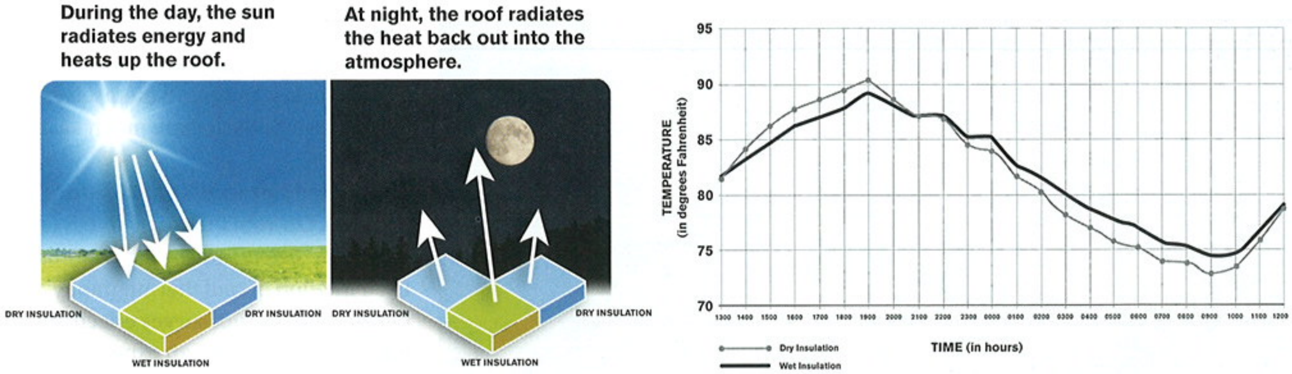

Figure 3: These diagrams show how heat absorbs into a roof and dissipates from a roof throughout a day.

of water by readings obtained from the gauge. Notwithstanding false or inaccurate readings, the sample of the roof is tiny given the amount of readings and associated labor. However, meter surveys only work to prove that a roof is so extensively wet that it is beyond repair. They are not used to find and delineate areas that need repair (*see "Figure 1," opposite page*).

In contrast, infrared thermography is considered a preferred method of locating roof moisture because 100 percent of the roof is surveyed. Therefore, if the survey is properly conducted, all areas of wet insulation can be found. Historically, roof thermographers have used *ASTM C1153-Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging* as their reference (the current iteration is Version 10).

Roof Infrared Basics

Infrared (IR) imagery is often a grayscale picture, whose scales (or shades of gray) represent the differences in temperature and emissivity of objects in the image. During the day, the sun radiates energy onto the roof and into the roof substrate; at night, the roof radiates this heat back into outer space. This is called radiation cooling. Higher-mass (wet) areas of the roof retain this heat longer than lower-mass (dry) areas. Infrared imagers can detect this heat and "see" the warmer, higher-mass areas during the "window" of uneven heat dissipation (*see "Figure 3," above*).

Infrared thermography is a process of pattern recognition (*see "Figure 2," opposite page*). Areas of roof moisture contamina-

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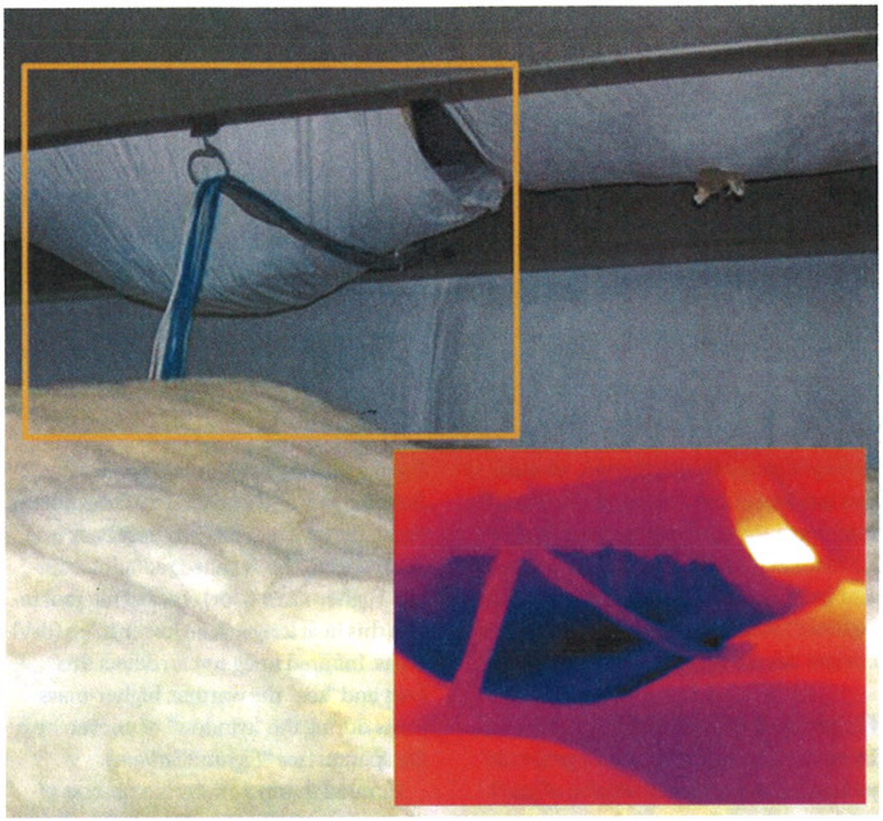


Figure 4: In this **under-roof survey**, an insulated metal roof is depicted, with a thermal image (inset) taken from the interstitial space underneath the roof.

tion often manifest themselves as warmer areas that may be nebulous in shape and sometimes mottled in appearance, although they are commonly found in two forms: linear or puddle-like shapes. Many times, linear shapes follow low areas, drainage routes, roof edges and seams. Puddle-like, round or oblong shapes often form around roof penetrations, such as mechanical equipment, standpipes, vents and drains.

Scanning Methods in Roof Moisture Surveys

Thermographers use four different methods of scanning roofs:

Under-Roof Infrared Roof Moisture Surveys. To perform an under-roof survey (*see "Figure 4," above*), the thermographer stands under the roof looking up at the bottom of the roof using the heat from the sun (or lack thereof) to see the difference in mass between the wet and dry substrate from the inside of the building. Direct line of sight to the underside of the roof is crucial (ideal applications are in open gymnasiums or similar buildings). Buildings with acoustical tile ceilings, or another obstacle in the field of vision, necessitate their removal. For vinyl-backed, fiber glass-insulated metal roofs, an air gap exists between the insulation and bottom of the metal deck; looking down at the roof will not work. Therefore, an under-roof survey is the only usable method of thermography for this roofing type. In contrast, while warm or compact roofs are candidates for this type of survey, they lend themselves to other methods that are much easier logistically.

On-Roof Infrared Roof Moisture Surveys. On-roof infrared surveys (*see "Figure 5," below*) are, by far, the most used method of roof thermography. To perform an on-roof survey effectively, efficiently and safely, an experienced infrared thermographer and a helper (at minimum) are needed. This crew needs authorization and access to all areas and levels of the roofs from either ladders or roof hatches and time to collect data under good conditions. Depending on logistics, how many problems are found and how long good conditions last, an on-roof crew can survey 25,000 to 100,000 square feet of a roof in a night. Areas that contain sub-surface moisture are verified wet and then marked with paint directly on the roof along the outer edges of the wet area. Using flash photography at night or during the next day, the thermographer then goes back on the roof to take visuals of those areas containing sub-surface moisture and matches the images in the report.

Elevated Vantage Point Infrared Roof Moisture Surveys. Elevated roof moisture surveys (*see "Figure 6," below*) offer high-quality spatial resolution and high usability of the infrared imagery—perspectives that offer the best of both worlds. Sometimes, a combination of elevated and on-roof methods is used to produce reports. One of the most common mistakes by inexperienced roof thermographers is to take very close-up images of wet areas, trying to fill the frame with the anomaly, while the only reason to get very close to a suspected wet area is to mark it.

Aerial Infrared Roof Moisture Surveys. Oftentimes, aerial surveys are used for

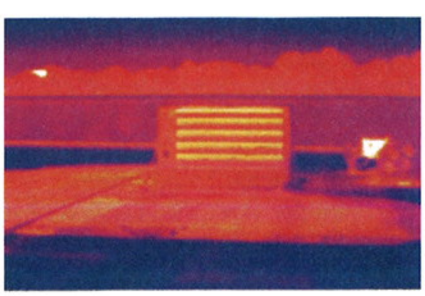


Figure 5: During an **on-roof survey**, the thermal image of a wet area is marked on top of the roof.

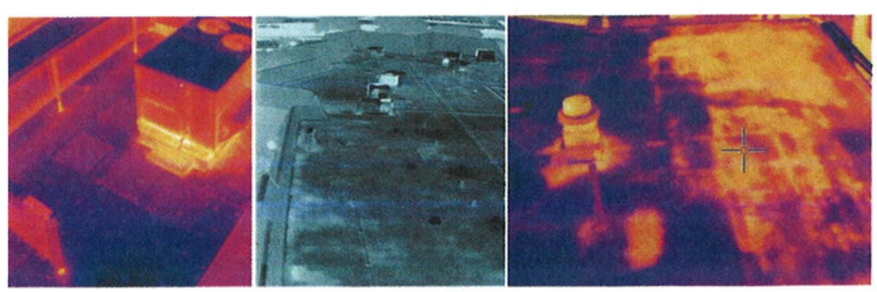


Figure 6: Thermal images of roofs from an **elevated vantage point** often offer one of the best survey outcomes.

large roofs where on-roof surveys are simply not practical or cost effective. For best results, such surveys are subject to the same weather limitations as other types of IR-based roof investigations, namely a dry roof, low winds and no rain. On the other hand, because aerial surveys require such high-resolution, thermally sensitive imagers, the "window of opportunity" is longer because slight nuances of temperatures over large areas are still recognizable. Another big advantage is that many roofs can be scanned in a very short amount of time, on the same night. Aerial infrared surveys work well for very large, inaccessible or dangerous roofs (*see "Figure 7," below*). In addition, building owners benefit because trending information (over time) is more easily rendered.

Methodologies and Other Considerations

While the same thermodynamics and laws of physics apply to all moisture problems in roofs, **the techniques for locating them and defining their extent will vary**, according to the height of the thermographer with respect to the roof surface.

Roof Types, Thermodynamics and Physics

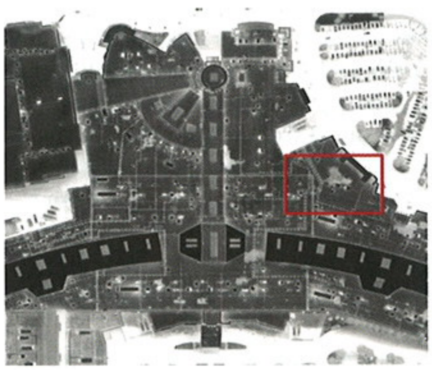
Generally speaking, the best roofs to effectively survey are those with highly emissive surfaces and highly absorbent insulations, but that is not always the case with roof thermography. Even with perfect ambient, weather and thermal conditions, factors on the roof can affect the collection, analysis and interpretation of the data. Some of these factors include reflective coatings, non-absorbent insulations, stains, ponding water on the roof, heavy build-up of ballast, moisture between layers, old patches, heavy flood coats, heat-producing equipment under the roof, heat blowing down onto the roof or air leaking out of the roof.

Roof types that are VERY DIFFICULT to effectively survey with infrared:

- Snow-blinding, white reflective roofing systems.
- Roofing systems installed over foil-faced insulations.
- Heavily ballasted roofs.
- Polymer modified asphalt (PMA) roofs.
- Roofing systems installed over lightweight concrete decks with retained moisture from installation.

Roof types that are IMPOSSIBLE to effectively survey with infrared:

- Inverted roof membrane assembly (IRMA) roofs.
- Metal roofs (except to see rust and stains, or to survey using the under-roof method).
- Shingled roofs (except under-roof surveys to find water on inside surfaces).
- Highly reflective aluminum coatings.
- Non-insulated roofs.
- New and relatively new roofing system installations with closed-cell foam or foam glass insulation.



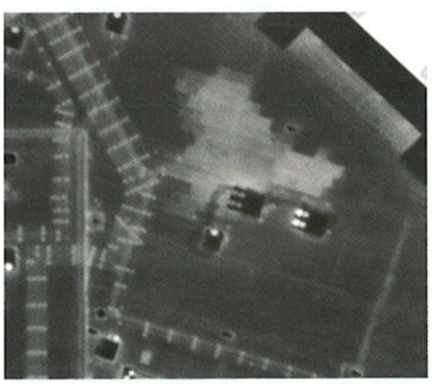


Figure 7: An **aerial** thermal image of a shopping mall illustrates how easily large-area roofs can be scanned. The red rectangular outline (top photo) shows moisture contamination on the roof, with a close-up of the affected area in the bottom photo.

Taking multiple shots is acceptable, but accurately stitching them together is somewhat more labor-intensive.

Infrared roof surveys are predicated on the fact that **wet areas of the roof have a higher mass, thermal conductivity and specific heat capacity**. Therefore, heat absorbs and dissipates from these areas at a different rate from dry areas. However, it is worth noting that heat coming through the roof (from below) makes it possible to survey a roof from the outside using this difference in temperature from inside to outside. The conditions that allow for this do not occur very often and are very hard to create and/or anticipate, especially in concert with uncontrollable other factors. The bottom line is that it is much easier to let the sun's solar radiation do its work.

Since white or reflective single-ply membrane roofs generally are better insulated, have little mass and are perpendicular to the night sky, they get cold very quickly once the sun goes down. Especially during the winter and depending on the dewpoint, condensation forms rapidly on these types of roofs. **This condensation has fooled many inexperienced roof thermoraphers** into believing that the wet facer is wet insulation. It is not!

In closing, infrared surveys are a very cost-effective and reliable means of locating and quantifying the extent of moisture problems in roofing systems, given the right combination of weather conditions, imager quality and thermographer experience. At the same time, no matter how brilliant the infrared images, they still are not proof-positive of wetness or in any way quantitative with respect to the moisture content of the roofing assembly. When these matters are at issue, definitive qualitative verification requires core sampling and measurement of the moisture content. NIBS

ABOUT THE AUTHOR: Gregory R. Stockton *is a principal in three infrared companies: Stockton Infrared Thermographic Services, Inc. (***www.StocktonInfrared.com***), United Infrared, Inc. (***www.UnitedInfrared.com***) and RecoverIR, Inc. (***www.RecoverIR.com***). As a Level III certified infrared thermographer with 30 years of experience, Stockton also has published many technical papers on the subject of infrared thermography and written numerous articles about applications for infrared thermography in trade publications.*