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Infrared thermal imagers: A primer for HVAC technicians

Application Note

Have you ever taken heat for an expensive failure after having performed routine maintenance? Have you ever wished for a crystal ball to see into the future or just to see things your traditional test equipment and eyes couldn't reveal? Compared to traditional test equipment, thermal imagers just may seem to have the predictive qualities of a crystal ball.

Unlike regular digital cameras that capture images of the visible light reflected by objects, thermal cameras create pictures by measuring infrared energy or heat. The thermal camera then assigns colors based on the temperature differences it measures. In a "radiometric" imager, each pixel of color on screen represents an individual temperature.

Thermal imaging has gained an invaluable predictive and diagnostic reputation in industries such as power distribution, plant maintenance, petro-chemical plants and process applications, to name a few. What industry is more suited for thermal imaging than the thermal dynamic industry of HVACR? Dynamic heat analysis of moving parts (Motors, bearings, sheaves, belts), electrical circuit quality (starters and contactors, disconnects, fuses and busses, electrical connections), duct heat loss or gain, conditioned envelope heat loss or gain, tracing membrane roof leaks, compressor operating condition (relative head, sump, suction, discharge temperatures and unloader or hot gas bypass operation), analysis of steam traps, radiators and convectors, radiant loops, or any process that can reveal the integrity of the process by comparative temperatures. The full range of HVACR applications for thermal imagers will only be realized once they are in the creative hands of HVACR technicians.

Using a thermal imager

An HVAC technician interpreting a thermal image is similar to a doctor interpreting X-Rays or MRI's. This may sound ominous, but you already have the HVAC knowledge and experience to know what you are looking for. Just add a few facts about the nature of thermal imaging, and you're home free.

IR radiation is just beyond the visible radiation spectrum. Radiated light is reflected off surfaces or emitted from sources that our eyes receive and our brain interprets. IR radiation is heat radiated by or reflected from a material; radiation that our eyes cannot see. Our skin is the best sensor of IR radiation. We feel the radiation from a fire. We feel the radiation loss when standing close to a cold wall. A thermal imager interprets IR radiated or reflected heat by assigning a visible graduated color or gray scale to a radiated portrait of the scene. The color palette displays hot spots as white with diminishing temperatures through red-orange-yellow-green-blue-indigo-violet to black being cold. The gray scale palette also shows hot spots as white with diminishing temperatures through progressively darkening shades of gray to black being cold. This allows us to see a visible representation of the unseen IR spectrum. What visibly looks like a disconnect in good operating condition may be revealed as the L2 pole is operating 35 °F hotter (red) than L1 pole (blue). Equal loads, but different temperatures. This disconnect has a problem that couldn't be seen. Yet the thermal imager takes a "picture" of the entire device and its electrical connections with comparative temperatures. All real world materials absorb, reflect and transmit IR radiation depending on their physical properties.

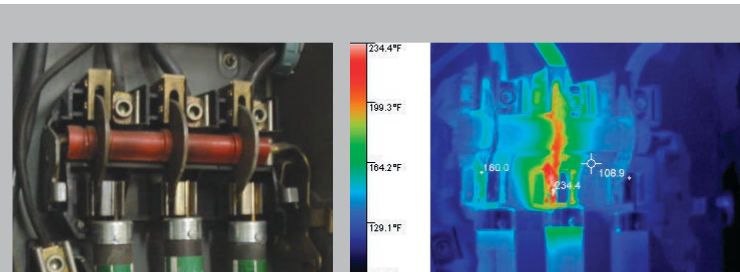

Figure 2. Fused power disconnect and corresponding infrared image.

IR radiation = Absorption + Reflection + Transmission

Whatever IR radiation is absorbed will be equally emitted. We do not encounter materials in the field that *perfectly* absorb and emit *all* IR radiation. A material that absorbs all IR radiation is called a "Black Body" and has an emissivity of unity (1). Most materials of interest that we encounter are called "Gray Bodies" since they are not perfect emitters, close maybe, but not perfect. Transmission through solids can usually be ignored in field work, with the exception being glass and plastic films which are referred to as "Non-Gray Bodies". This simplifies our working formula to:

Emissivity = 1 - Reflectivity

Reflectivity is inversely proportional to emissivity. The more an object reflects IR radiation, the less it emits. Reflectivity can be relatively judged according to our sight determinations of reflectivity. Polished chrome has a very high reflectivity and low emissivity. Brushed stainless steel has less reflectivity and more emissivity. Tarnished brass and copper have even less reflectivity with proportionately more emissivity. Most painted surfaces have very high emissivity and negligible reflectivity.

"Qualitative vs. quantitative"

Most thermal imaging tasks are qualitative as opposed to quantitative. Quantitative is accuracy of temperature, while qualitative is relativity of temperature. When viewing a contactor for instance, the interest is in the temperature difference of the 12 contact points. Are the electrical connections all the same temperature (T1-L1, T2-L2, T3-L3)? Are the temperatures consistent between the fixed and movable contacts (T1C-L1C, T2C-L2C, T3C-L3C)? Seeing one point of elevated temperature directs us to a poor electrical connection or failing contactor points without being concerned that the reported temperature is off by some percentage. Painted surfaces have high emissivity and a very small margin of quantitative error. So our thermal image of a compressor, motor, bearings, steam traps, transformers, etc. will tend to be fairly accurate without taking the steps to fine tune imager emissivity.

Adjusting emissivity

Thermal imagers have adjustments for both emissivity and reflectivity. Both are easy to measure and compensate for when the need for quantitative readings outweighs qualitative readings.

For emissivity adjustments, a strip of black electrical tape can be fastened to a surface and the taped and untaped surfaces can be measured with the imager. The emissivity is adjusted until the untaped surface temperature equals the taped surface temperature. For high temperature surfaces, a contact temperature probe can be used to measure surface temperature, then the emissivity can be adjusted until the IR temperature equals the contact temperature. Charts are also available which list the emissivity of various materials.

Reflectivity adjustments

For reflectivity adjustments, a piece of aluminum foil is crumpled, then straightened and attached shiny side out to a piece of cardboard. Crumpling the foil creates a multi-faceted surface to reflect radiation from all directions. The foil covered cardboard is held in front of the target to reflect ambient IR radiation. The reflectivity is adjusted until the temperature equals ambient air temperature. Reflectivity is usually insignificant unless very high temperatures are being radiated in the vicinity of the target.

Level and span

Level and span represent the expected target temperature (level) and the differential from target temperature (gain). If level were set to 100 °F and gain were set to 25 °F, then the temperature range would be limited to 75 °F to 125 °F. Thermal imagers will automatically select the best level and span of the target. Set at automatic, the imager displays the highest and lowest temperature values in the scene. The minimum and maximum values of the scene define the extremes of the color palette. A white spot would not necessarily indicate a very high temperature, only the highest temperature in the scene. The highest temperature in one scene may be 90 °F, while another scene may have a white spot indicating 250 °F, if that is the highest temperature in that scene. The palette is proportional to the temperature range of the scene, not a fixed value. A slight relocation of the spot on the target can change the gradient display depending on the range of temperatures now in the scene. A semi-automatic setting will allow an upper temperature limit to be selected while the imager automatically and continuously recalculates the minimum scene temperature. High and low temperature alarms can be set so that when temperatures approach the limits of reliability, the user can be notified graphically.

Some thermal imager applications

Thermal Imagers can be used for purposes where heat relationships are meaningful and provide very fast, multiple point temperature measurements of a scene. They are ideal for moving targets and machinery, hazardous and inaccessible or distant targets, electrical components, "big picture" evaluations of machinery or surfaces, trending records, and even protection against litigation and insurance claims.

Keep in mind that thermal imagers measure surface temperatures only. The interpreter of the images must understand what is happening beneath those surfaces in order to make accurate judgments. Temperatures of materials with differing emissivities within a scene will not report temperature relationships equitably. Digital photographs of the same scene as the thermal image are useful not only for scene identification purposes, but also to identify materials of differing emissivities within the scene.

A few applications for thermal imagers follow.

Duct leaks beneath insulation or in walls

When ductwork is located externally to the conditioned envelope, air leaks can present conditions for pressure differentials across the conditioned envelope, create opportunities for moisture conditions that support mold growth in or on the ductwork or even hidden within walls. The effects are similar to unbalanced ventilation and exhaust air.

- Air leaks from ductwork beneath duct wrap insulation
  - Initiate a heating or cooling demand
  - Set emissivity to 0.2 for foil faced insulation, or 0.95 for vinyl or PVC faced insulation
  - Scan ductwork with thermal imager
  - Dynamic, real-time temperature variations of insulation surface will be displayed and continually updated as they occur
  - Indications of an air leak will be displayed as an extreme temperature at the point of the leak, with temperature gradation away from the leak location to areas of ambient temperatures
  - The imager can record selected images of interest for download, if desired
- Air leaks from ductwork behind walls
  - Make an initial imager scan of walls concealing ductwork with the system blower off
  - Start the blower and repeat the initial scans
  - Compare results of the blower-off to the blower-on scans
  - Significant temperature deviations may indicate return leaks that are causing pressure differentials within the walls that encourage air and moisture migration from outdoors
  - Start heating or cooling operations
  - Repeat the wall scans
  - Even temperature gradients of the wall that follows the ductwork should be expected
  - Uneven or spreading temperature gradients may indicate leaking ductwork
  - Pay attention to temperature gradients along baseboards and around fenestration
  - The imager can record selected images of interest for download, if desired

Diffuser discharge and surface effect ceiling temperatures

- Start heating or cooling operation
- Scan diffuser outward along ceiling toward intersecting walls or zones
- Watch temperature change along ceiling to evaluate surface effect
- Watch for temperature change at intersecting wall surfaces to evaluate throw
- This provides a good preliminary analysis prior to breaking out the ladders and air balancing equipment
- Throw should be between 75 % to 110 % of distance from diffuser to intersecting surface

Insulation effectiveness and air leaks

- Insulation on all surfaces can be scanned for leakage and losses
  - Boiler, furnace, process equipment, service water heater insulation
  - Walls that separate conditioned from unconditioned spaces
  - Pipe and duct insulation
  - Higher temperatures are indicated by a shift toward white.
  - Lower temperatures are indicated by a shift toward black
- Scan conditioned envelope walls or ceilings for even temperatures
  - Initial scan should be made with HVAC equipment off for insulation effectiveness
  - Subsequent scan should be made with blower, economizer and exhaust fans operating to evaluate for air leaks
  - Economizers and power exhaust can be temporarily re-adjusted to increase pressure differentials across the conditioned envelope for testing purposes
  - Scan on both conditioned and unconditioned side of surface
  - Pay special attention to areas of fenestration and along sill plate areas

Water leaks beneath membrane roofs

Rooftop HVAC equipment is often blamed when roof leaks appear, but tedious and time consuming evaluations frequently dispel the accusations. Thermal imagers can be used to quickly track water beneath a membrane roof back to possible sources of entry.

- As the sun sets, water beneath the roof membrane will change temperature more slowly than areas of dry insulation under the roof membrane.
- Scan the roof surface and follow the higher temperatures to possible entry sources

Electrical devices

Thermal imagers can be used for a quick analysis of individual devices, or an array of contactors or relays in a control panel. From ground level, inaccessible transformer connections or line splices can be scanned for hot spots indicating high resistance of problematic connections. Panel buss connections can be quickly scanned for circuit integrity.

- Disconnects, contactors, relays
  - Scan disconnects, contactors, relays for temperature consistency
  - All conductors connected to device should have equivalent temperatures
  - All mechanical connections to device should have equivalent temperatures
  - Circuit temperature and thermal characteristics of each pole should be consistent with the circuit temperature and thermal characteristics of the other poles
  - Movable contacts are likely to show higher temperature than fixed connections
  - Specification data should provide the rated temperature rise of the device under full load conditions
  - Wire insulation, paper covering of fuses, and insulated connections will be displayed as areas of higher temperature than uninsulated connections, buss bars, and bare wires due to the differences in material emissivity
  - Circuits within an enclosed relay will radiate heat to the casing. Relays under similar load should show similar heat patterns on the casing
  - Insulated conductors and electrical connections should be cool leading to and connected at the relays, contactors
- Line splices, powertransmission connections, transformer connections
  - Temperatures should be consistent along conductors lengths
  - Temperatures of splices or connections should be consistent with approaching and departing conductor temperatures
  - Disturbed by wind or branches, poor connections or splices can produce line transients that can affect the reliability and operation of equipment. Electronic devices are particularly susceptible to the effects of line transients.

Motors, bearings, sheaves, and belts

- Motors can be scanned for operating temperatures within specifications
- Bearings can be scanned for consistency of temperature
  - Bearings under equal load should display equal temperatures
  - A hotter bearing on sheave side of motor could indicate over-tightened belts
- Sheaves that are hotter around circumference could indicate slipping belts
- Belts that do not cool between the motor and blower sheaves could indicate slipping belts

Dynamic gas pressure within above grade LP tanks

LP tanks must be sized for the load in order to evaporate sufficient gas while maintaining minimum pressures.

- Above grade LP tanks can be scanned to estimate liquid level and vapor pressure
  - The heat of vaporization is extracted from the Liquid LP
  - When demand is high, the horizontal line of temperature change on the outside of the tank will approximate the liquid level within the tank.
  - The liquid LP absorbs heat from the ambient air through the tank walls
  - The tank surface temperature pressure corresponds to the vapor pressure in the tank. If a P-T chart for LP gas is not available, a P-T chart for R-22 can be used to "ball-park" the pressure. R-22 pressures below freezing are usually about 4 pounds less than LP gas pressures at equivalent temperatures.

"All points" operating temperatures of compressors

A thermal image snapshot of an operating compressor (or other machinery) can be saved in a trending or maintenance record. The image will contain operating temperatures of all points in the image such as sump temperature, head temperature, suction and discharge temperatures, etc. Ambient and operating conditions should be saved along with the image.

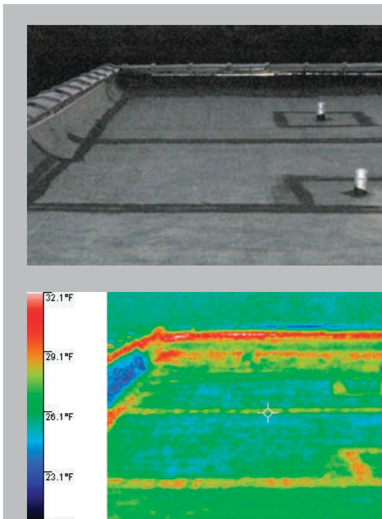

Figure 5. Cool areas on this roof exposure probably indicate moisture buildup. Mark with tape and investigate with core samples.

Steam traps, lines, radiators and convectors

Thermal imagers are ideally suited for assessments of steam heating processes. They can quickly see the trap and line temperatures into and out of traps. They can be used to follow pipe temperatures to the source of problems.

- If temperature is low in steam pipe, low in trap and low in condensate return, trap may be stuck closed.
- If temperature is high in steam pipe, high in trap, and high in condensate return, trap may be stuck open.
- If temperature is high in steam pipe, high in trap, and slightly lower in condensate return, trap is probably operating properly.

Tracking hydronic radiant heat loops

Thermal imagers can be used to track radiant loops under solid surfaces. The radiant loop should appear as similar palette gradient along the loops. Loop temperatures can be temporarily elevated for tracking purposes.

Air-to-air condenser or evaporator circuitry

A thermal snapshot of condenser or evaporator return bends or distributor tubes can find circuit problems much more quickly than using contact thermometers for the same task.

- Each circuit will condense or evaporate refrigerant at a constant temperature
- Subcooling or superheat should be equivalent in the last passes of each circuit
- All distributor tubes should be at evaporating temperature

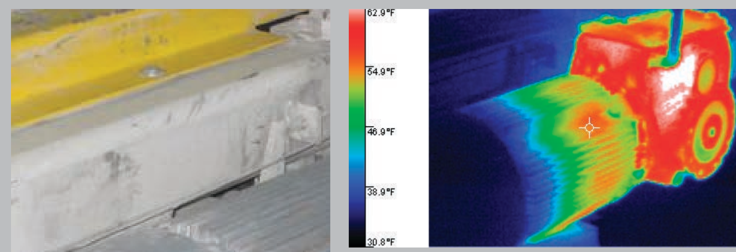

Figure 6. This thermal image shows a cool motor on the left and a hot gearbox on the right, with an especially white-hot anomaly.

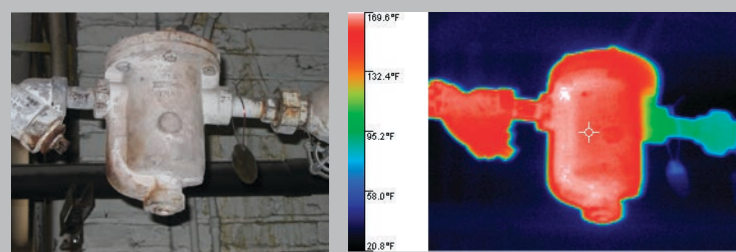

Figure 7. When operating correctly, as in this example, steam trap thermal images should show an abrupt change in temeperature.

Conclusion

This brief introduction to thermal imagers is offered to present the potential user some insight to typical applications and may spark ideas for additional uses. For instance, a routine walk-through of a facility with a thermal imager showing real-time movies of critical machinery or processes is not only easy and time saving, but can alert the user to processes that warrant further attention.

For information on building envelope leak testing, ASTM standard E1186-03 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems

ASTM standard E779-03 Standard Test Method for Determining Air Leakage Rate by Fan pressurization.

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IR terminology basics

Infrared Radiation (IR Radiation)

Heat radiation beyond the visible spectrum. IR thermal imaging devices designed for field use generally detect IR wavelengths from 7 to 14 micro-meters, wavelengths slightly longer than the color red. IR radiation equals the sum of emitted, reflected, and transmitted radiation.

Emissivity

IR radiation emitted from a body indicating the heat of that body. Emitted IR radiation equals absorbed IR radiation.

Reflectivity

Ambient IR radiation reflected from a body unrelated to that body's own heat.

Transmissivity

IR radiation transmitted through a body such as a gas or liquid and some solids such as glass or plastic films. For most solid bodies, transmissivity is zero.

Distance to spot ratio (D:S)

The size of the measurement spot on the target relative to the distance the imager is from the target. A D:S of 90:1 would result in a one inch spot at a target distance of 90 inches or a one foot spot at a target distance of 90 feet.

Field of View

Spot size relative to target area. Spot size should be contained within the perimeter of the target, centered on the area of interest.

Spatial resolution

The best spatial resolution has the largest number of detector pixels within the smallest field of view. Spatial resolution is measured in mRads, and the smaller the number the better. Low spatial resolution increases the details in your infrared image so you can see more.

Focus

Similar to a photographic camera. A photographic camera is focused to obtain crisp visual resolution. AN IR Thermal Imager is focused to obtain crisp IR radiation temperatures.

Minimum Focal Distance

Closest distance to target that an imager can be focused and used.

Environmental Conditions

Thermal Imagers are calibrated to operate within a temperature range (14 °F to 122 °F). Accuracy is compromised outside of these conditions. An adjustment period is required for sudden changes of 18 °F or more degrees for the imager to be accurate under the new conditions. Particulates in the air (steam, dust, smoke) between the imager and the target will distort the readings.

Quantitative Temperatures

Accuracy of temperature takes precedence.

Qualitative Temperatures

Accuracy of temperature is secondary to relative temperatures. This is the most common use of thermal imagers.

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