# Aerial Infrared
# – An Asset Management Tool for District Heating System Operators

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**Abstract**

The imagery (IR) from aerial infrared thermal surveys of facilities, complexes, campuses, military bases and cities can be used for many purposes. Systems like supply steam and condensate return lines, hot water lines, chilled water lines, supply water mains, distribution piping, storm water drains and sewer lines can be monitored by looking at surface temperatures/patterns. In the case of district heating systems, the distribution system can be flown rapidly and inexpensively to provide thermal data for asset management planning and predictive maintenance (PdM). As a result of finding and repairing leaks in the steam system, energy usage can be reduced with all the related benefits.

## Introduction

Leaks and insulation failure in overhead steam lines and underground steam lines (direct-bury lines and in steam tunnels), can result in less than optimal energy efficiency, especially when the steam leaks and line heat losses (see Figure 1), are undetected, inaccessible or difficult to find given the vast acreage at some facilities. The longer that a steam leak, excessive heat loss on a line and/or undetected draining of fluids (see Figure 2) goes undetected; the greater the energy loss, the more make-up chemicals have to be added and the more potential there is for negative environmental impact.

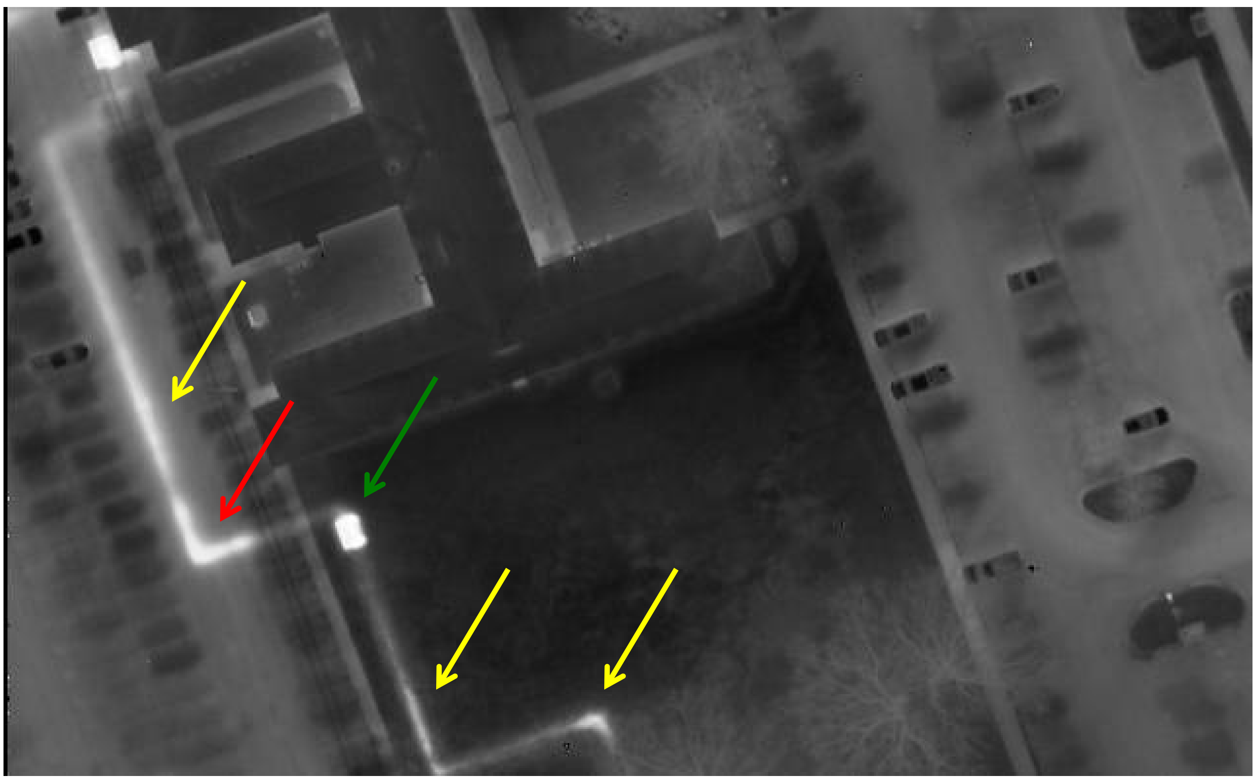


**Figure 1) Typical steam system heat losses.**
**(Red is more heat loss than yellow and green is normally operating apparatus.)**

**Figure 2) Steam line leaking onto the ground surface.**

### Understanding Aerial Infrared

Aerial infrared can help monitor the steam distribution system so that those charged with the task, can manage the assets better. Checking the boilers, lines and steam traps inside buildings and inside steam tunnels are jobs best accomplished on the ground, but the distribution and condensate return lines are best surveyed from the air. Thermal contrast between active lines and the surrounding ground are usually good depending on the depth of the line, temperature, flow and the materials covering the lines. The entire system can be flown, a mosaic thermal image produced and the areas with suspected problems can be pinpointed and documented. On-ground, hand-held IR surveys on all but very small areas within a system are time-consuming, labor intensive and produce small field of vision imagery and/or paint on the ground. Owing to recent developments in infrared technology and the availability of high thermal sensitivity/high spatial resolution (large format) thermal imaging systems mounted on an aerial platform, the on-ground survey has become outdated.

The methodology for taking aerial infrared thermographs is similar in many ways to taking aerial photographs. To collect the data, the aircraft flies over a given area with a camera mounted to the airframe and oriented looking straight-down to the ground (NADIR). The imagery is stored on a computer hard drive and later post-processed. Where aerial infrared thermography differs from aerial visible photography is the time of day when the survey occurs and the wavelength of the imagery that the detector collects. IR thermography of ground objects is performed at night. Thermography reveals sources of heat and the relative differences in heat from one object to another.

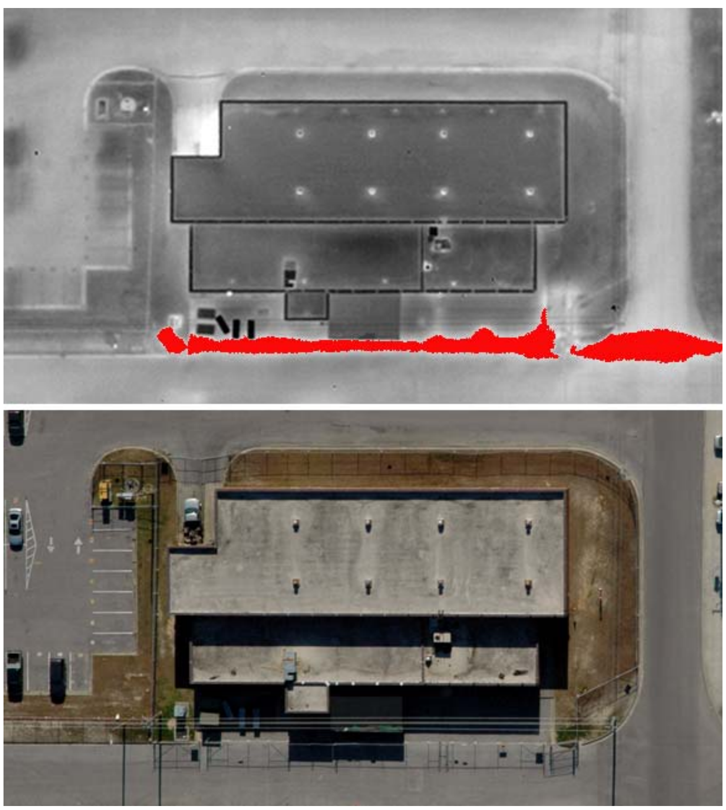
*Infrared imagery is a grayscale picture whose scales (or shades of gray) represent the differences in temperature and emissivity of objects in the image. Typically, objects in the image that look lighter are warmer, and those that look darker are cooler…bright white objects being the warmest and black objects, the coolest.*

*Any object with a temperature above absolute zero (0 Kelvin or –273 degrees Celsius) emits infrared radiation. An infrared picture only shows objects which emit infrared wavelengths in the 3000-5000 nanometer (mid-wave) range or 8000-14000 (long-wave) range. Objects in visible light wavelengths of 400 to 700 nanometers are detected, but only because they also emit heat. An example of this would be a street light that can be seen in the IR imagery because the ballast and bulb are warm.*

*Infrared imagery is usually recorded on digital media and later copied to DVD-Video, videotape and/or captured as digital image files. The images may then be modified in a number of ways to enhance their value to the end-user, such as creating false-color images and/or adjusting the brightness and contrast of a grayscale image to be used in a report.*

**Steam Leak Infrared Surveying**

Steam and condensate return lines are almost always readily visible with infrared imaging, even when no notable problems exist. This is due to the fact that no matter how good the insulation, there is always heat loss from the lines which makes its way to the surface. Problem areas are generally quite evident, having brighter infrared signatures (see Figures 3) that exceed the norm.

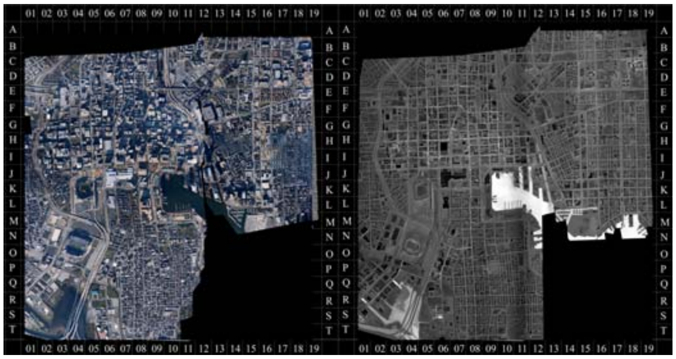


**Figures 3a and 3b) IR and visual image of a steam line with leak colorized red.**

Steam line faults normally appear as an overheated line or as a large hotspot in the form of a bulge or balloon along the line. Overheated lines often occur when the steam line is located in a conduit or tunnel. If there is a leak in the line, it will heat up the conduit with escaping steam. If a steam line is buried directly in the ground with an insulating jacket, a leak will usually saturate the insulation, rendering it largely ineffective and begin to transfer heat into the ground around the leak, producing the classic bulge or balloon-like hot area straddling the line.

Some leaks show up as an overheated manhole or vault cover. Manholes or vaults that contain steam system control apparatus which are leaking, will often heat the covers to warmer than normal temperatures. Unless these leaks are severe enough to significantly raise the manhole temperature above their normally slightly elevated temperatures, these leaks can be difficult to identify.

In fact, steam line infrared imagery can be a little misleading, unless one understands and interprets the relative brightness and temperature of a given line correctly. For instance, a steam line that is the same temperature from one end to the other that passes under different surfaces and materials can exhibit a variety of real and perceived temperature variations. Five different apparent temperatures will result from the same temperature line that runs under a grass-covered field, an asphalt roadway, a concrete loading dock, a gravel-covered parking lot and a bare earth pathway.

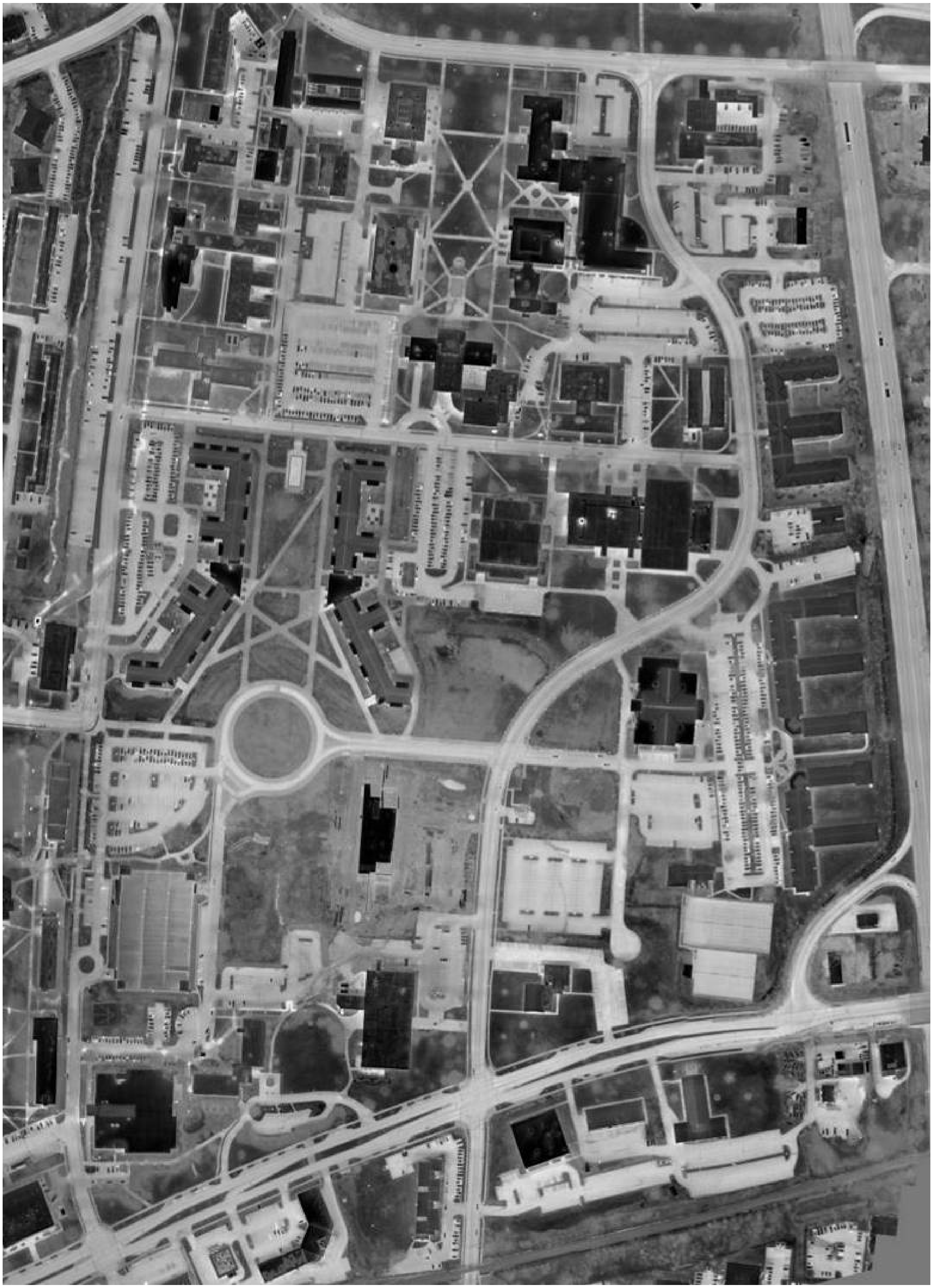


**Figures 4a and 4b) Mosaic visual and infrared imagery of a city steam distribution system.**

**Thermal Mapping, Ortho-Rectification and Post-Processing**

Using a non fixed-mounted high-resolution thermal imager to survey a couple of buildings or a few thousand feet of underground lines can be done by flying over and locating the target(s) in the imagery, saving the data and putting it together into a report. This works for very small areas, but it is not possible to make precise thermal maps of a whole complex, campus, military base or city (see Figures 4) without ortho-rectification of the imagery. In order to produce ortho-rectified thermal maps, much more information must be gathered and tagged to the IR imagery. During the flight, the aircraft flies straight, smooth lines on a pre-planned grid, allowing overlap and sidelap of the imagery. The IR operator manages the sensor data-acquisition following a structured checklist for orderly data file management. The imagery must be collected with a precise direct-digital timing system, a 3-axis ring-laser-gyro and an inertial navigation system (INS), which is tightly-coupled to a real-time differential GPS satellite positioning system that provides x, y, z positioning of the sensor at all times.

After data is collected, the digital infrared imagery is processed into a series of ortho-rectified image tiles, which are then stitched together to create a giant mosaic image. A computer system puts all this information together using a digital elevation model (DEM) of the scene that consists of a uniform grid of point elevation values and the position and orientation of the camera with respect to a three-dimensional coordinate system output. The result is presented as a high-resolution thermal image in the form of a geo-TIFF (see Figure 5), which is compatible with any GIS software such as ESRI ArcView™, AutoCAD® Map 3D, Global Mapper, MapInfo™, etc. Once high quality digital thermal and photographic ortho-rectified maps are created, they can be added as layers other data sets, to existing or new CAD and GIS systems. Digital data can also be post-processed in other ways, such as creating false color imagery to highlight areas of interest, adding temperature data and/or creating graphic reports (see Figure 6).



**Figures 5) Mosaic infrared image (geo-TIFF) of a small college.**

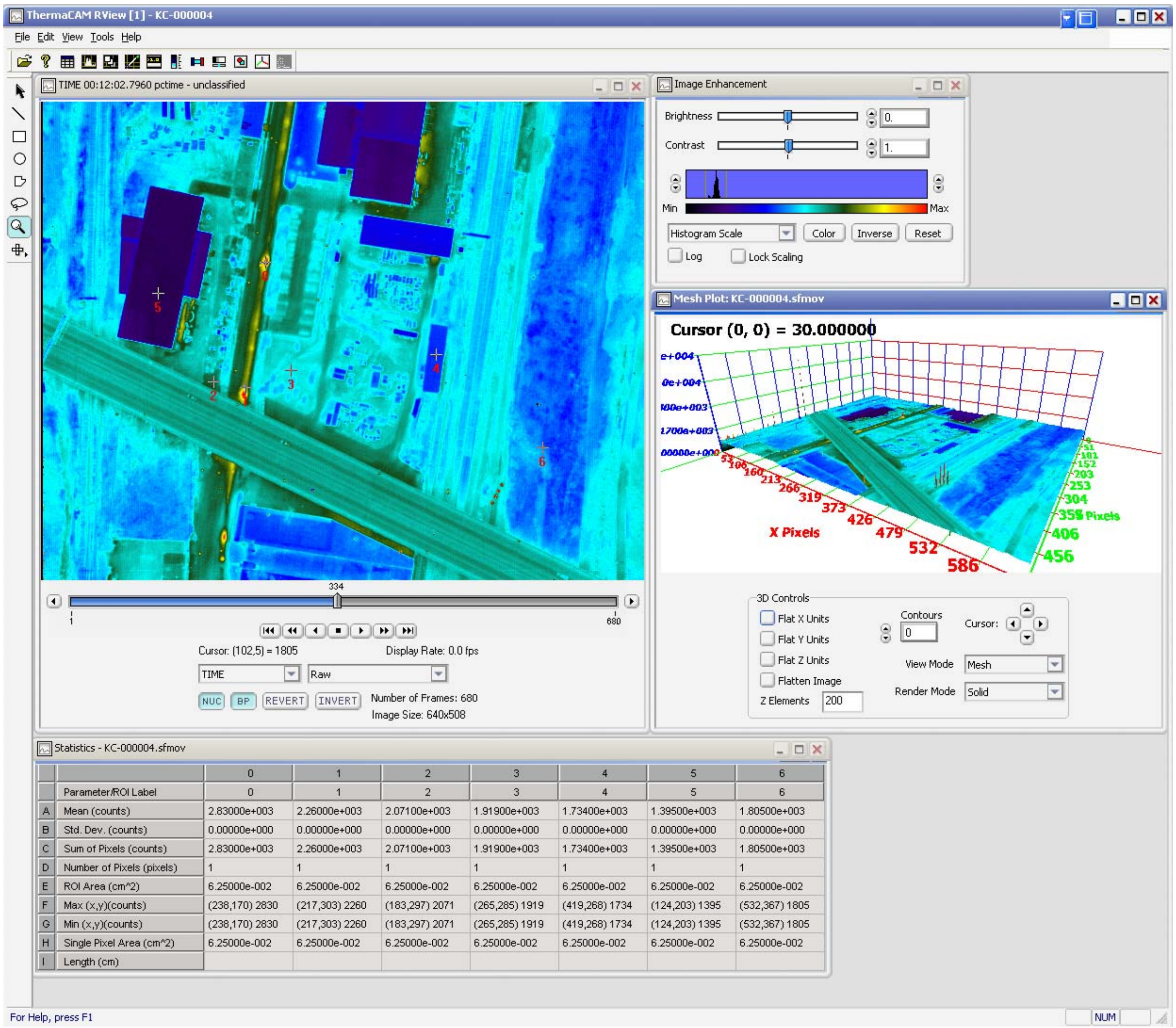



**Figure 6) Colorized thermal imagery and post-processing example.**

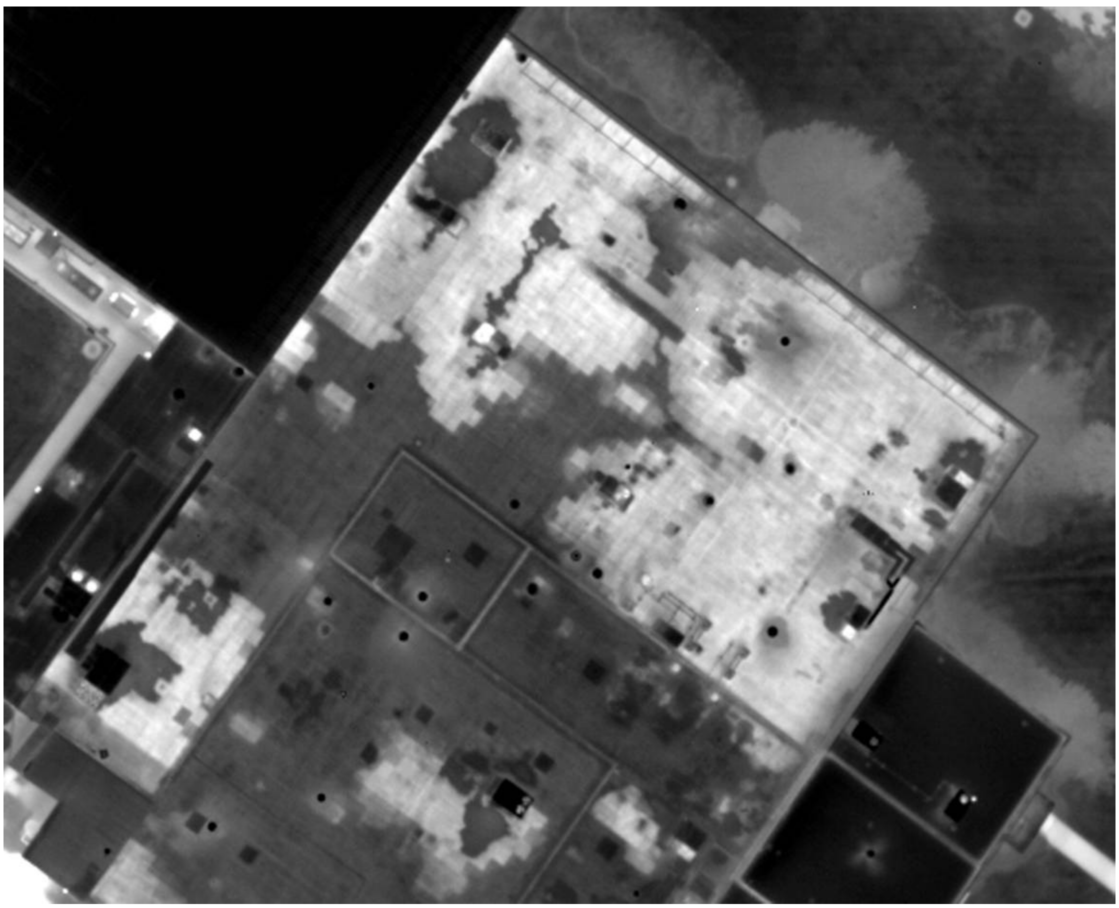
### Qualitative v. Quantitative Evaluations

The imagery approach described above is qualitative. It identifies and locates problems in steam systems based on their anomalous heat signatures. This is low-hanging fruit with regard to return on investment. Now, this method does not *quantify* the amount of heat loss. In order to develop quantitative information, if desired, some additional work is needed in the form of additional field effort in the infrared data acquisition phase combined with heat transfer analysis of the steam distribution system.

To understand the quantitative approach, it is necessary to understand how heat moves and the factors affecting its transfer, as well as the physics involved in determining the infrared signature. In order to know exactly what the radiated energy of any object is, the characteristics of the sensor, atmosphere and the target must be taken into consideration and one must know the transmission, emissivity and reflectivity of the target. There are big differences in the emissive qualities of the concrete, asphalt, grass, dirt, etc. The ability to obtain quantitative measurements is built into a radiometric imaging system, so one must use a radiometric infrared camera to collect the imagery and in a form that can be post-processed.

Heat energy moves by conduction, convection and radiation. In order to make meaningful quantitative thermal calculations, the pipe's or pipe's content's temperature, insulation properties and the complete thermal properties of all the materials in the ground (specifically heat capacity, thermal conductivity, and density) must all be known and made part of the calculation. As-built drawings and the thermal properties are not always readily available, if available at all. This generally means that estimates of the heat loss, implications of temperature values obtained, and quantitative evaluation of the pipe's performance can only be developed as estimates.

Even though some large format thermal imaging systems are fully capable of accurate radiometric measurements and rapid frame-by-frame digital temperature data acquisition of every pixel of every IR image, the cost of quantitatively gathering measurements and using steady-state and transient heat transfer analysis calculations (typically done with FEA or finite element analysis), make quantitative measurement a more expensive step, than simply using the image data to make judgments based on experience of the person analyzing thermal data. Most of the time, identifying leaks and excessive line heat loss is straightforward, but making calculations regarding insulation effectiveness and other qualities is an additional step that adds cost, which may add value, but also could offer a lower return on investment. In other words, grab the low-hanging fruit first by identifying leaks and if you have a known issue (or find one) requiring quantification, then post-process the thermal data. If you expect to need quantification, it is wise to plan it ahead of time since it will slightly affect the methods used for IR image acquisition.



**Figures 7) Thermal image of a flat roof (wet areas are lighter).**

**Ancillary Benefits**

Safety is improved, asset reliability by condition monitoring can be achieved and wasted energy can be saved by aerial IR imaging, analysis and repair the steam distribution system. Creating a ‘thermal map’ of a given area has benefits far beyond that of just steam. A thermal map helps asset managers in the analysis of many other types of systems, such as HTHW (high temperature hot water) lines, MTHW (medium temperature hot water) lines, LTHW (low temperature hot water) lines, CHWS (chilled water supply), CHWR (chilled water return), supply water mains, storm water drains, sewer lines and any other distribution piping. Electric power lines and substations can be surveyed to point maintenance personnel at the facility to electrical problems.

Drawing the entrained moisture in flat and low-sloped roofs on a CAD drawing with surgical precision provides a significant predictive maintenance benefit. Roofs are an expensive and onerous asset to maintain. Entrained moisture (see Figure 7) in the insulation and other roof substrates is indicative of leaks into the roof substrates, seam and flashing failures.

However unfortunate, ‘wholesale’ building heat loss surveys cannot be accomplished with a NADIR thermal survey, primarily because most building roofs are decoupled from the heat loss of the building, either with ventilation, with insulation or by being so reflective that they are immeasurable with IR sensors. Oblique aerial or on-ground, right-angle infrared surveying of the walls will be necessary to accomplish building heat loss surveys.

**Author Biography**

Gregory R. Stockton is president of Stockton Infrared Thermographic Services, Inc. Based in Randleman, NC, the corporation operates six applications-specific divisions. Greg has been a practicing infrared thermographer since 1989. He is a Certified Infrared Thermographer with twenty-six years experience in the construction industry, specializing in maintenance and energy-related technologies. Mr. Stockton has published eleven technical papers on the subject of infrared thermography and written numerous articles about applications for infrared thermography in trade publications. He is a member of the Program Committee of SPIE (Society of Photo-Optical Instrumentation Engineers) Thermosense and Chairman of the Buildings & Infrastructures Session at the Defense and Security Symposium.

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