Using Aerial Thermal IR Imaging to Monitor Underground Piping in District Heating and Cooling Systems

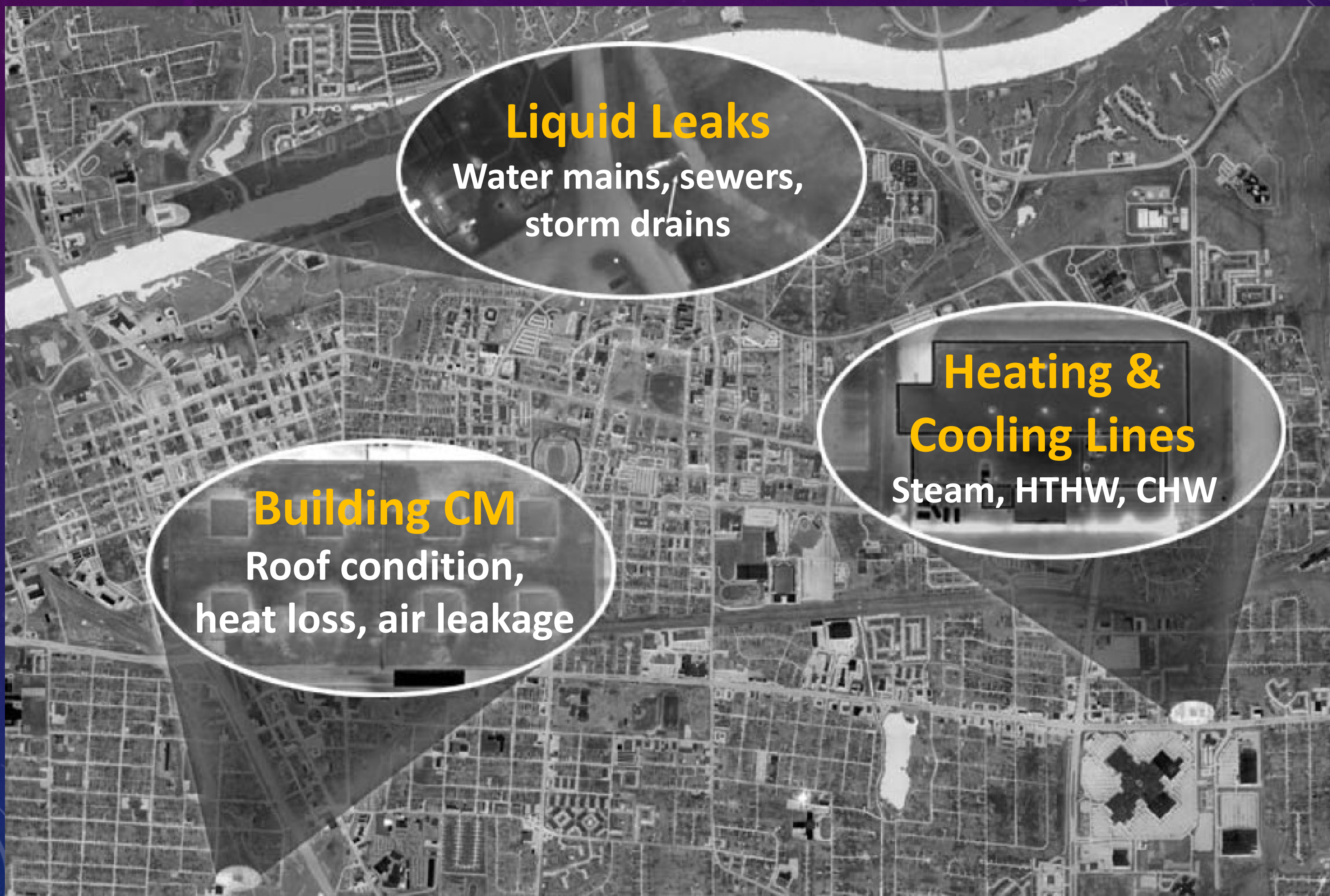
Presentation Sections:

- Abstract
- The Purposes of Thermal Mapping
- Methods & Platforms
- Thermal Mapping & Resolution (GRE)
- Thermal Imagery
- Quantifying and Classifying Problems
- Heating & Cooling Line Problem Examples
- Other Uses for Thermal Mapping
    - Liquid Leaks
    - Roof Moisture Surveys
    - Solar Field Commissioning
    - Heat Loss & Air leakage from Buildings
    - Others

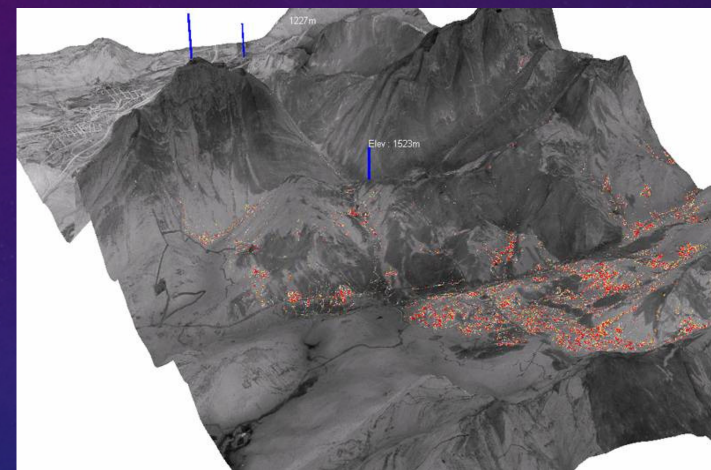
Abstract

Supply steam and condensate return lines, hot water lines, chilled water lines, supply water mains, storm water drains, and sewer lines can be monitored for leaks and/or faulty insulation by using aerial thermal infrared (IR) imagery. Distribution piping systems can be flown over rapidly and inexpensively to provide thermal data for asset management, predictive maintenance (PdM) and planning purposes. As a result of finding and repairing leaks in these systems, energy usage can be reduced with all the related benefits.

Three Main Purposes of Thermal Mapping

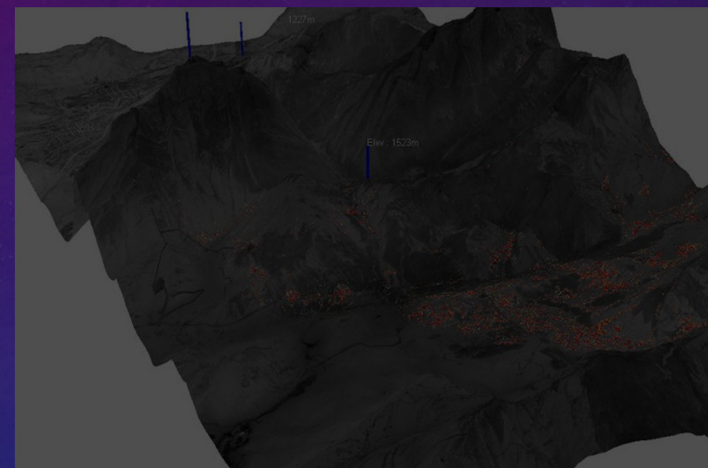


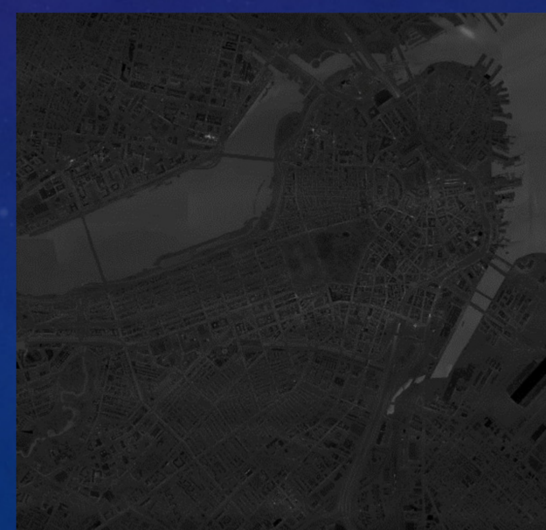
Typical Users are Owners / Operators of:



Typical Users are Owners / Operators of:

- Cities
- Military Bases
- Universities
- Airports
- Large Industrial Sites
- Utility Power Plants
- Large Manufacturing Sites
- Large Building Complexes
- Utility Solar Plants





Return on Investment

Cost of Steam Trap Leaks at $5.00 / 1,000 lbs.

Table CG-3. Cost of Various Sized Steam Leaks at 100 psi
(Assuming steam costs $5.00/1,000 lbs)

Size of Orifice (in)	Lbs Steam Wasted Per Month	Total Cost Per Month	Total Cost Per Year
1/2	835,000	$4,175.00	$50,100.00
7/16	637,000	3,185.00	38,220.00
3/8	470,000	2,350.00	28,200.00
5/16	325,000	1,625.00	19,500.00
1/4	210,000	1,050.00	12,600.00
3/16	117,000	585.00	7,020.00
1/8	52,500	262.50	3,150.00

The steam loss values assume clean, dry steam flowing through a sharp-edged orifice to atmospheric pressure with no condensate present. Condensate would normally reduce these losses due to the flashing effect when a pressure drop is experienced.

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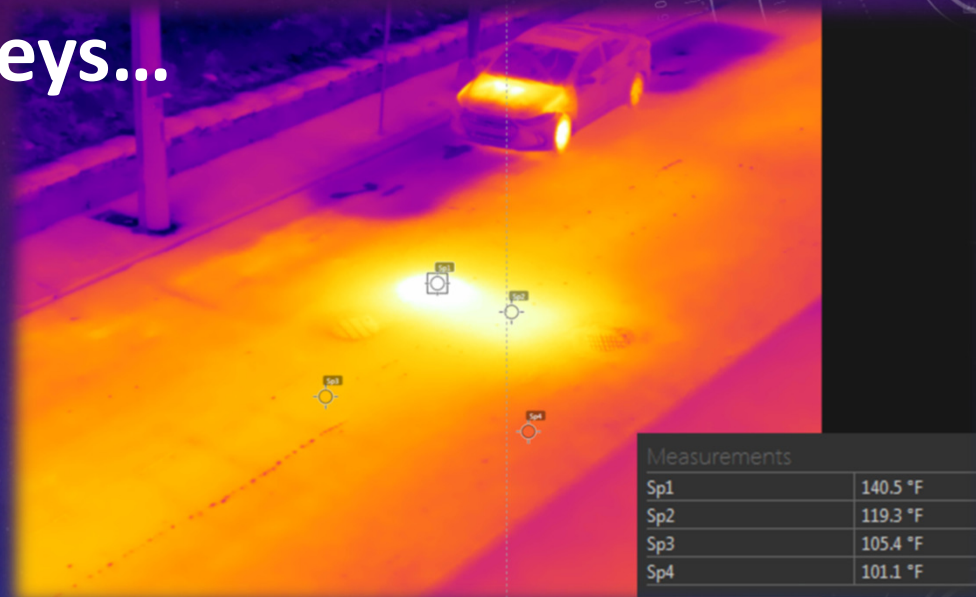
– How much are you paying?

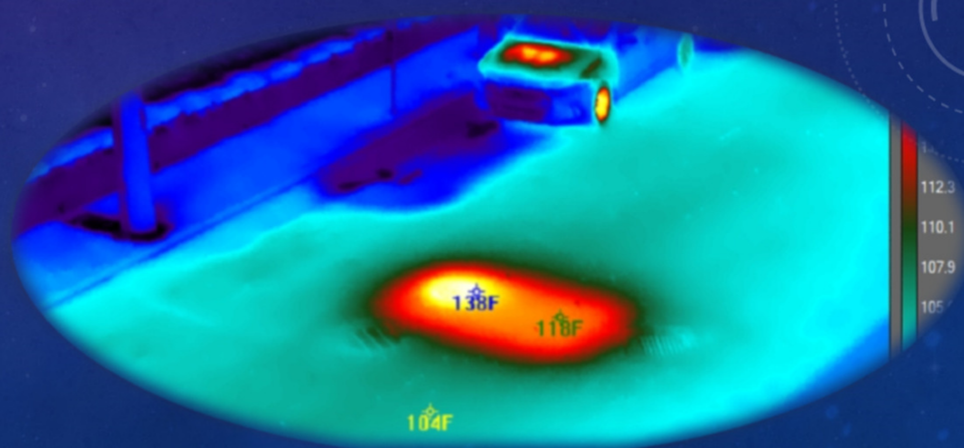
Methods of IR Surveys…

- **Walking**
- **Driving**
- **Elevated View**
- **Aerial View**

NADIR or Oblique

All have their advantages and disadvantages…





Platforms of IR Surveying

- Personal Carry (On-Ground)
- Personal Carry (Elevated Platform)
- UAVs (rotor-wing and fixed-wing)
- Helicopters (rotor-wing)
- Airplanes (fixed-wing)

NADIR or Oblique

All have their advantages and disadvantages…

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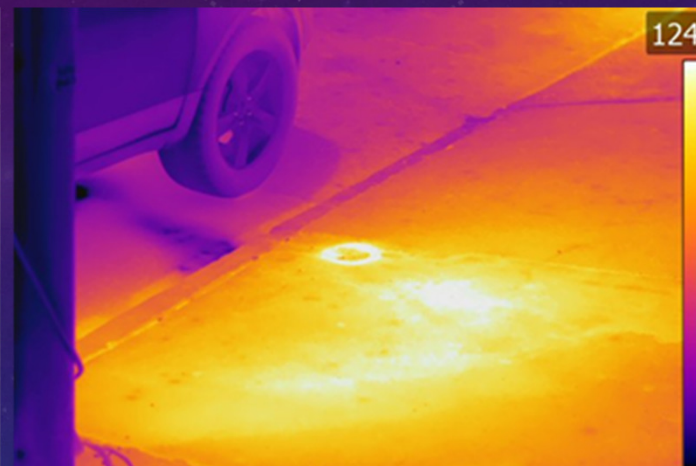
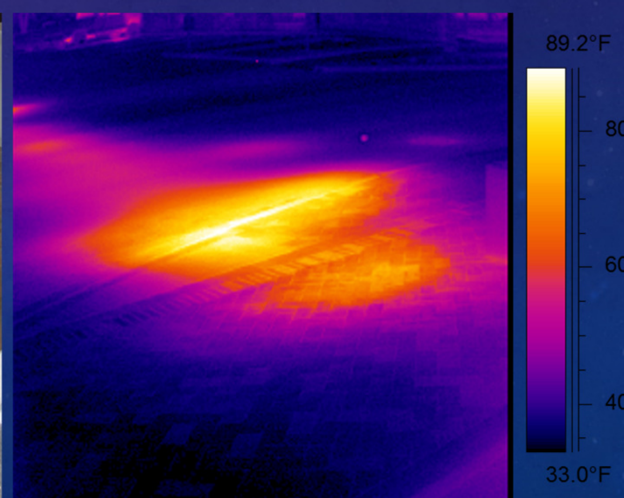
Walking / Driving IR Surveys of Steam Lines





Using Aerial Thermal IR Imaging to Monitor
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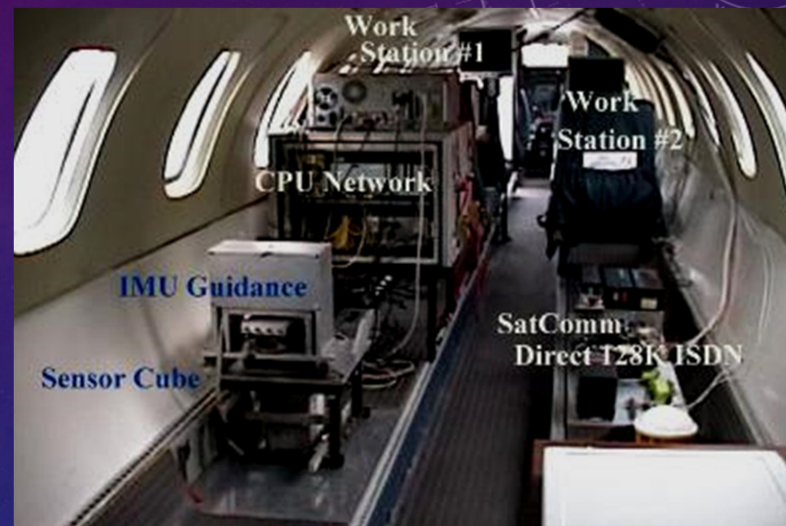
Elevated / UAV IR Surveys of Steam Lines

UAVs (rotor-wing and fixed-wing)

Helicopters (rotor-wing)

Airplanes (fixed-wing)



Thermal Mapping and Ortho-Rectification

A competent thermographer can survey some buildings or a mile or so of underground lines using a thermal imager by walking, driving, getting on adjacent buildings or using a drone to fly over an area. The thermographer locates the target(s) in the imagery, saves the data and puts it together into a report. Scale information can be gathered by using maps Google Earth™, existing CAD drawings or having someone walk over the area with a tape measure. This works fine for relatively small areas, but it is not possible to make precise thermal maps of a whole complexes, campuses, military bases or whole city steam distribution systems, etc., without flying an aircraft over the area and ortho-rectifying / geo-referencing the imagery data.

In order to produce ortho-rectified thermal maps of large areas -the most sophisticated and useful product, much more information must be gathered and tagged to the IR imagery. During the thermal flight (at night), the aircraft flies straight, smooth lines on a pre-planned grid, allowing side lap of the imagery. The IR operator manages the sensor data-acquisition following a structured checklist for orderly data file management.

Thermal Mapping and Ortho-Rectification

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 aircraft.

After the imagery is collected and QC is verified, the digital infrared imagery is then processed into a series of ortho-rectified image tiles, which are stitched together to create a giant mosaic image. An on-board 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.

The result is presented as a high-resolution IR image in the form of a geo-TIFF, which is compatible with any GIS software such as ESRI ArcView, AutoCAD 3-D Map, Global Mapper, MapInfo, etc. Aerial photographs (taken during the day) receive the exact same treatment. These images can all be saved as JPEGs or KMZs, or other types of image files. Then, detailed reports can be generated.

Ground Resolution Element (GRE) = 30”

Resolution

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Ground Resolution Element (GRE) = 24”

Resolution

Ground Resolution Element (GRE) = 18”

Resolution

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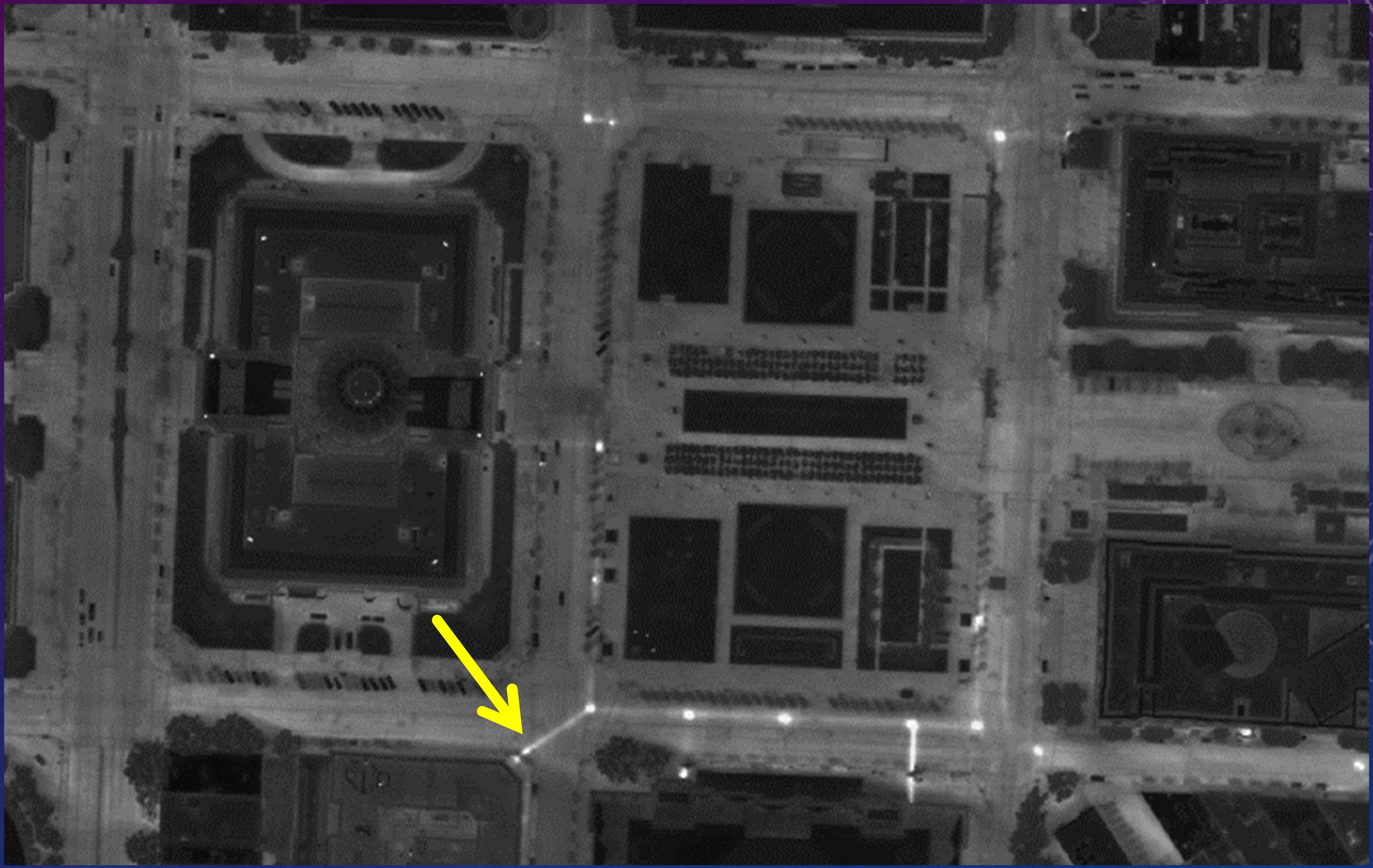
Ground Resolution Element (GRE) = 12”



Resolution

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Ground Resolution Element (GRE) = 6”

Resolution

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Ground Resolution Element (GRE) = 3”

Resolution

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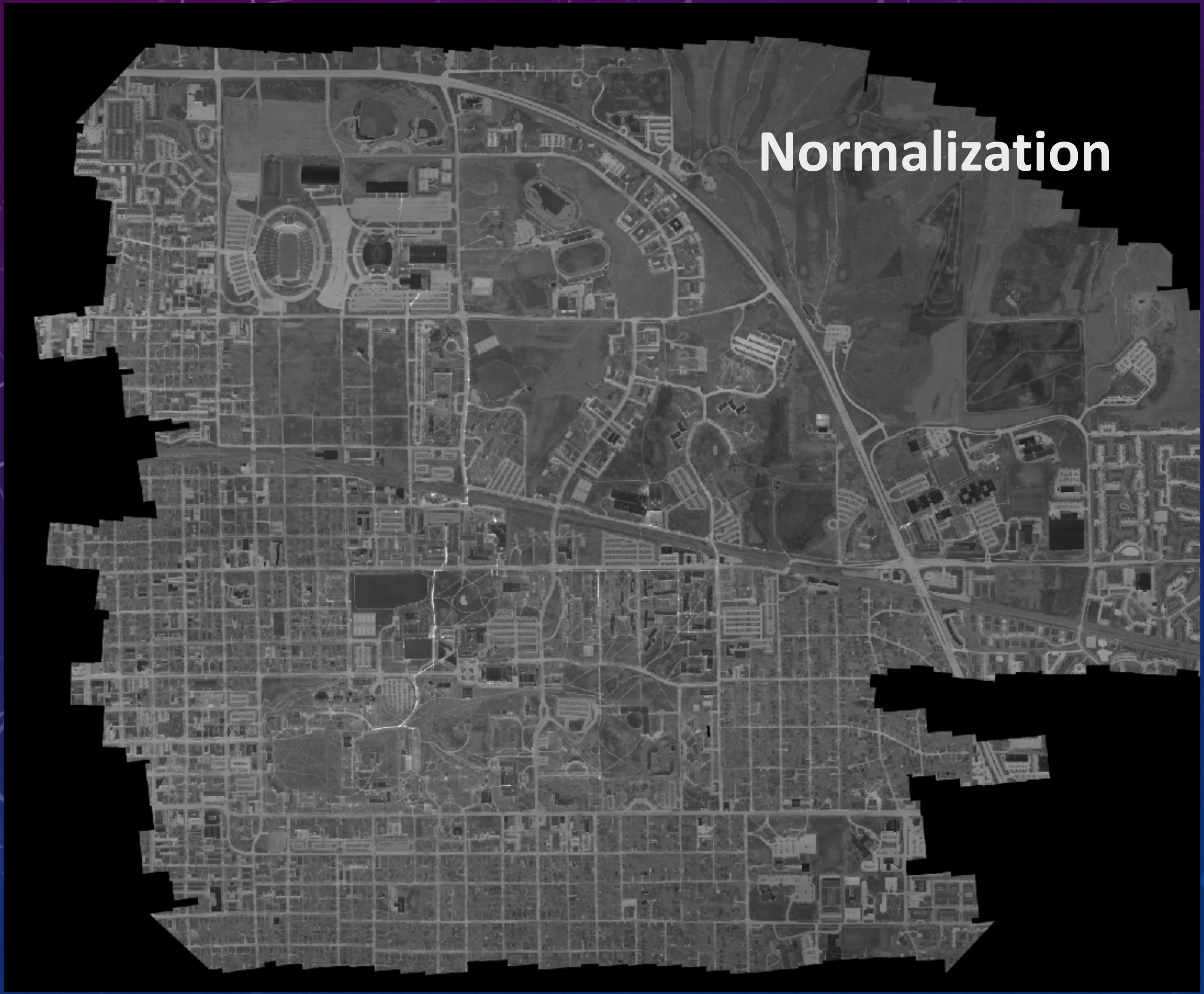
Aerial Infrared of Steam and HTHW Distribution Systems



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Aerial Infrared of Steam and HTHW Distribution Systems

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AITSCAN
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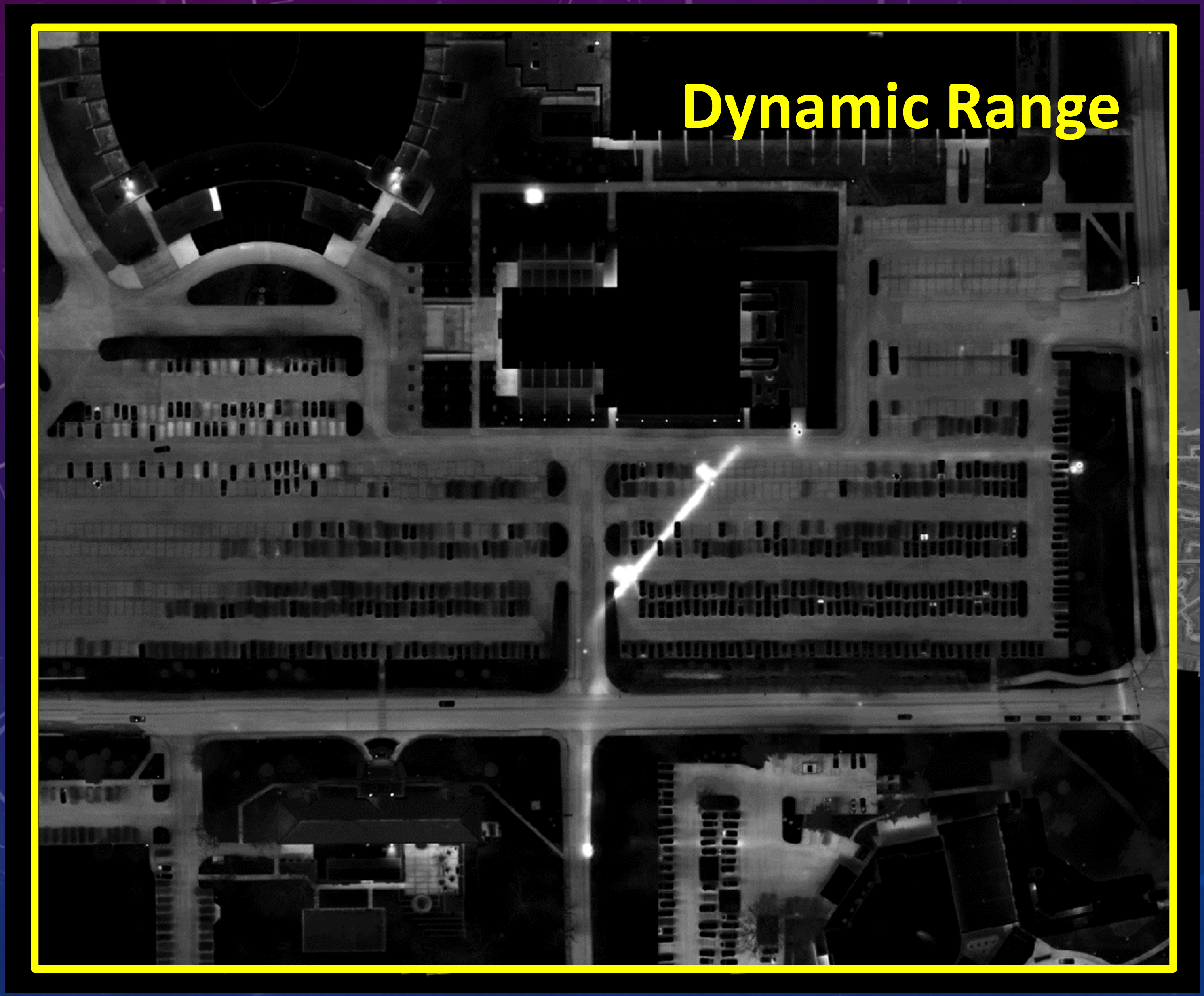

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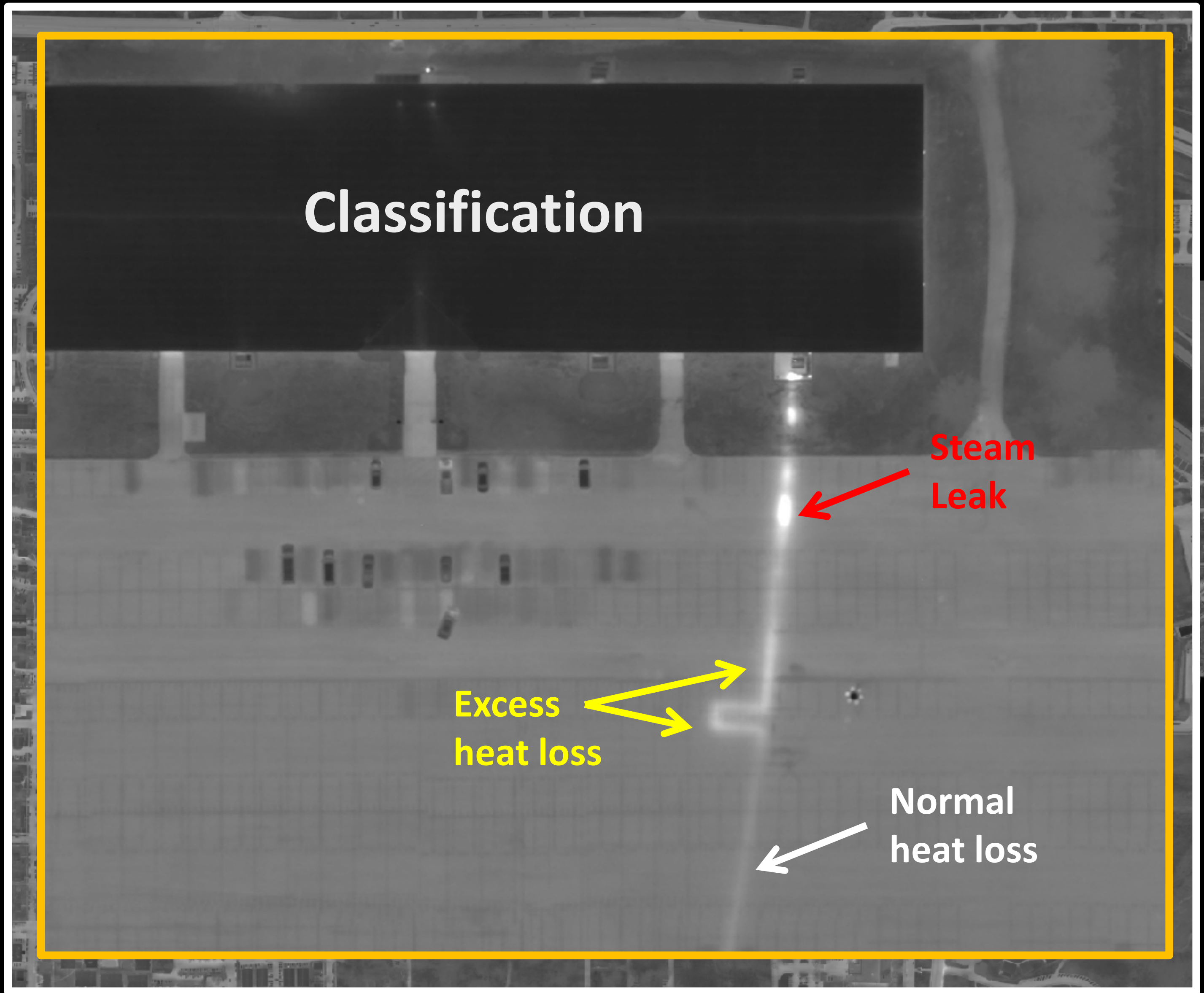


Heating Systems Thermal Imagery

Steam and HTHW lines can be overhead, underground direct-buried or in tunnels. Analyses of overhead lines is somewhat straightforward if you understand the physics. One can stand on the ground close to the line, find overheating areas, measure temperatures directly from a few feet away. As shown below, it is also possible to fly over overhead heating systems and measure temperatures very effectively as well -if close enough to the target.

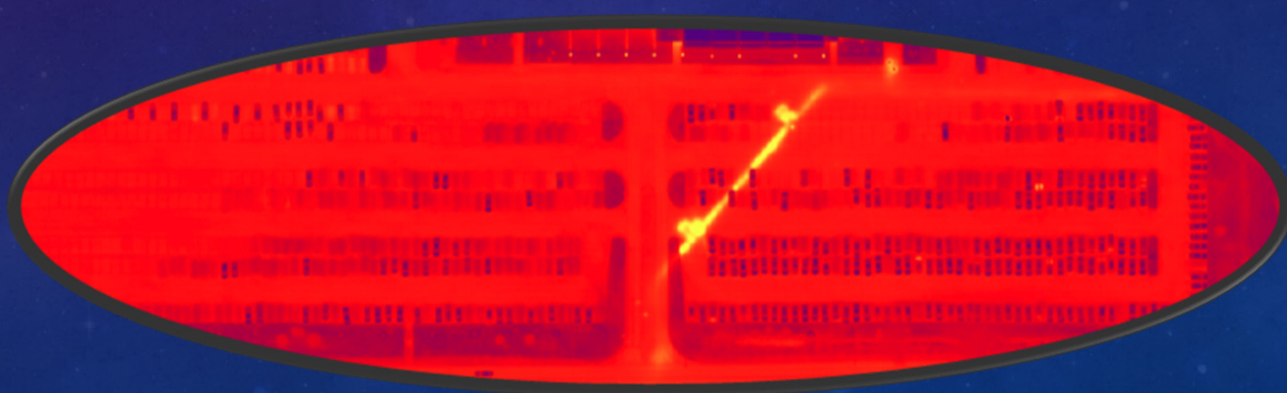
Whether buried directly or contained in tunnels, the thermal signature of underground heating lines are almost always readily visible with infrared imaging -even when no notable problems exist. This is due to the fact that no matter how good the insulation, there is always some heat loss from the lines which makes its way to the surface.

Problem areas are generally quite evident, having brighter IR signatures that exceed the norm. Heating line faults normally appear as an overheated area in a line or as a large hotspot along the line.

Heating Systems Thermal Imagery

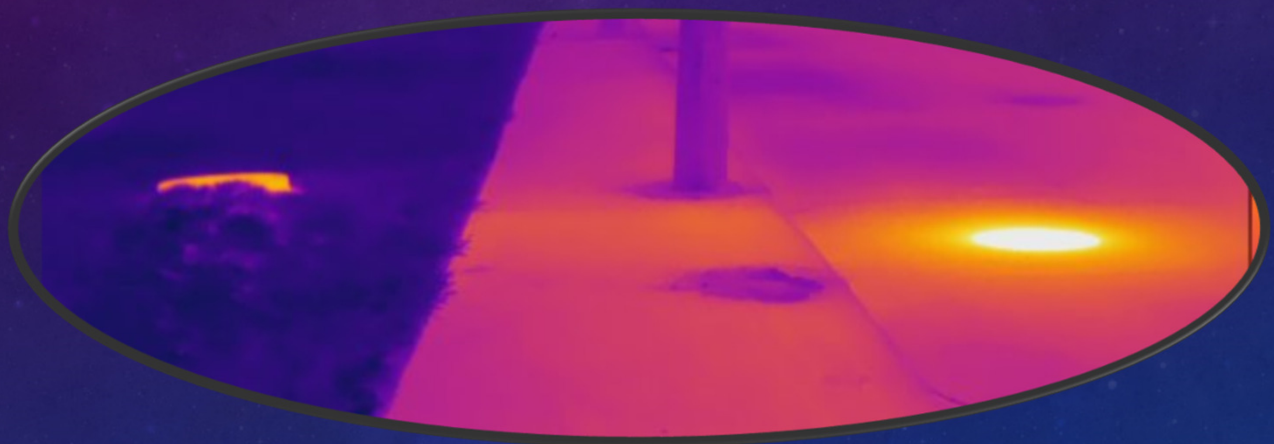
Overheated line faults often occur when the heat escapes into the insulating jacket, saturating the insulation and rendering it largely ineffective. The line will then begin to transfer heat producing the classic bulge or balloon-like hot area straddling the line.

Now, some heating lines are not visible through thermal imaging because no heat makes its way to the surface -either because of the depth of the line, the material around the line, or the insulative value of the overburden above the line. In these cases, we consider usually the lines to be in good shape. Even if a line cannot be seen, if there is a leak on the line, the leak area will usually be seen.



Heating Systems Thermal Imagery

Heating line thermal imagery can be a little misleading, unless one understands and interprets the relative brightness and temperature patterns of a given line correctly. A line that is the same temperature from one end to the other can exhibit a variety of temperature variations…



For example, five different apparent temperatures will result from the same temperature line that runs under a grass-covered field, an asphalt parking lot, a concrete loading dock, a gravel-covered area and a bare earth pathway.

More on this now…

Thermal Mapping and Temperature Readings

Detecting underground heating and cooling line faults can be accomplished as clearly shown in this presentation. But accurate temperatures of faults are impossible to quantify, because the surface of the ground is an indirect temperature measurement of the target. The target is the pipe -not the ground surface over the pipe. Qualitative analysis is the only analysis when determining whether a line fault exists and how bad the fault might be. The shape and intensity of temperatures –commonly referred to as its thermal signature, are much more important to the analyses than the temperature itself. So…

Temperature measurements of ground surfaces should not be used to determine the severity of any subsurface problem.

Thermal Mapping and Temperature Readings

Even the temperature measurement of the ground surface itself is hard to obtain accurately from the air. There are several problems associated with temperature measurement which come into play, which include spot size to target distance ratios, variability of emissivity of the ground surveyed, having a constant load on the line at the time of the survey and knowing everything about the characteristics of the surface.

Adding to the inaccuracies…Nyquist's frequency theorem states that an object less than two times the size of a sensor's GRE cannot be resolved for measurement, so a 3x3 pixel or GRE spot is needed for reliably obtaining measurements.

REPEATING THIS STATEMENT…

Temperature measurements of ground surfaces should not be used to determine the severity of any subsurface problem.

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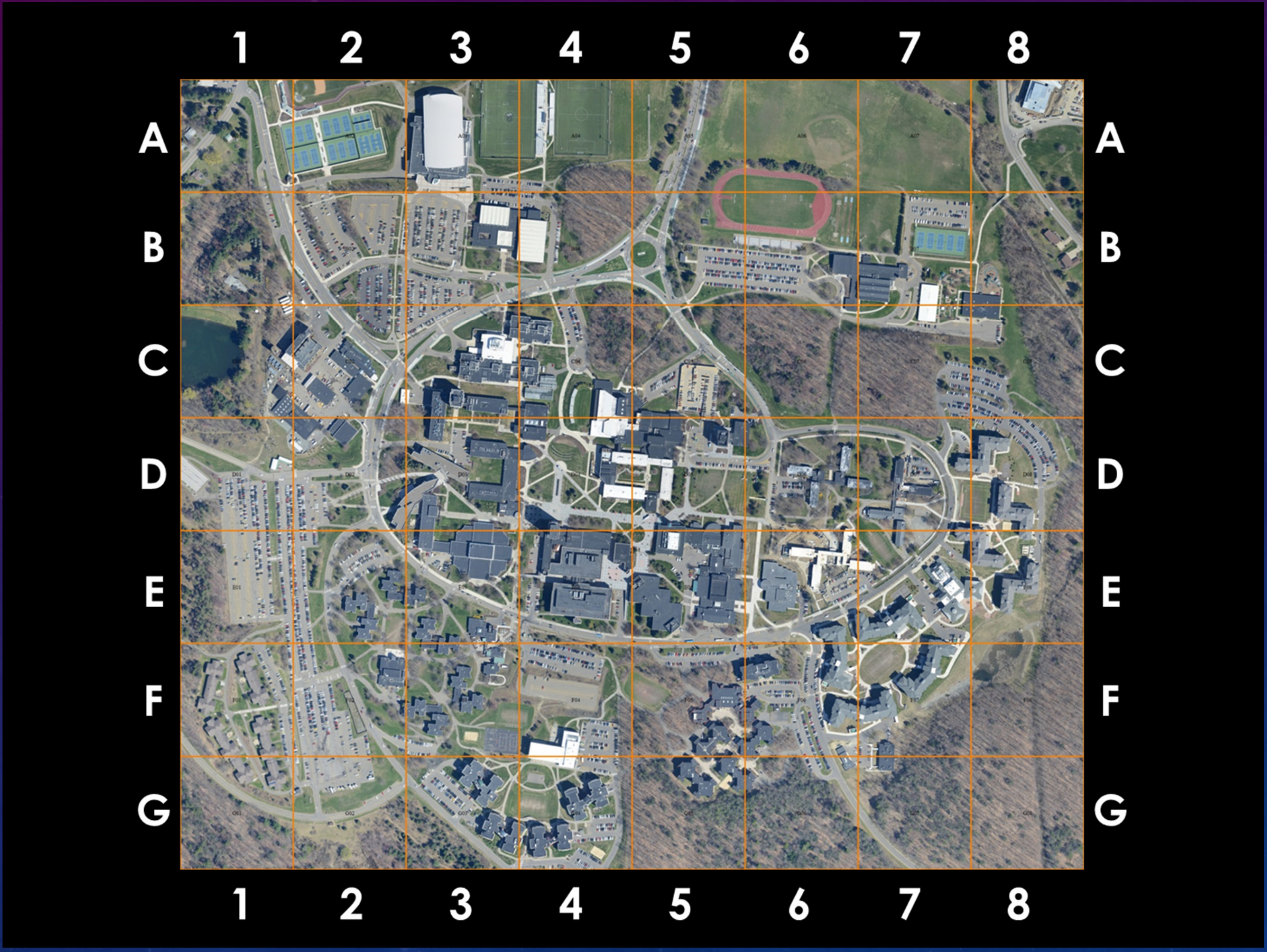

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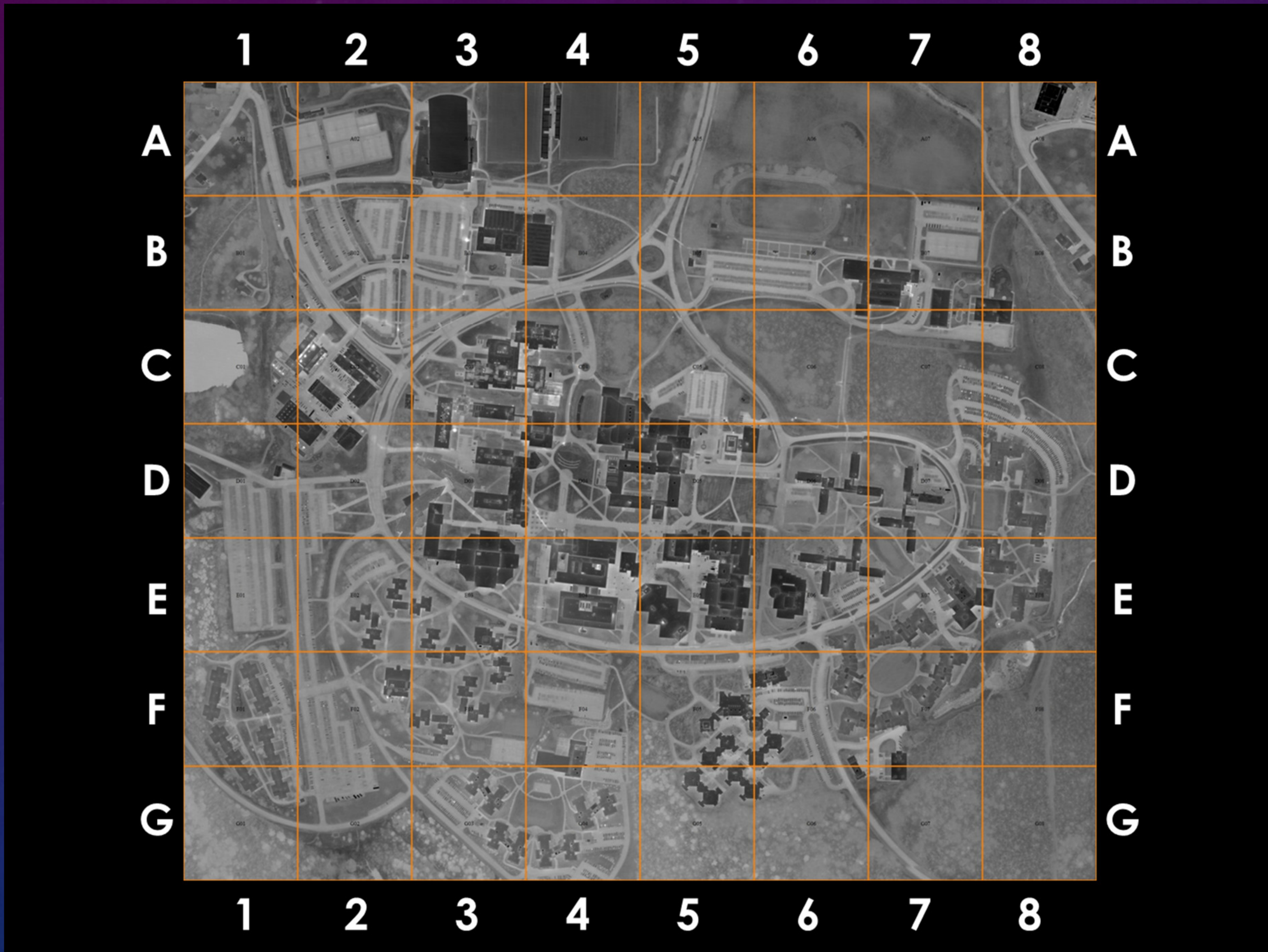

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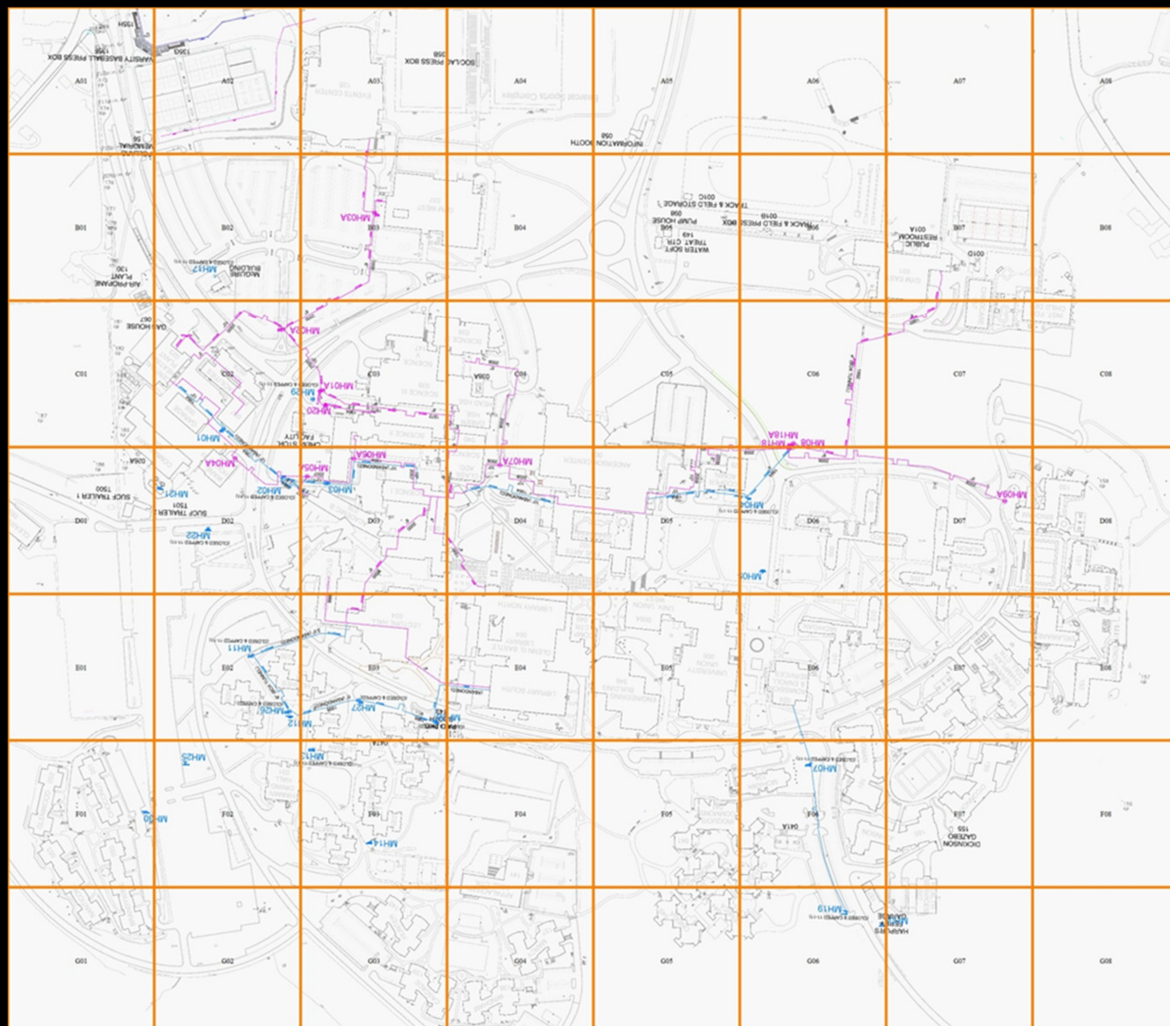

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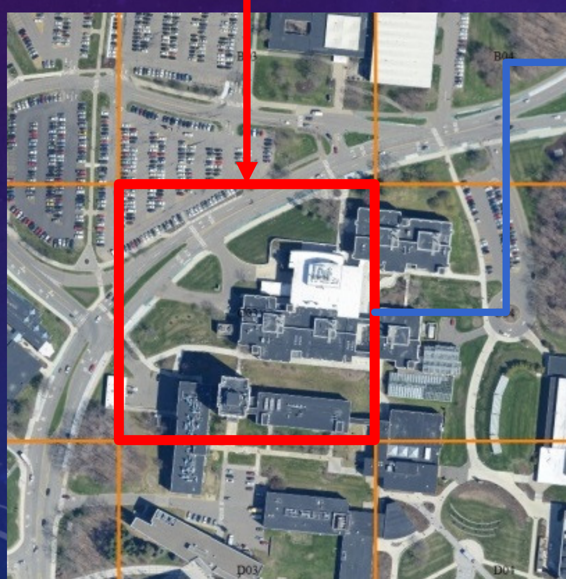

Photograph Layer

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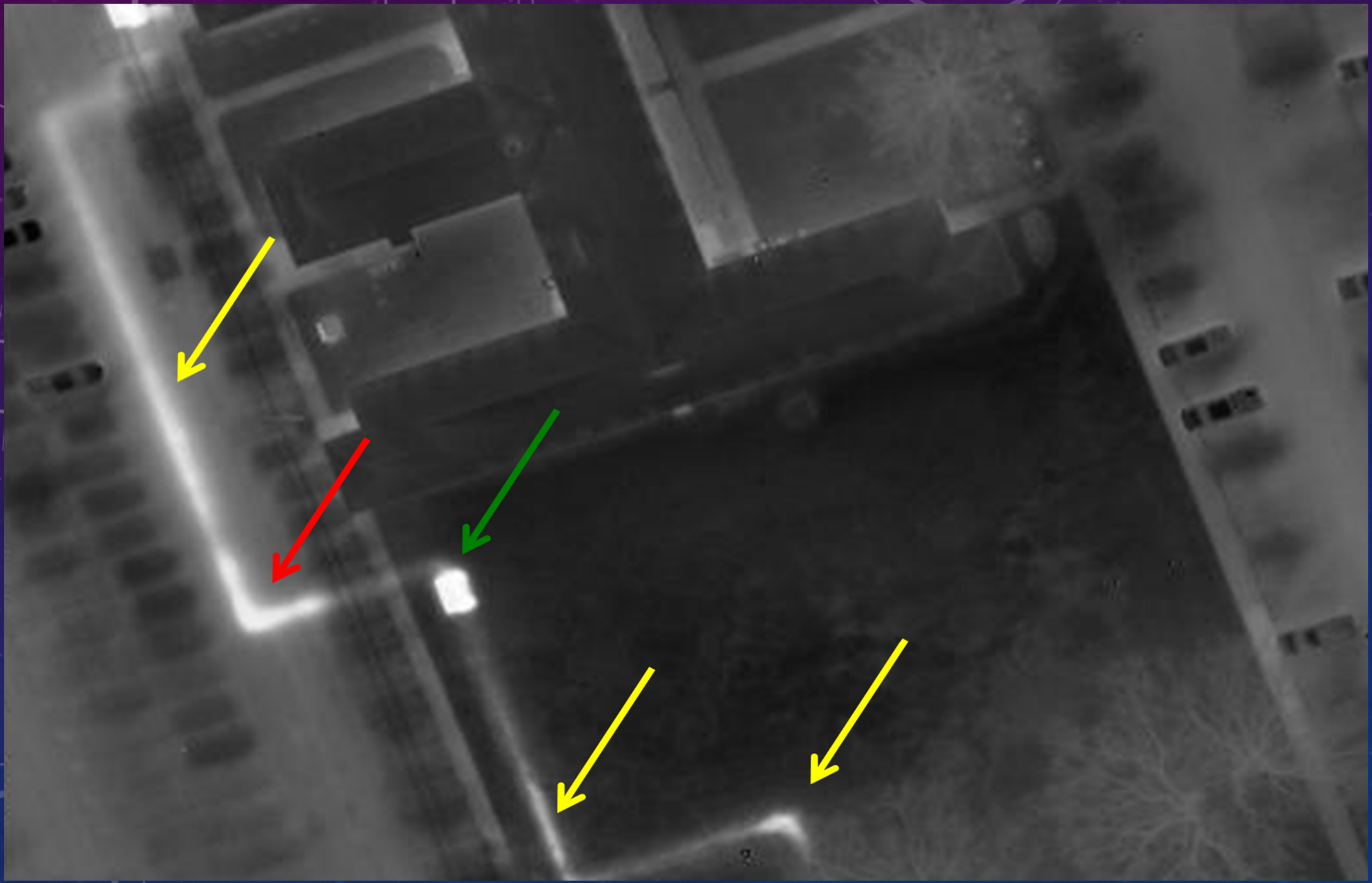
Direct Bury Lines Transfer Heat to the Ground Above



Using Aerial Thermal IR Imaging to Monitor
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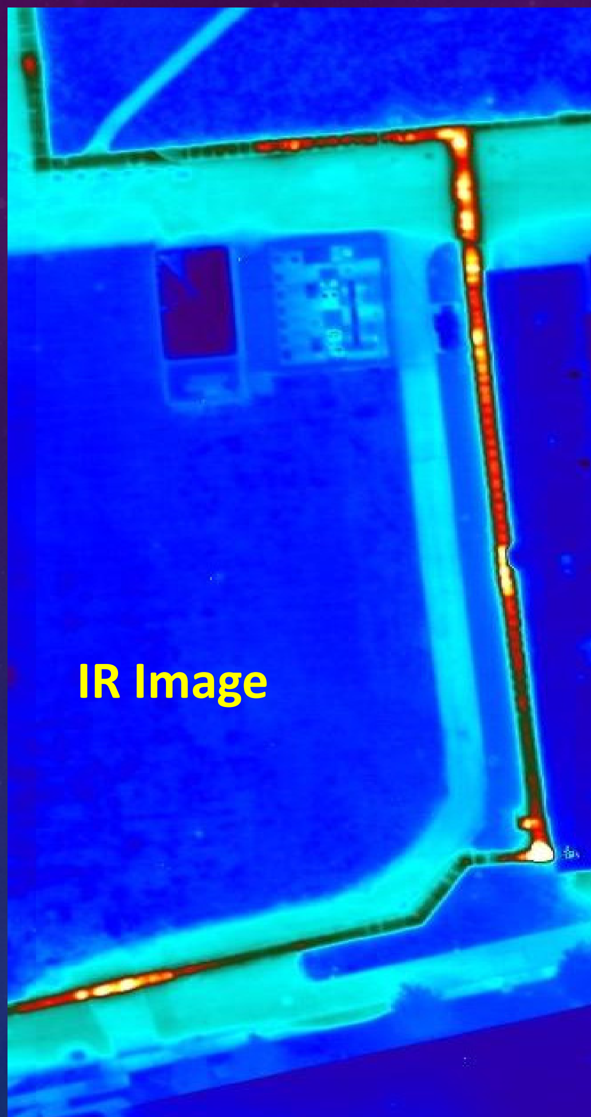
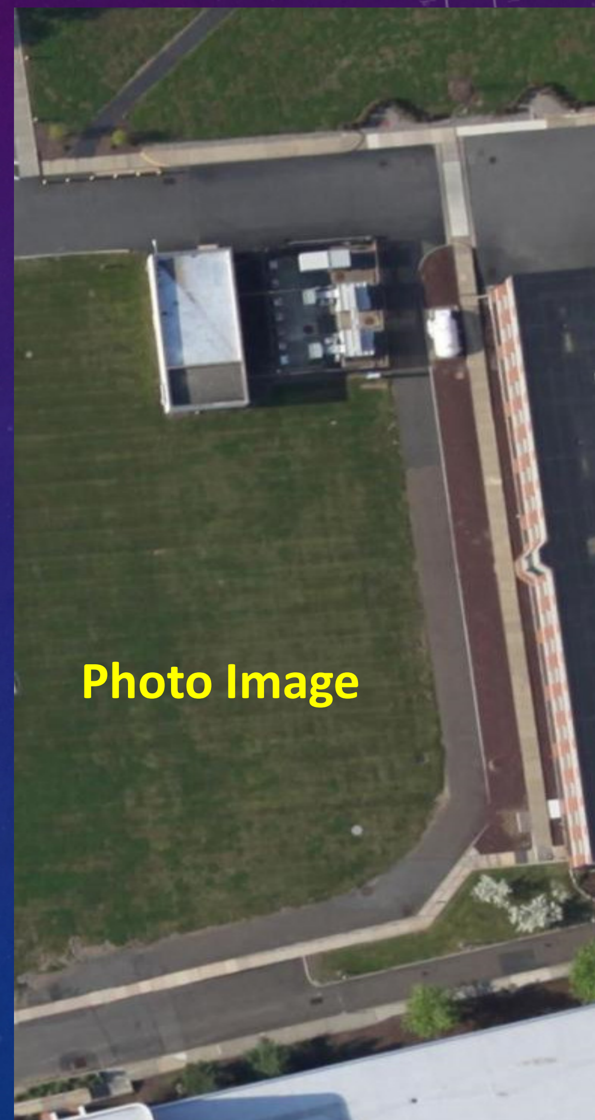
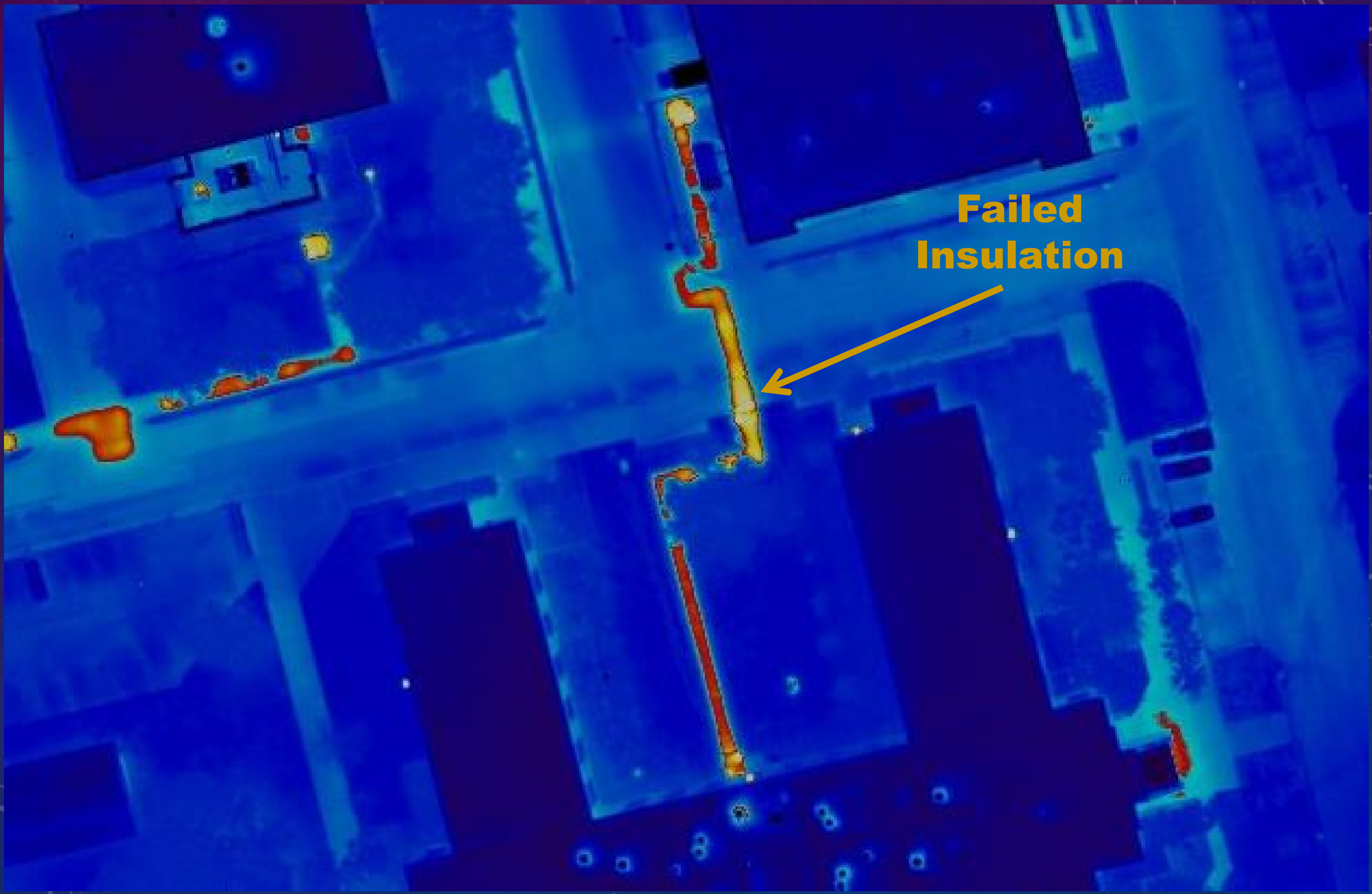
Direct Bury Lines Transfer Heat to the Ground Above





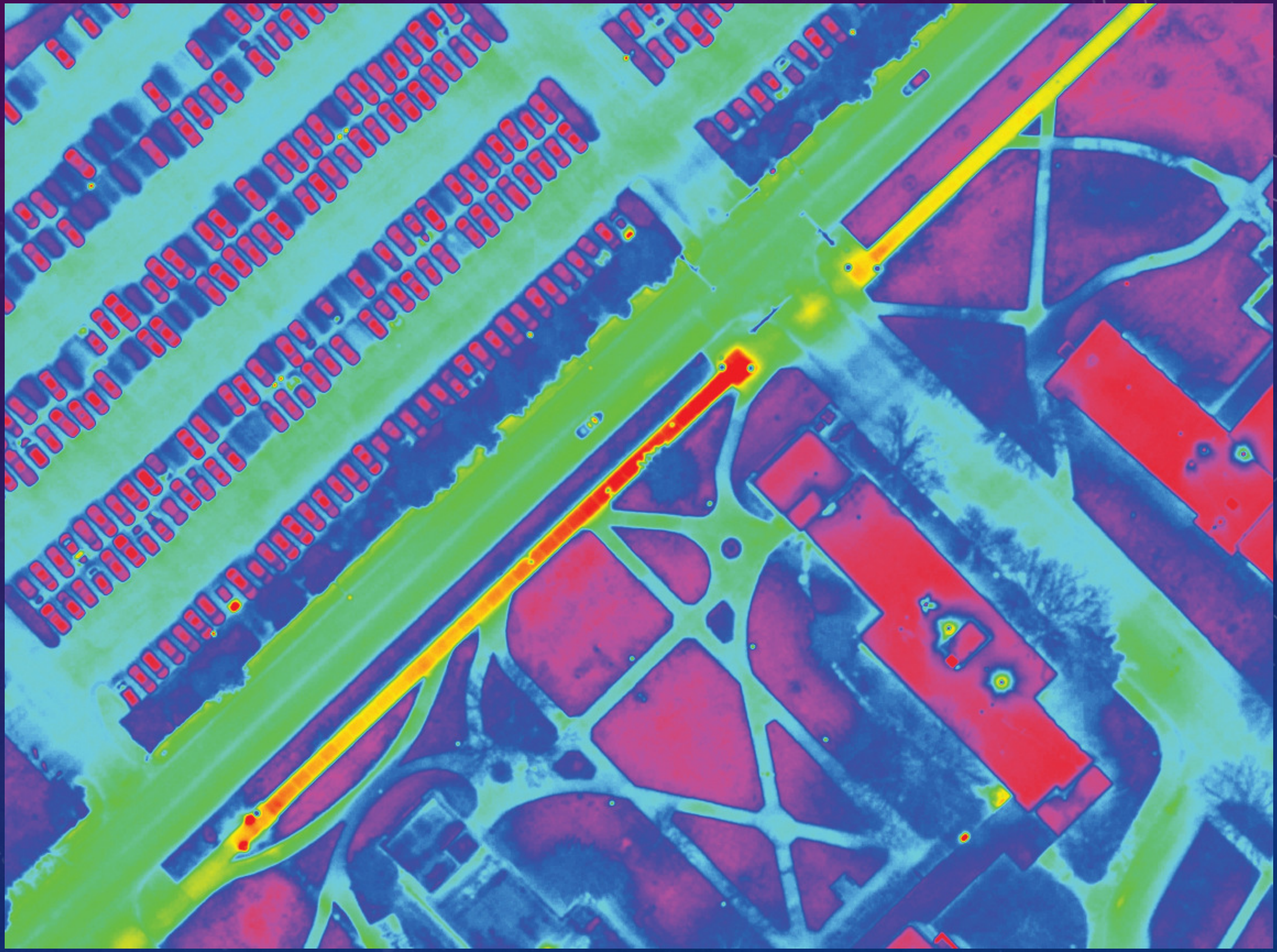
Direct Bury Lines Transfer Heat to the Ground Above



Direct Bury Lines Transfer Heat to the Ground Above

Tunnels Transfer Heat to the Ground Above

Tunnels Transfer Heat to the Ground Above



Leaks Come to the Ground Surface

Buried Chilled Water Lines Cool the Surface Above the Line

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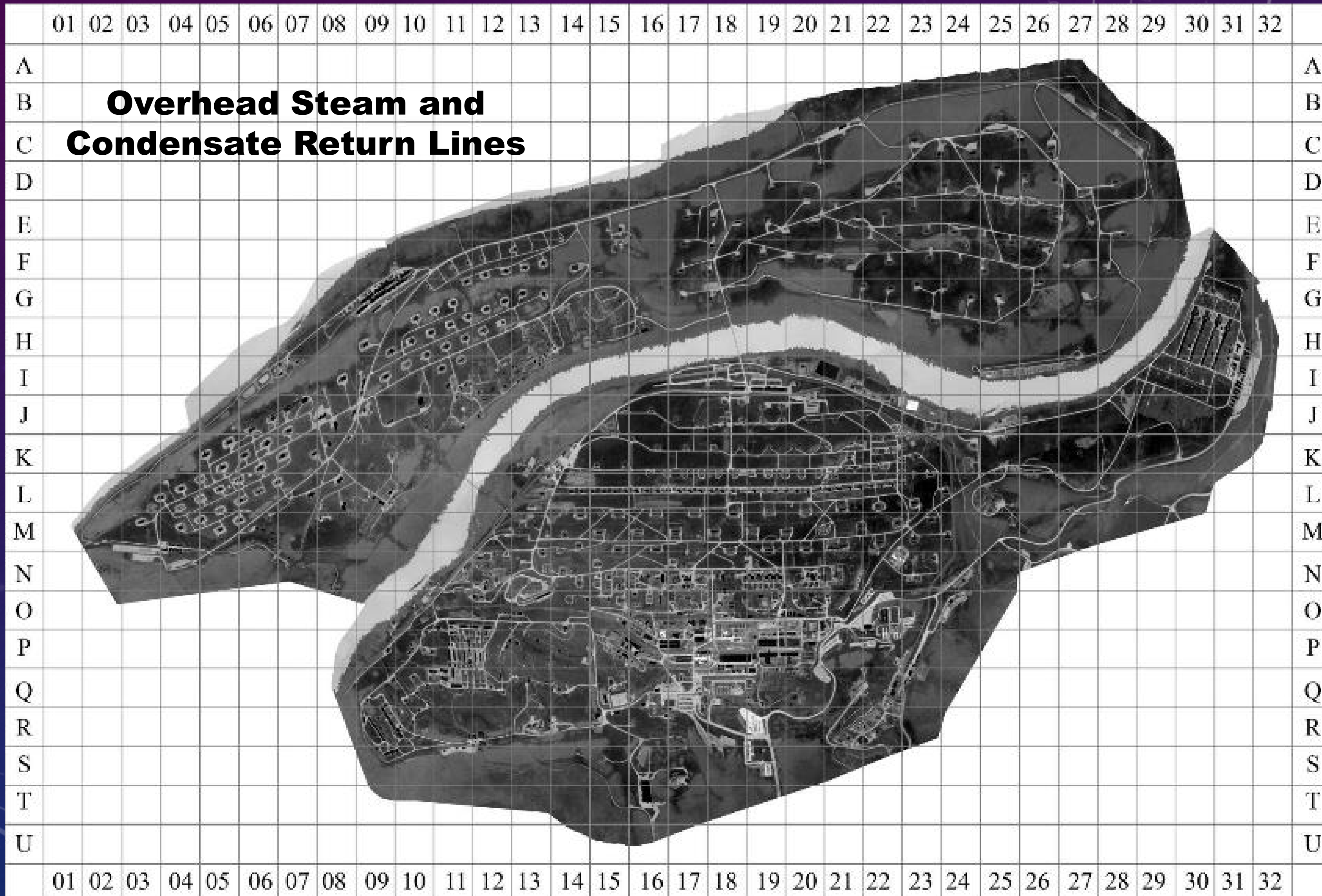

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Other Uses for Thermal Mapping…

- Liquid Leaks
- Roof Moisture Surveys
- Solar Field Commissioning
- Heat Loss & Air leakage from Buildings
- Others

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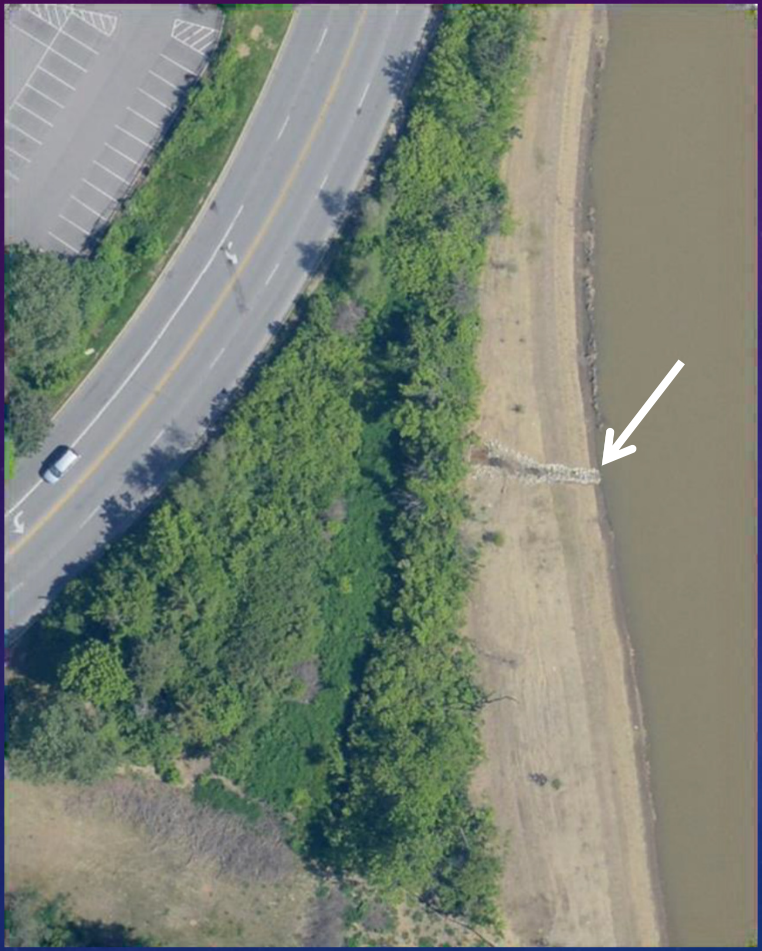
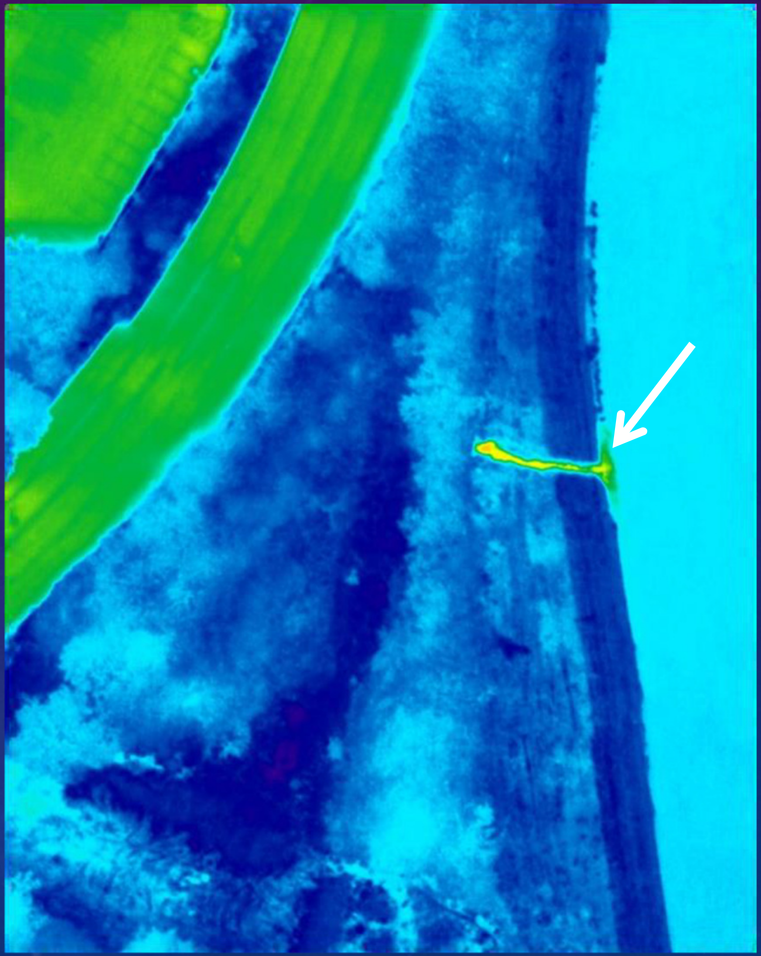
Liquid Leaks

Liquid Leaks





Liquid Leaks

Liquid Leaks – Sewer lines, Water Supply Lines, Storm Drains and Irrigation

A given area of any waterway will exhibit near homogenous temperature patterns except for areas where another liquid has joined the flow. This flow of liquid typically appears warm as compared to the surface water in a creek, stream, river or lake - particularly during cooler times of the year, due to the relative warmth of the ground a short distance below the surface. Leaks from nearby liquid lines often come to the surface through lateral transfer to a creek, stream, river or lakebed, or to a slope leading down to the surface of the water. These leak areas and the warm plume of liquid joining and flowing downstream with the body of water are visible in the thermal infrared spectrum due to the difference in temperatures of the two liquids.

Liquid Leaks

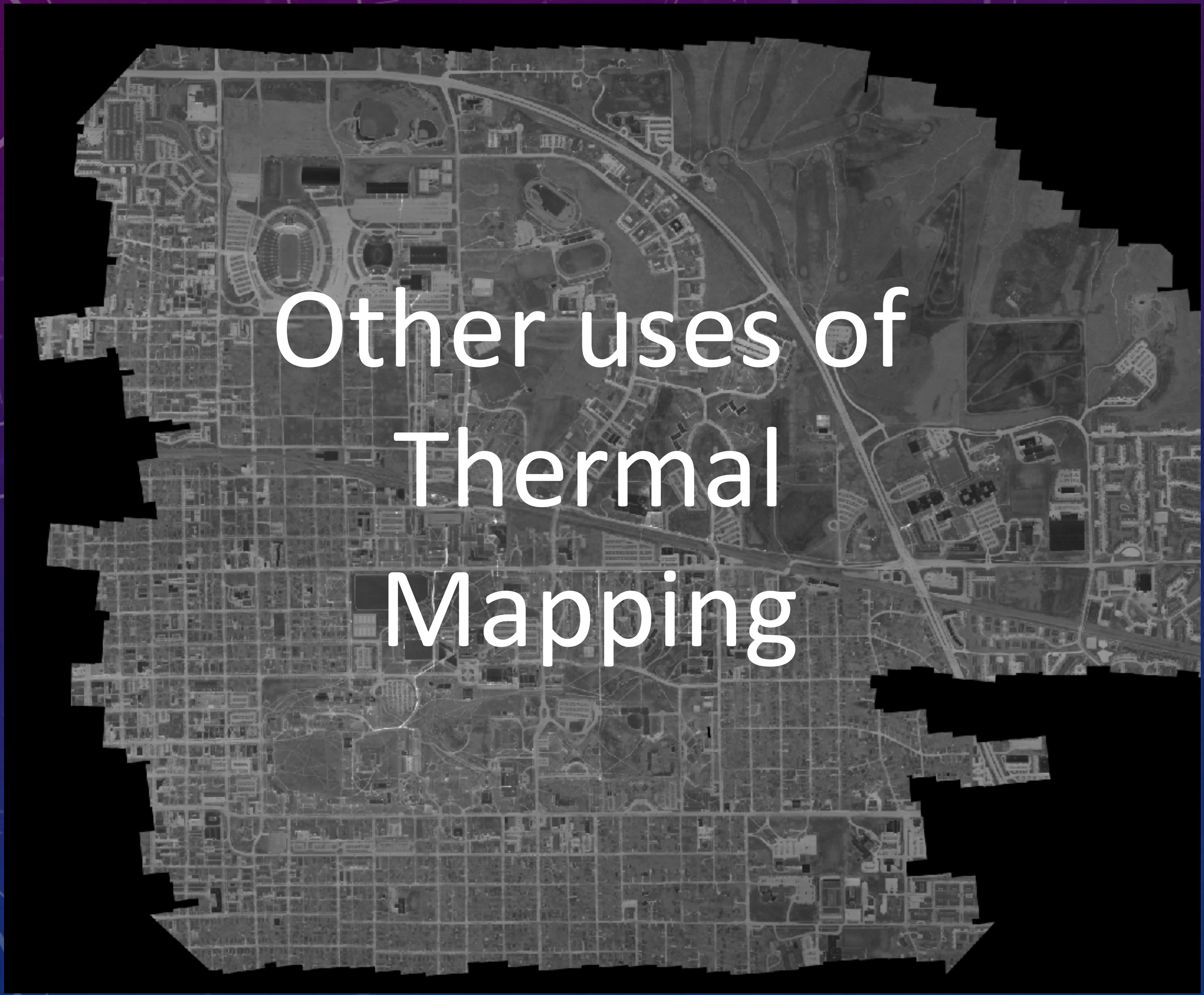
Liquid Leaks – Sewer lines, Water Supply Lines, Storm Drains and Irrigation

Leaking sewage collector lines, storm water drain discharges, supply water pipes, drainage lines, etc., can often be identified by their thermal infrared signatures. As these sources run across the ground, seep or empty into ditches, creeks, streams, rivers and lakes, their thermal signatures vary from their surroundings, and they can be pinpointed accurately from the air.

Liquid Leaks

Liquid Leaks – Irrigation

With irrigation systems, evaporative cooling causes any leaks onto the surface of the ground to show up as cooler areas. Leaks in the lines, misdirected sprinklers and inefficient watering of any area can be monitored.


Other uses of Thermal Mapping

Return on Investment

Flat & Low-Sloped Roofs

Advantages to using Thermal Mapping for Roof Condition Assessments…

- Roofs are surveyed en masse.
- All roofs are surveyed under good conditions.
- All roofs have single thermographs and photographs.
- NADIR Imaging allows for well-matched imagery.
- Analyses are quick, effective and efficient.

Return on Investment

Flat & Low-Sloped Roofs

Typical On-Roof IR Survey of a 50,000 SF Roof….. **$2,000**

- Suspect Wet Roof Areas are marked with paint.
- A drawing / map of the roof is made of wet areas.

Typical Aerial IR Survey of a 50,000 SF Roof……… **$200**

- Suspect Wet Roof Areas are found on thermal map images.
- Scaled Auto CADs are made showing wet areas.
- Aerial photographs and thermographs are overlaid on CAD.

What makes roof moisture surveying so valuable to the owner of a roof? Of course, cost-savings… 95+% of all roofing materials that are removed are dry

- Best practice condition monitoring (PM) for roof maintenance
- Salvage the thermal value of the existing undamaged insulation
- Avoid costly tear-off expense in labor to R&R wet insulation
- Avoid cost to bury perfectly good insulation in a landfill
- Save time: recover is faster vs. tear-off and replacement
- Minimize risk of leaks and consequential damage
- It is "Green" not to throw away perfectly good materials

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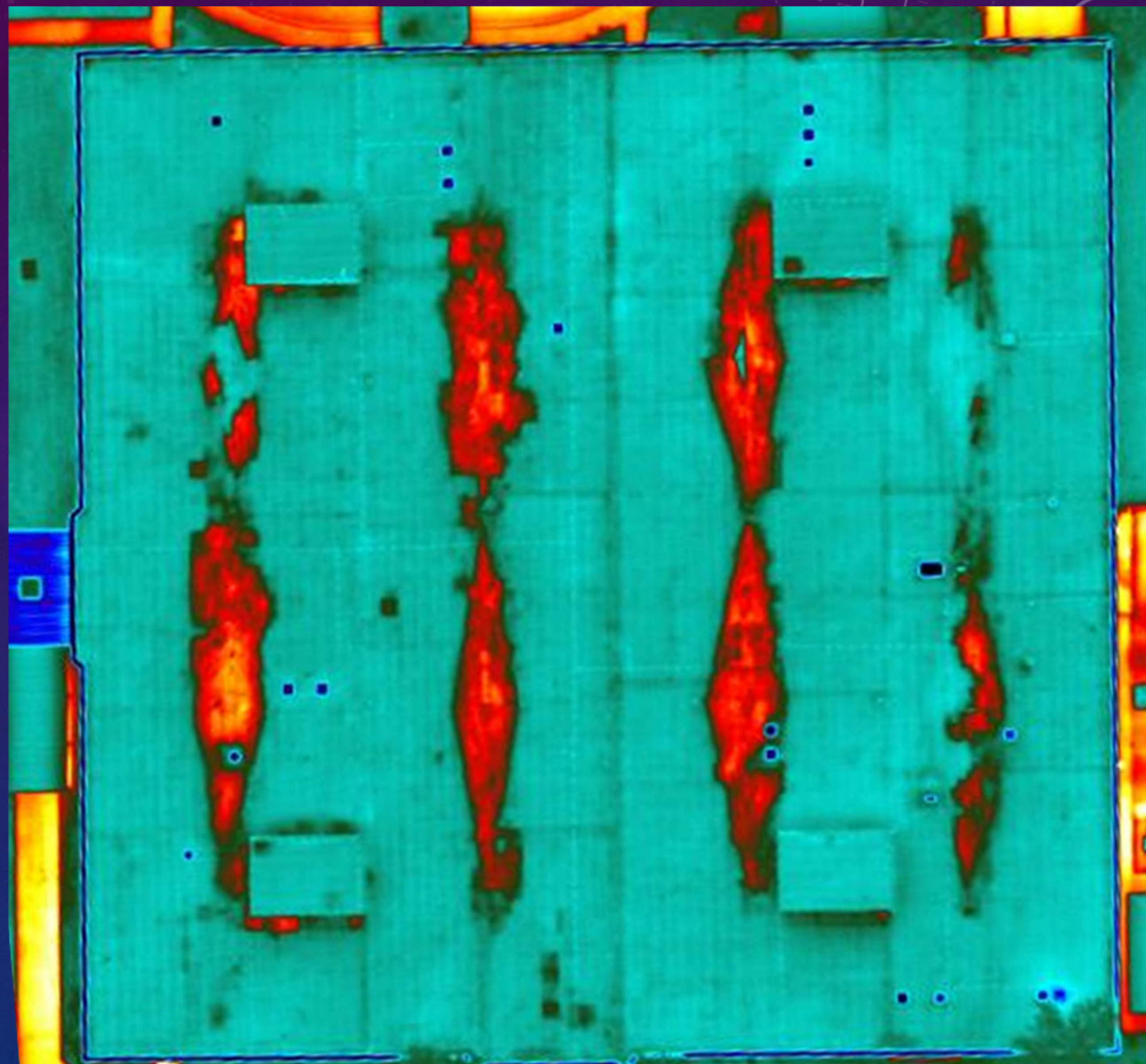
Flat & Low-Sloped Roofs

IR Finds Subsurface Wet Insulation



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Wet insulation can be mapped and removed surgically…

Flat & Low-Sloped Roofs

Three (3) NDT Devices to find moisture

- **Nuclear Density Gauges**
  - **which count slowed neutrons**
- **Dielectric Capacitance Meters**
  - **which measures differences in dielectric constants**
- **Thermal Infrared Cameras**
  - **which measure heat differences**

Infrared

Four methods to accomplish IR Roof Moisture Surveys:

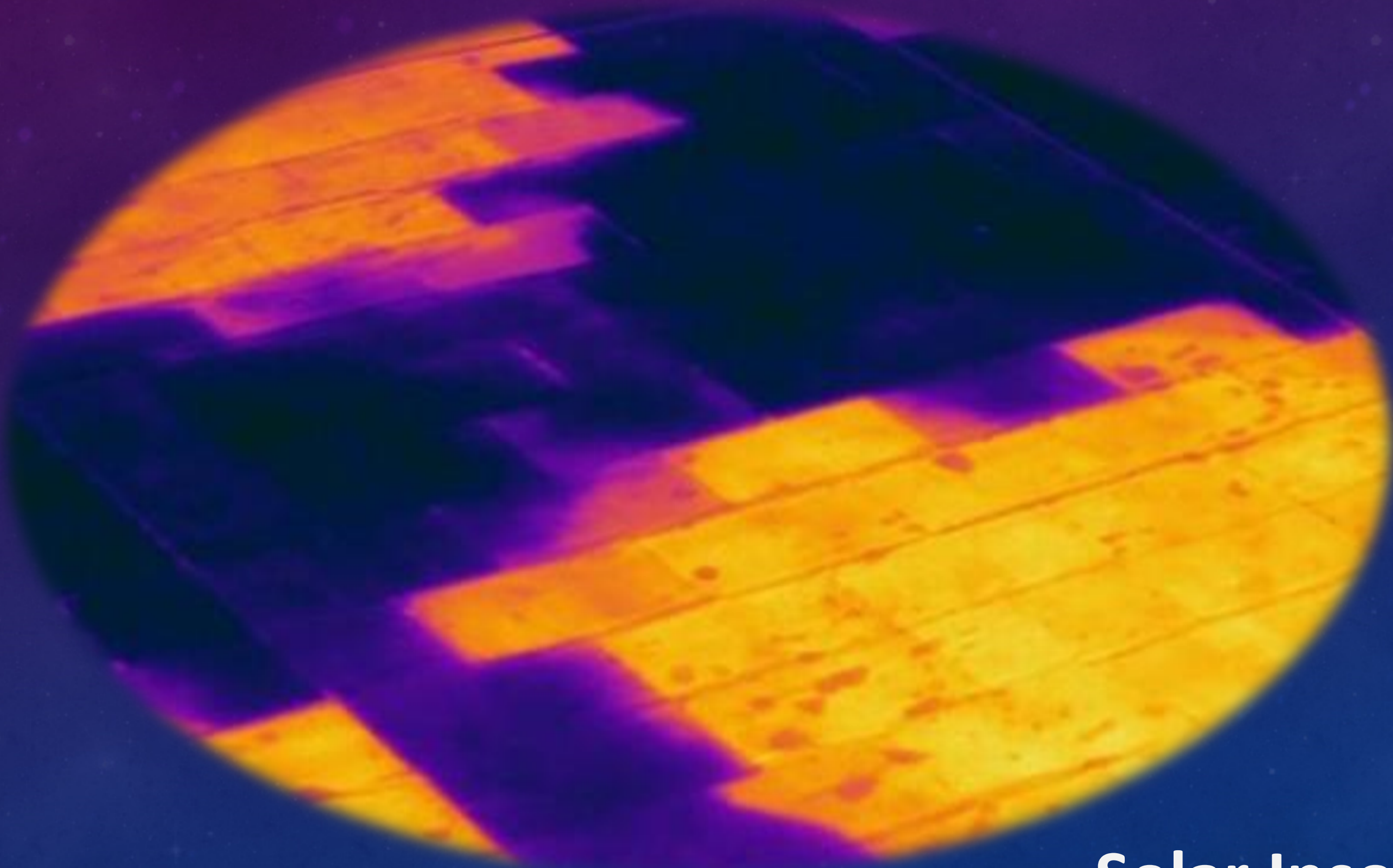
- Under-Roof Infrared Roof Moisture Surveys
- On-Roof Infrared Roof Moisture Surveys
- Elevated Vantage Point Infrared Roof Moisture Surveys
- Aerial Infrared Roof Moisture Surveys

The same thermodynamics and laws of physics apply to all.

- **A dry roof, low winds and no rain are needed on the night of the survey. The more clear the sky, the better.**
- **Solar Insolation is the main factor as far as thermal conditions.**

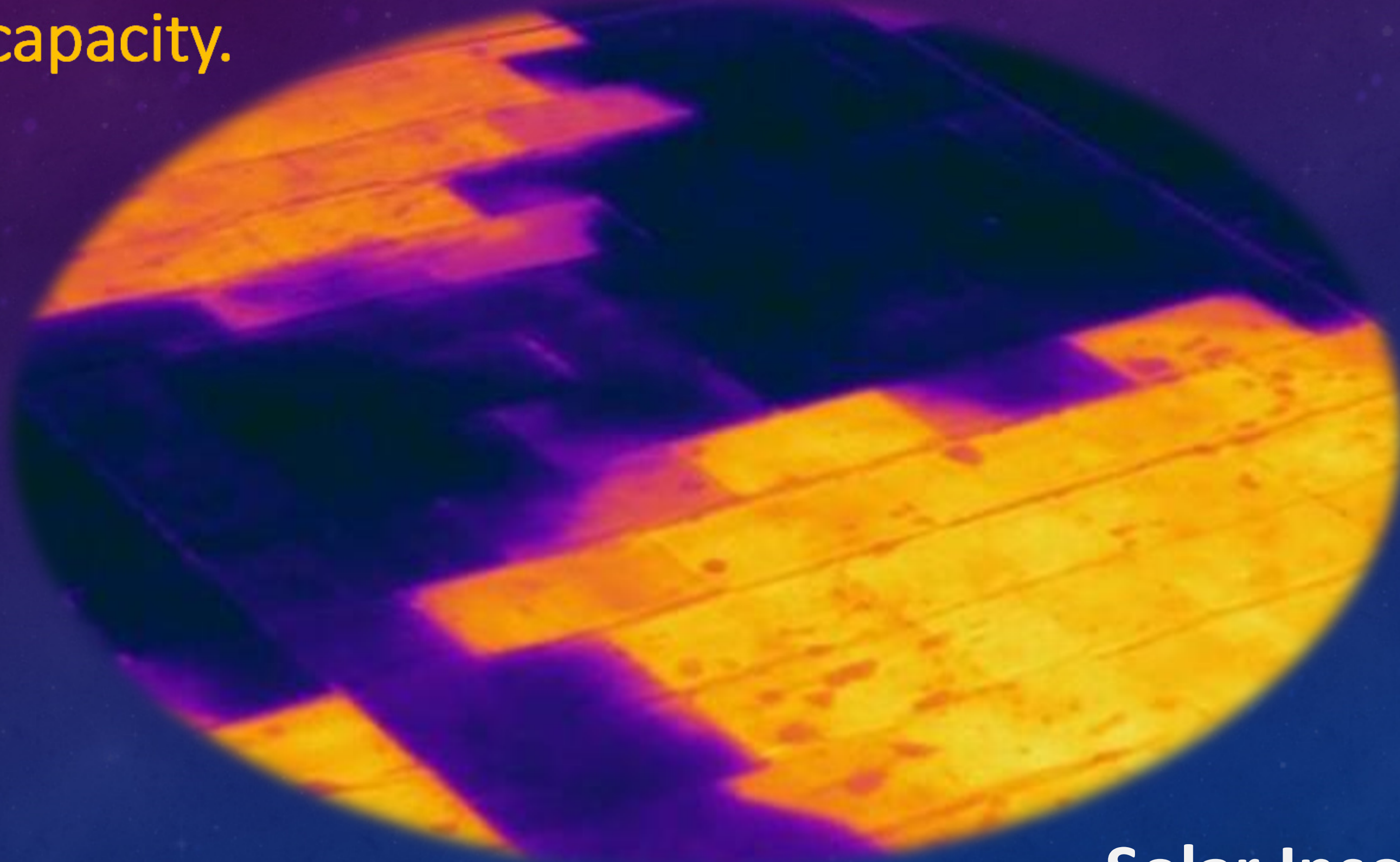
All methods have advantages and disadvantages…

The infrared method is based on pattern recognition.

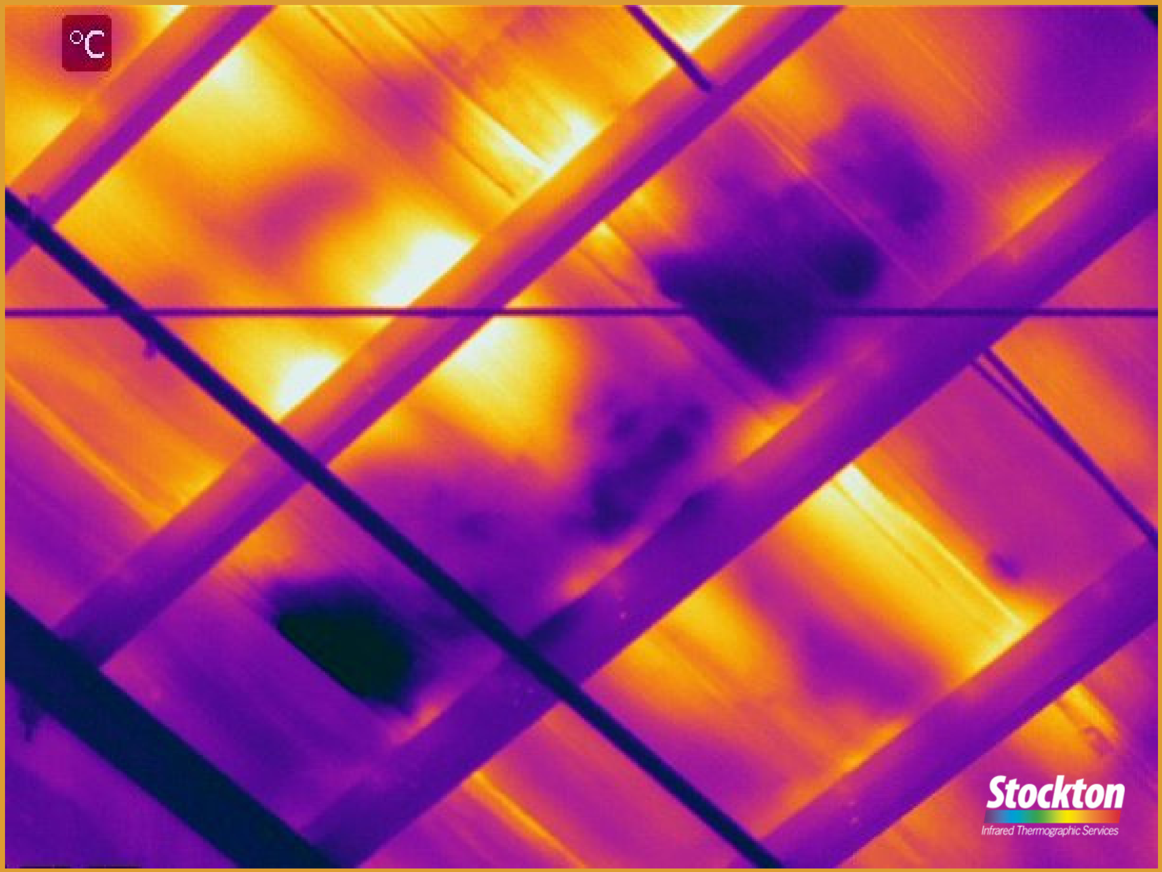


Solar Insolation

Wet substrates have higher mass and thermal conductivity, therefore higher specific heat capacity.



Solar Insolation



Under-Roof Moisture Surveying

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On-Roof Moisture Surveying

Areas of suspect subsurface moisture are marked directly on the roof.

On-Roof Moisture Surveying

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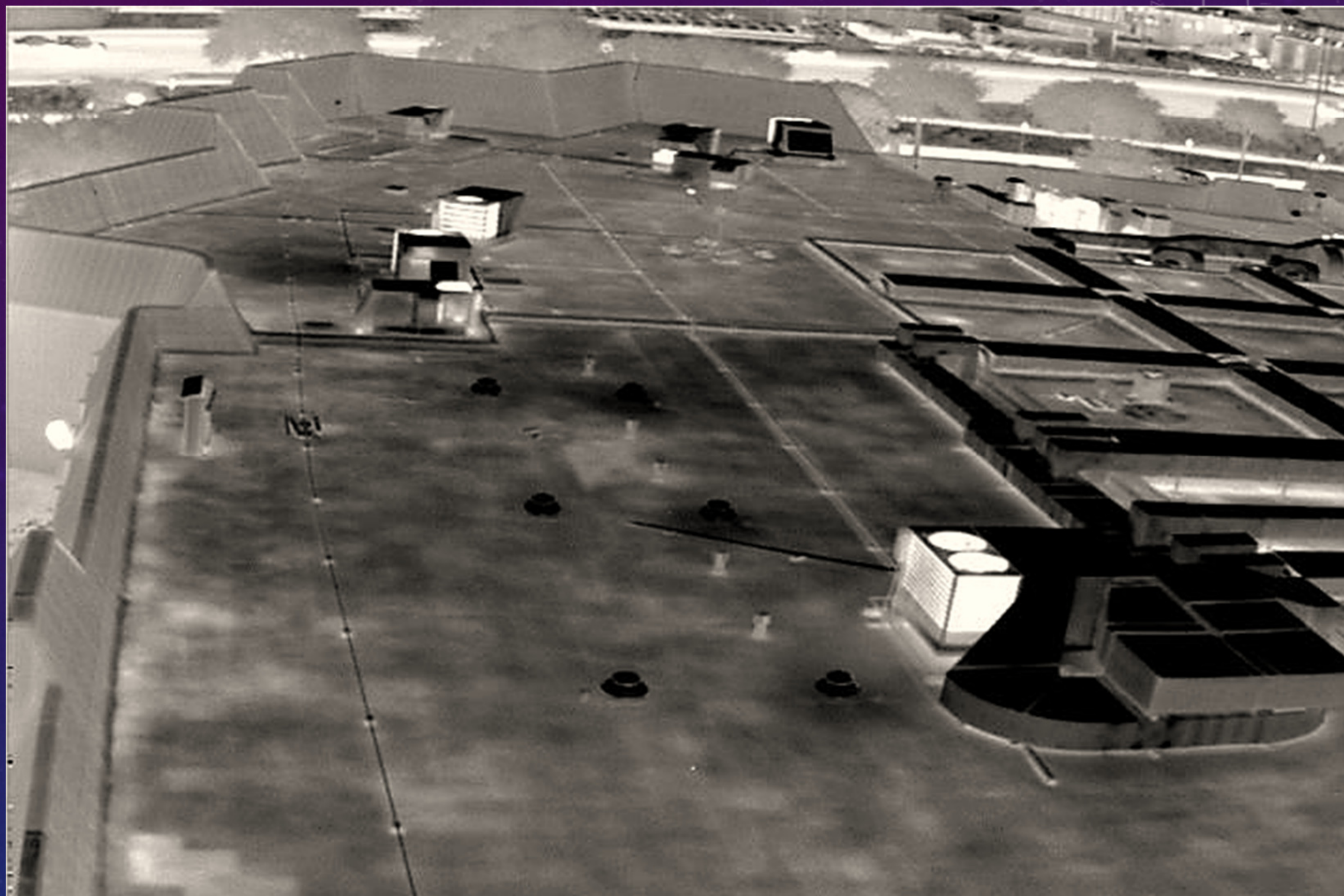

Elevated Roof Moisture Surveying

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Aerial Roof Moisture Surveying

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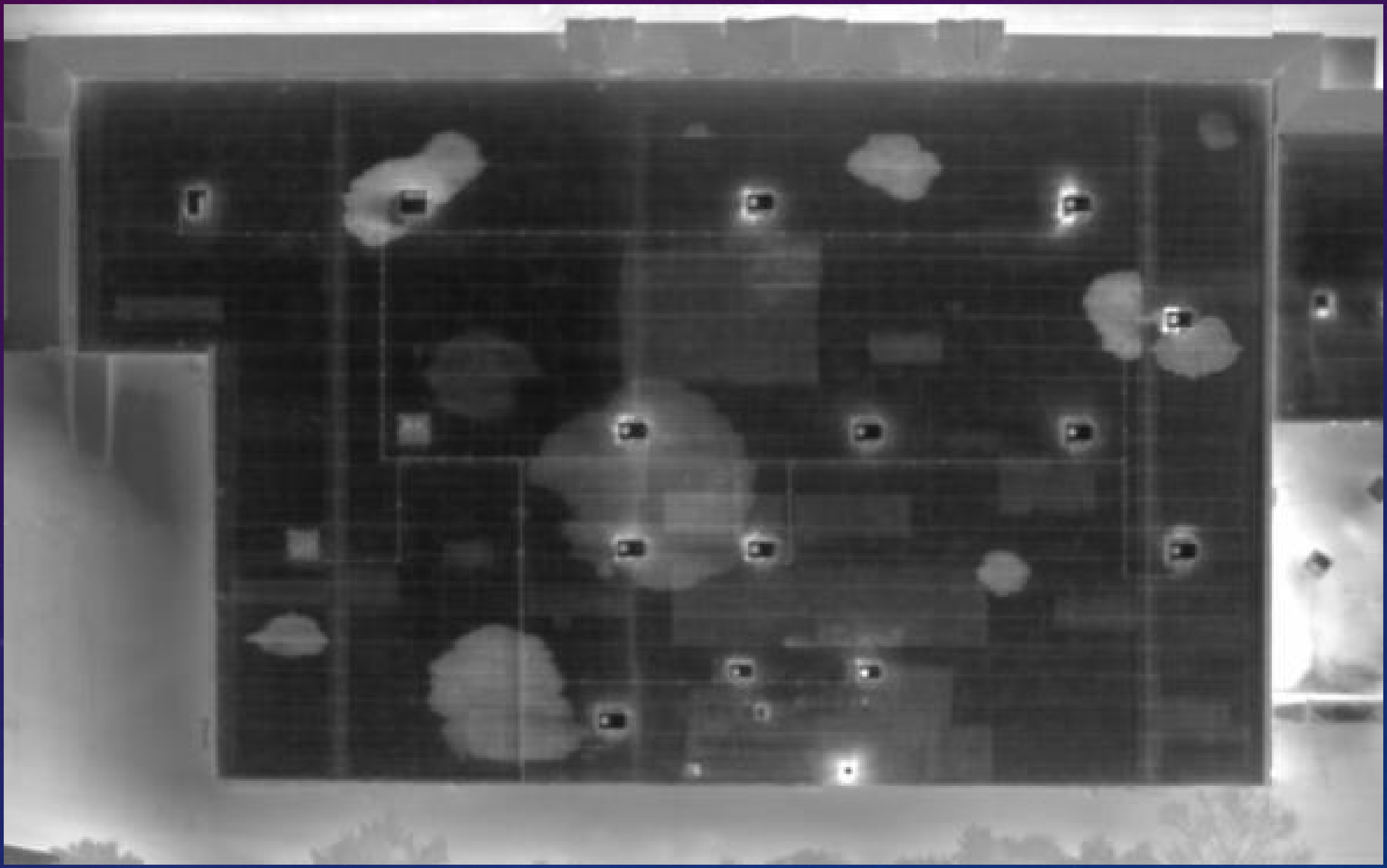

Aerial Roof Moisture Surveying

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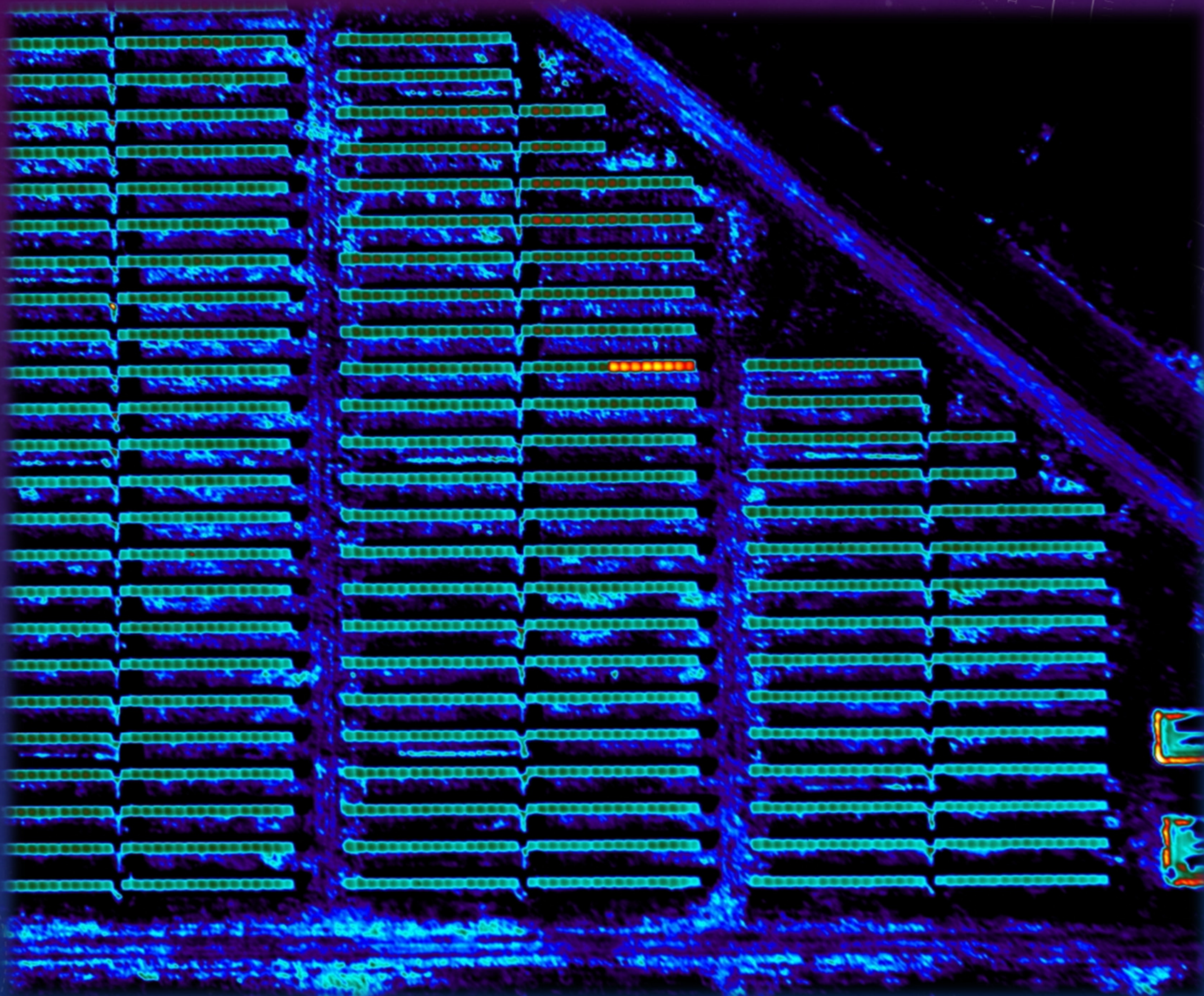


Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

Commissioning Solar Installations

Rooftop and Ground-Mounted

Factors Which Can Affect the Overall Performance and Efficiency Performance of PV Solar Plants

1. Missing solar panels; never installed or removed without being replaced.

2. Open strings of solar panels (open as result of multiple reasons including being electrically disconnected or resulting from electrical openings in the panels or the wiring that prevents continuity of current in the string).

3. Hot / cracked / damaged panels (significantly hotter than the operating temperature of the other panels in the solar plant, which may result from a variety of reasons including cracking of the panel, internal shunts which are shorting in the panel, and any other reason which is significant enough to prevent proper operation the panel yet still able to provide electrical continuity in the string of the panel).

4. Excessive heating of the panels closest to the ground (the lowest rank) as a result of a combination of (a) reflected solar irradiation and re-radiated solar heat from the ground reducing the differential temperature between the panels and the ground, and (b) variable airflow and environmental conditions associated with the lower ranks resulting in higher panel temperatures and lower PV panel operating efficiencies.

5. Non-uniform temperatures caused by a variety of factors including, but not limited to conduction and convection of the solar panels on a table which may cause meaningful variance in the output voltage from the panels on the table, and potential increase in the overall average operating temperature of the panels thus further reducing the efficiency of some of the panels.

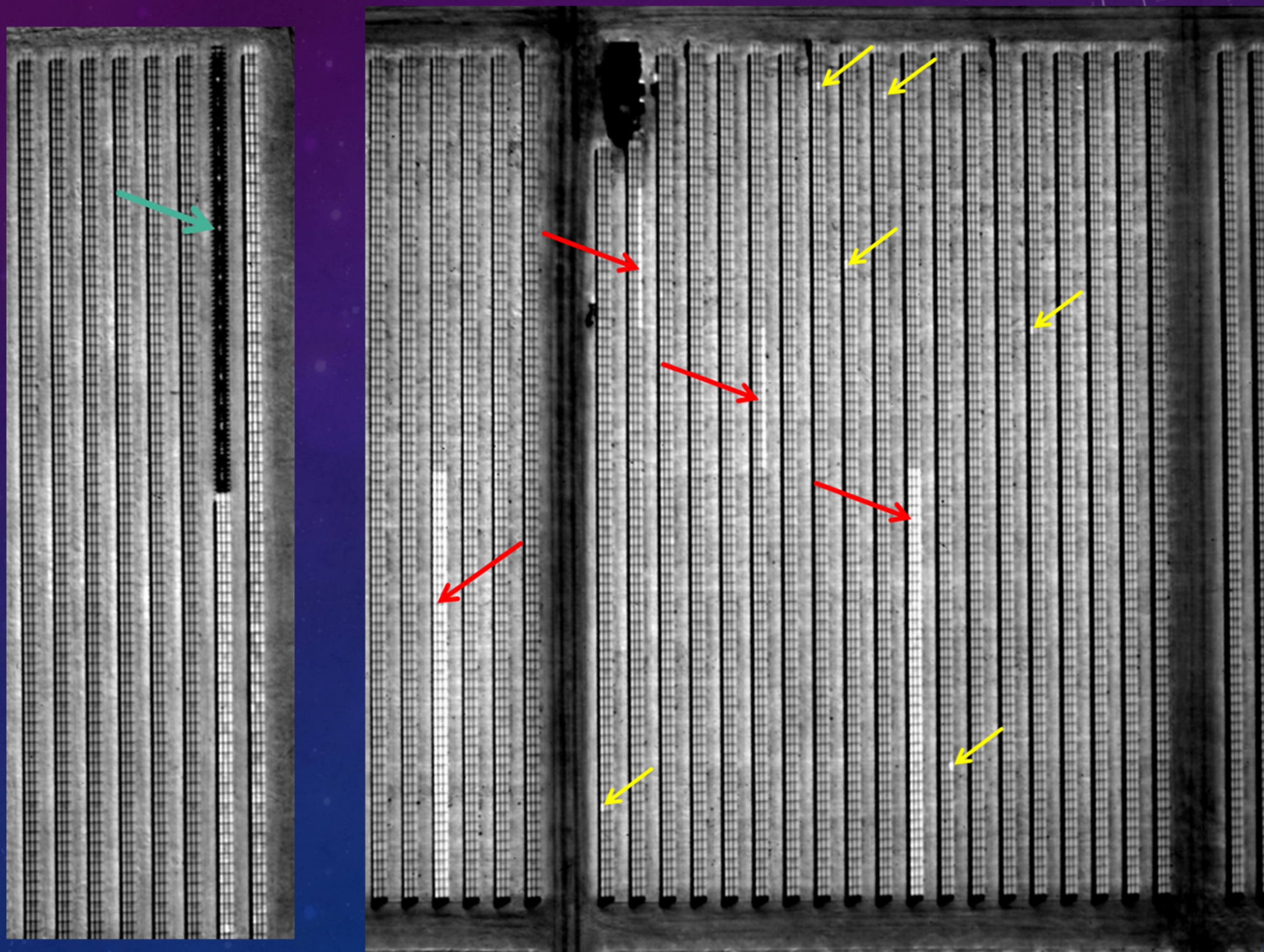
6. Variance in the output of the strings going to the combiners and the inverters, as well as variance in the operating temperature of the inverters which may cause operating efficiency variances among the combiner and inverter combinations of as much as 3% or more.

7. Varying amounts of moisture can reduce the operating efficiency of the solar panels.

8. Thermal and electrical effects of partial shading in monolithic thin-film photovoltaic modules.

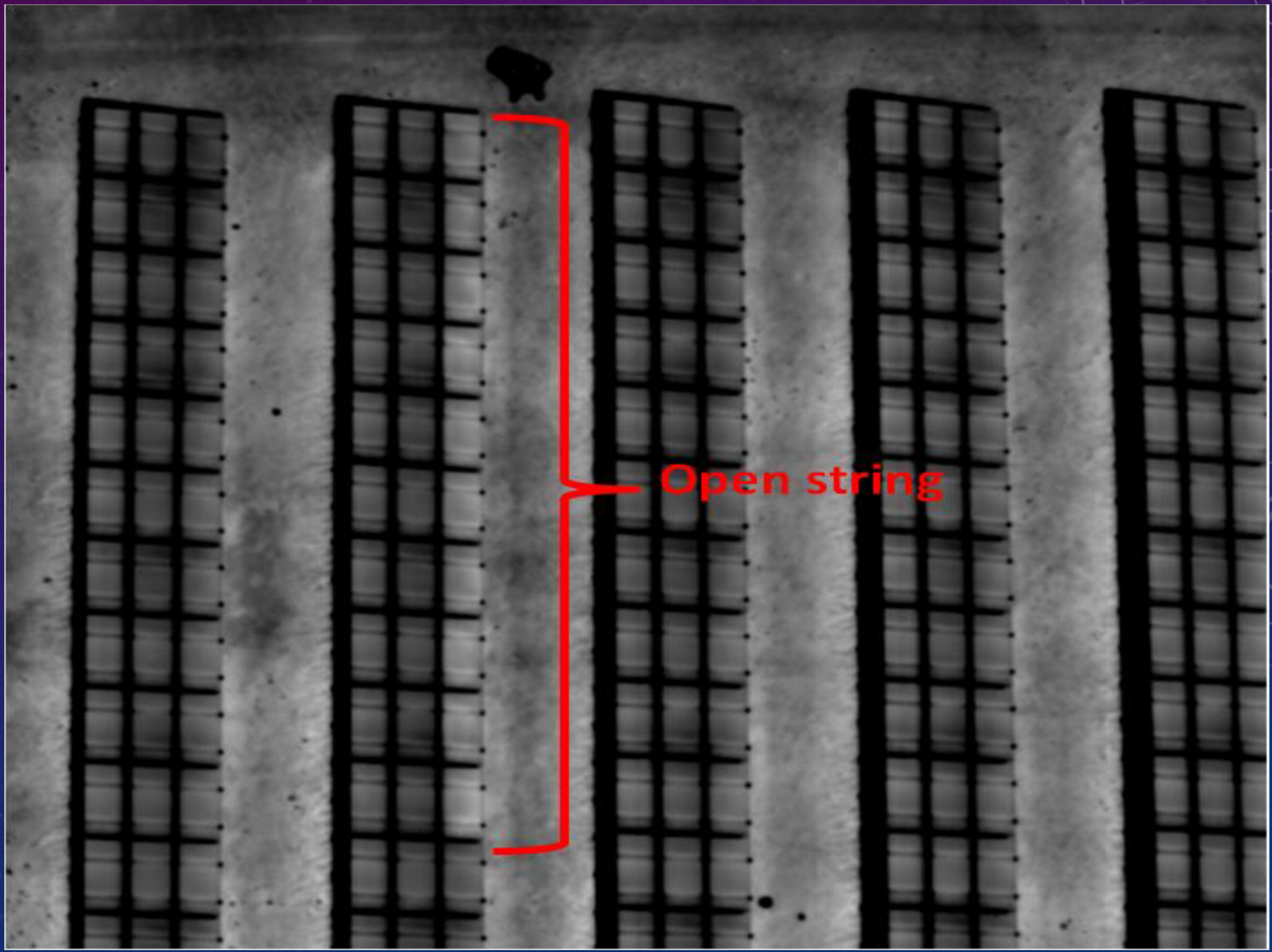
9. Less than optimal design of the solar plant layout may result in less-than-optimal convection and advection cooling and may even result in a localized "heat island" effect which can cause a portion of the solar plant to run hotter than it should and operate at lower operating efficiencies.

Missing Panels – Open Strings – Hot / Cracked Panels



Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

Open String



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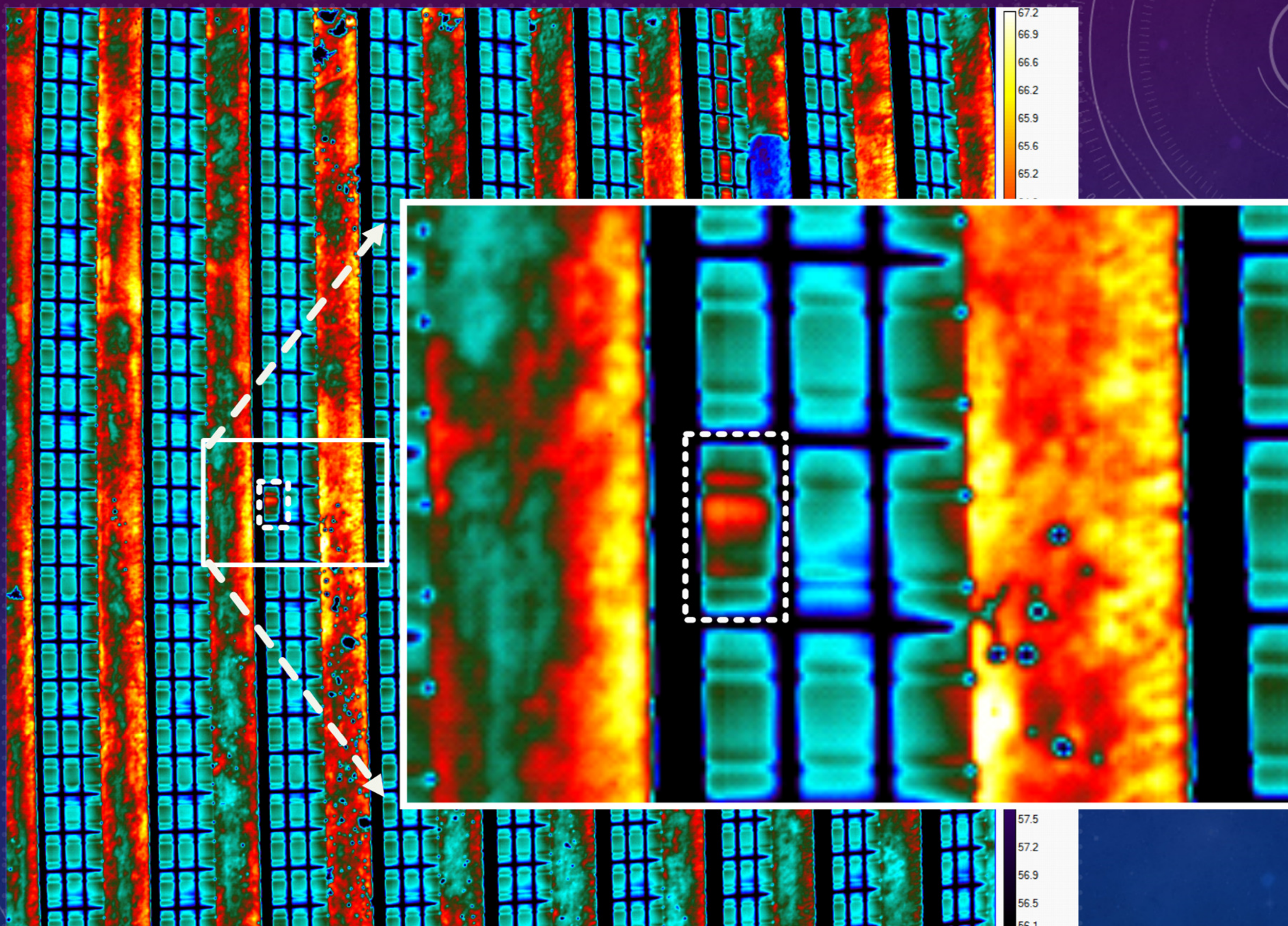
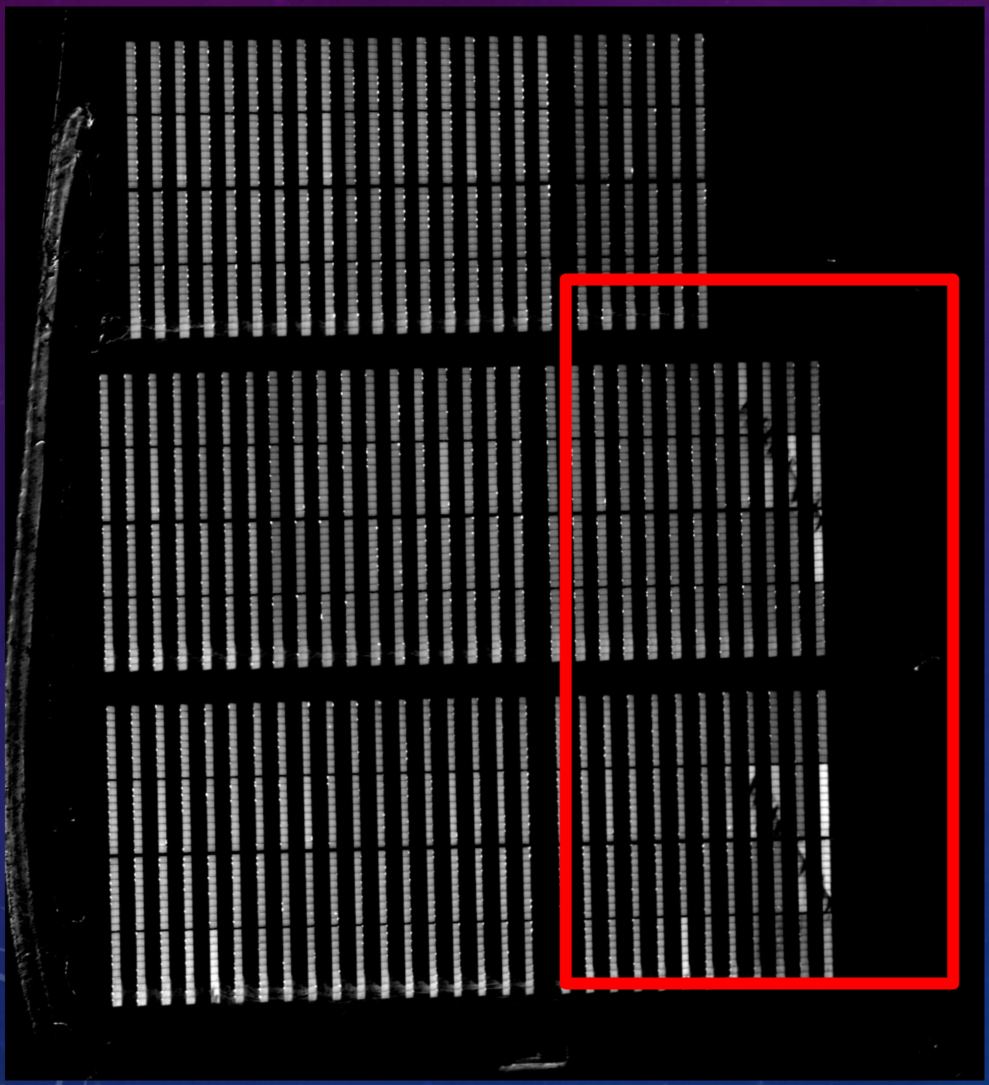
Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

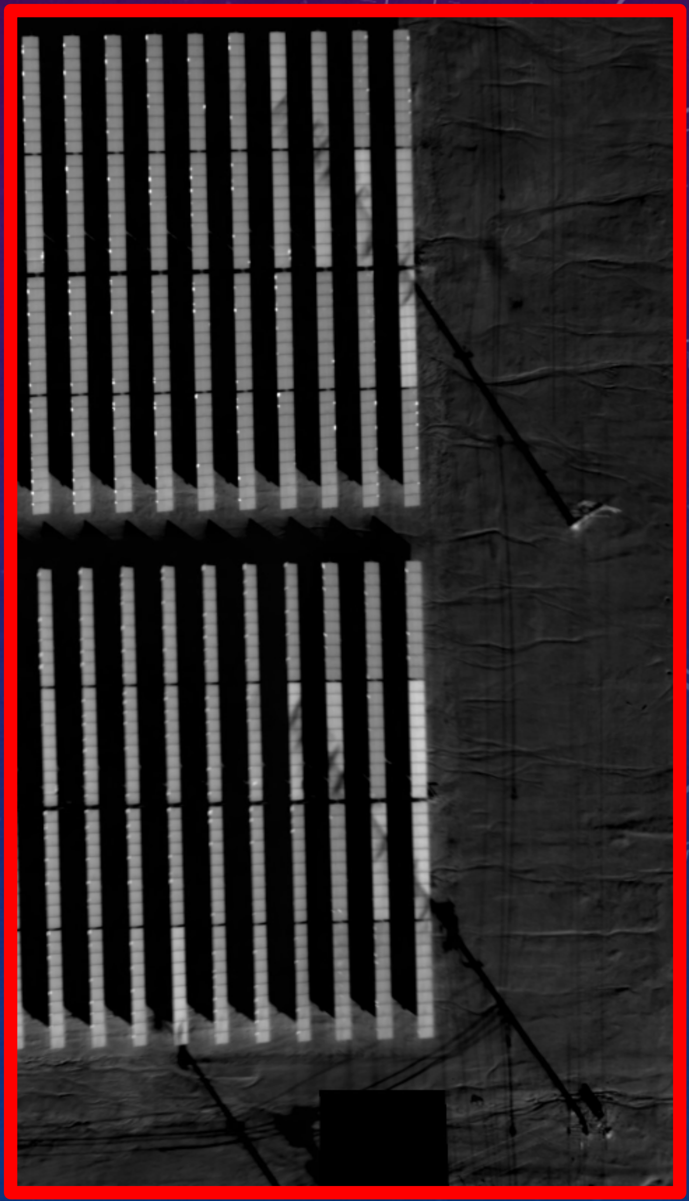


Hot / Cracked Panels

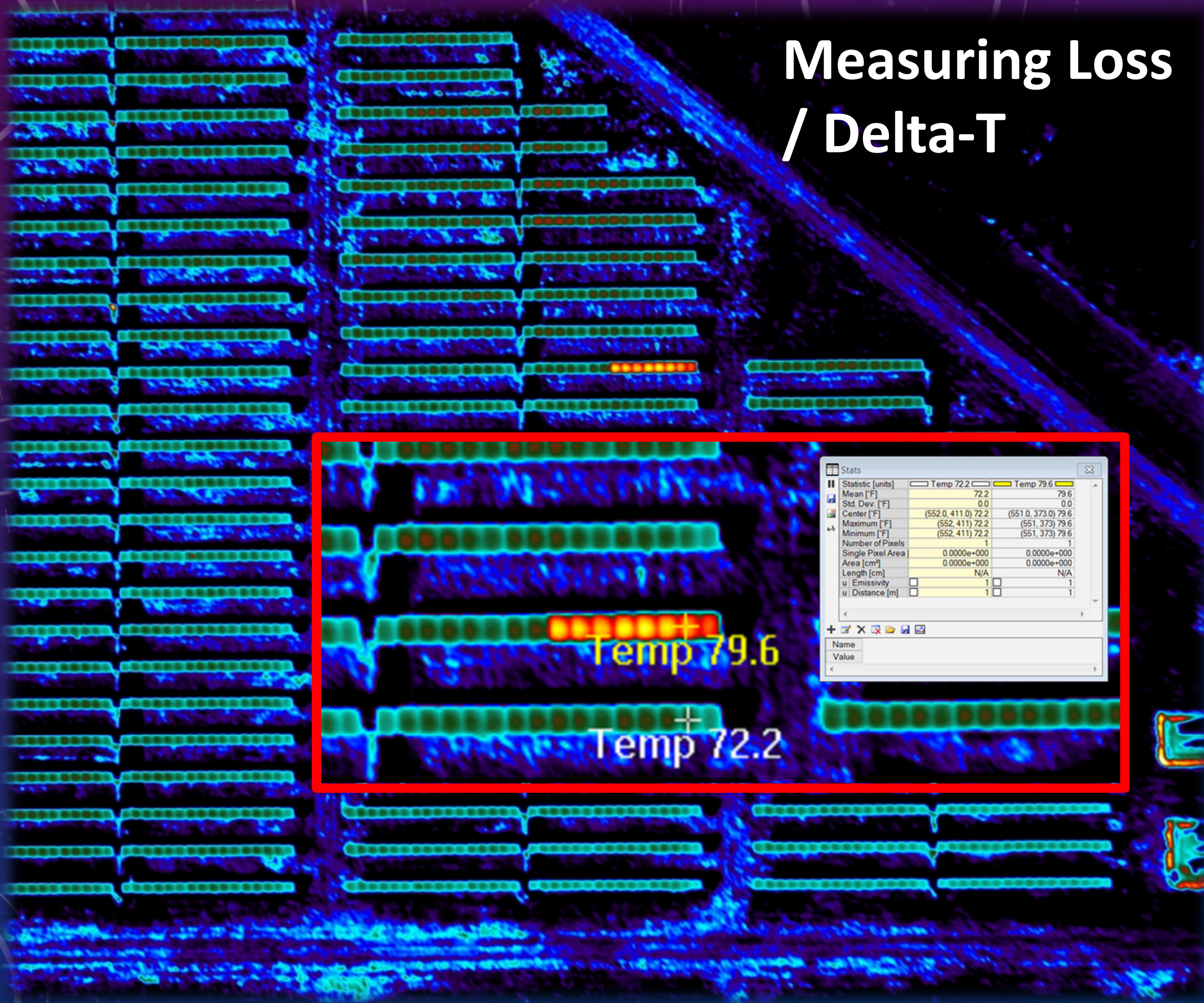
Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

Partial Shading





Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems



Statistic [units]	Temp 72.2	Temp 79.6
Mean [°F]	72.2	79.6
Std. Dev. [°F]	0.0	0.0
Center [°F]	(552.0, 411.0) 72.2	(551.0, 373.0) 79.6
Maximum [°F]	(552, 411) 72.2	(551, 373) 79.6
Minimum [°F]	(552, 411) 72.2	(551, 373) 79.6
Number of Pixels	1	1
Single Pixel Area	0.0000e+000	0.0000e+000
Area [cm²]	0.0000e+000	0.0000e+000
Length [cm]	N/A	N/A
u Emissivity	1	1
u Distance [m]	1	1

IDEA2021

Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

AITSCAN Thermal MapIR™

Rooftop Solar Installations

Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

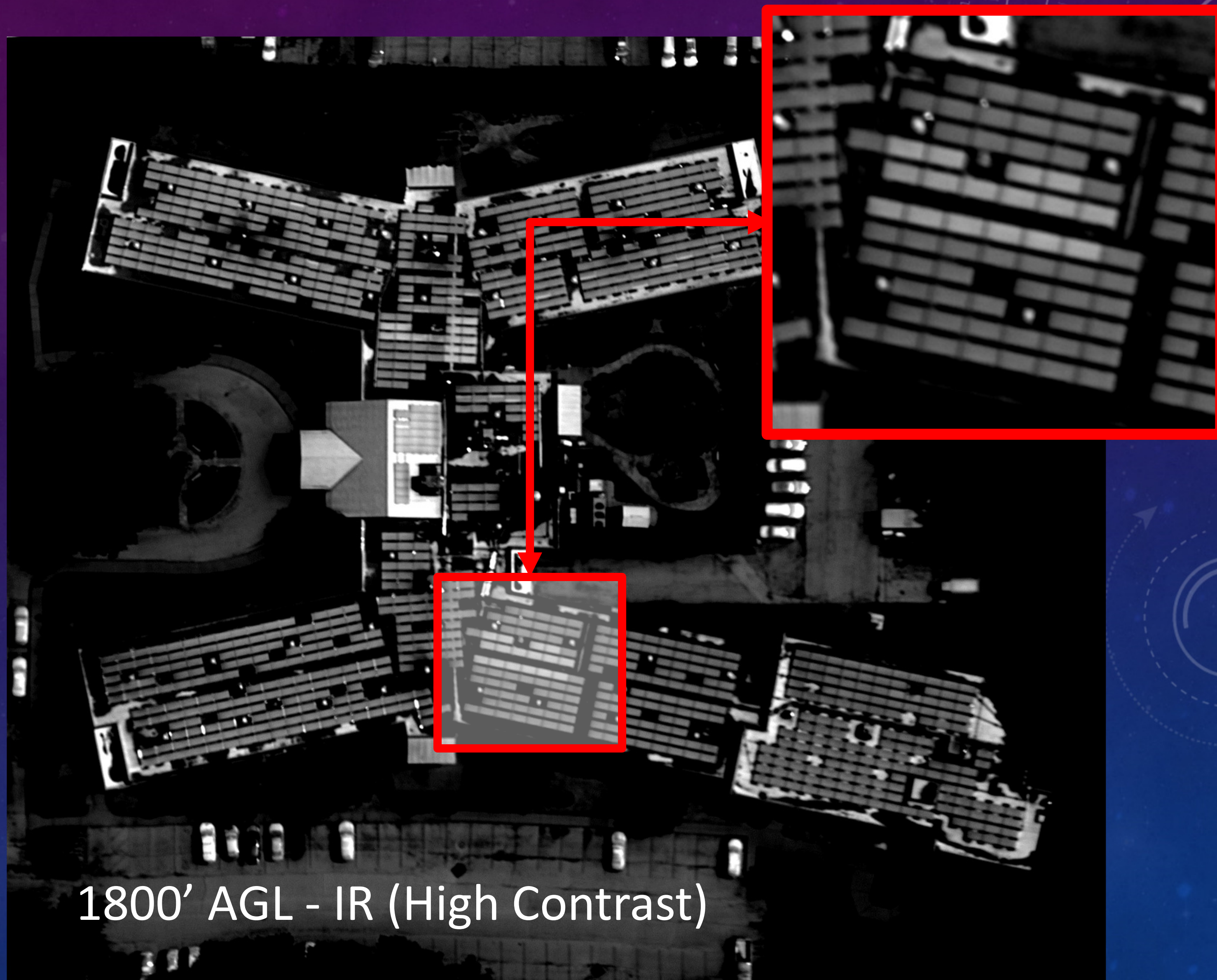
Rooftop Solar Installations

IDEA2021

Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

AITSCAN Thermal MapIR™

Rooftop Solar Installations



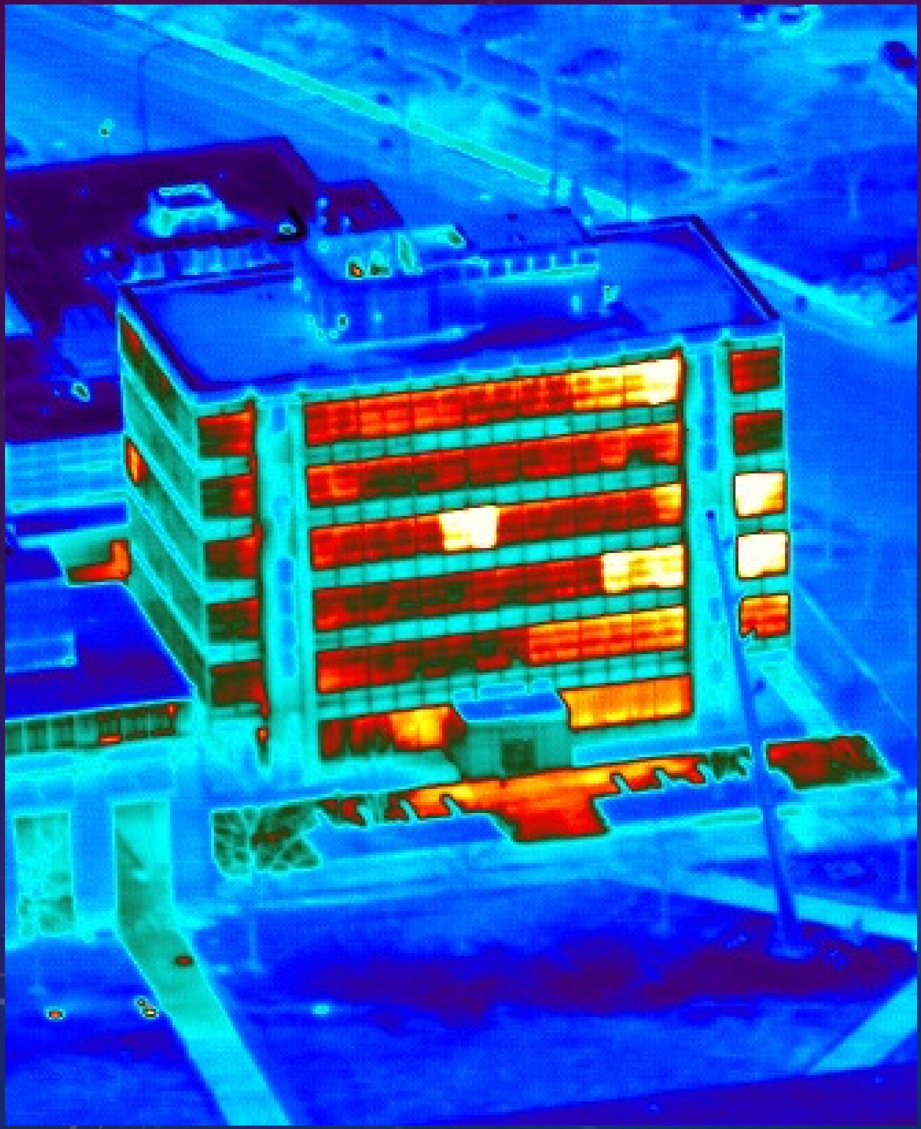
Heat Loss & Air Leakage from NADIR IR Imaging of Buildings

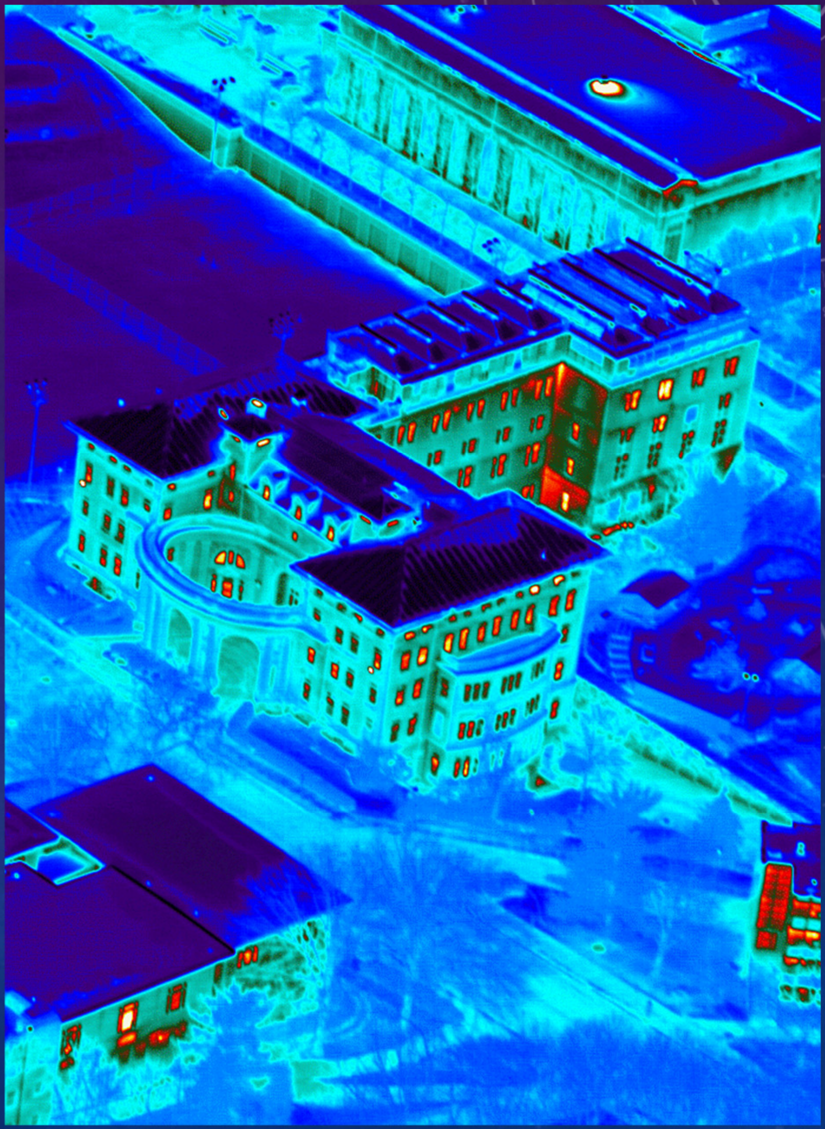
Hot Air Exhaust

Oblique IR Imaging Showing Building Heat Loss

Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

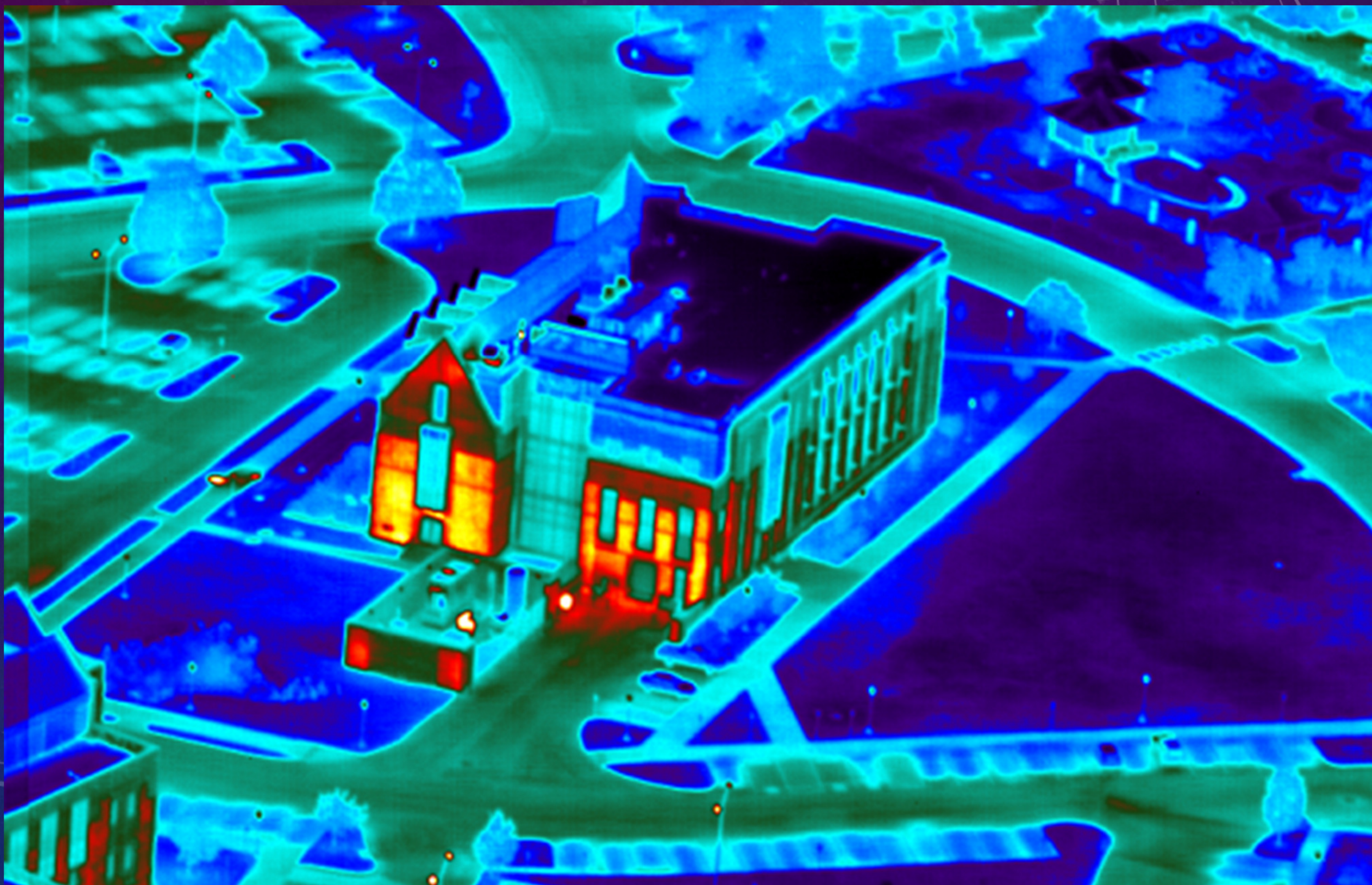
Oblique IR Imaging Showing Building Heat Loss





Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

Oblique IR Imaging Showing Building Heat Loss



Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

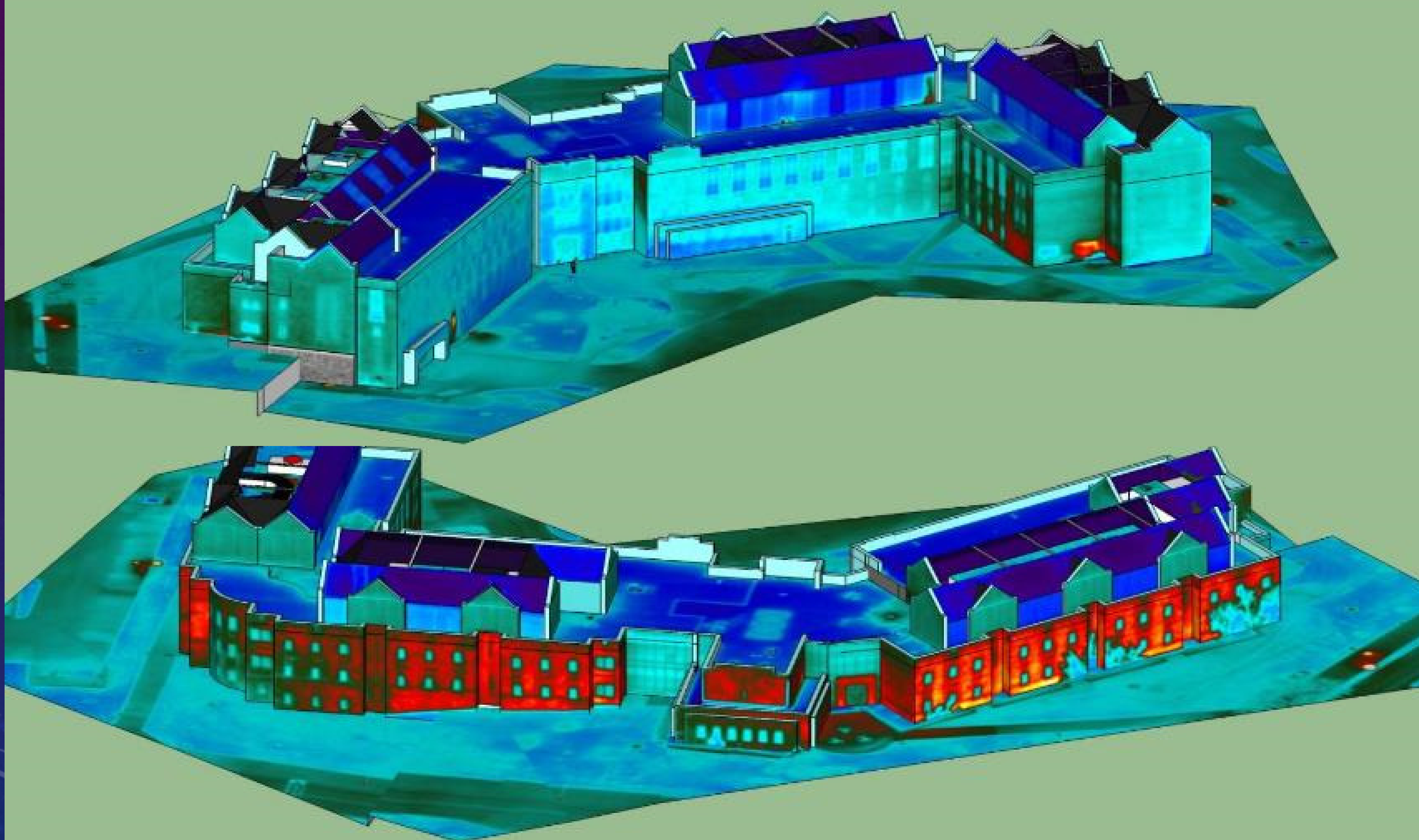
Oblique IR Imaging Showing High-Rise Building Heat Loss

Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

Oblique IR Imaging Showing High-Rise Building Heat Loss

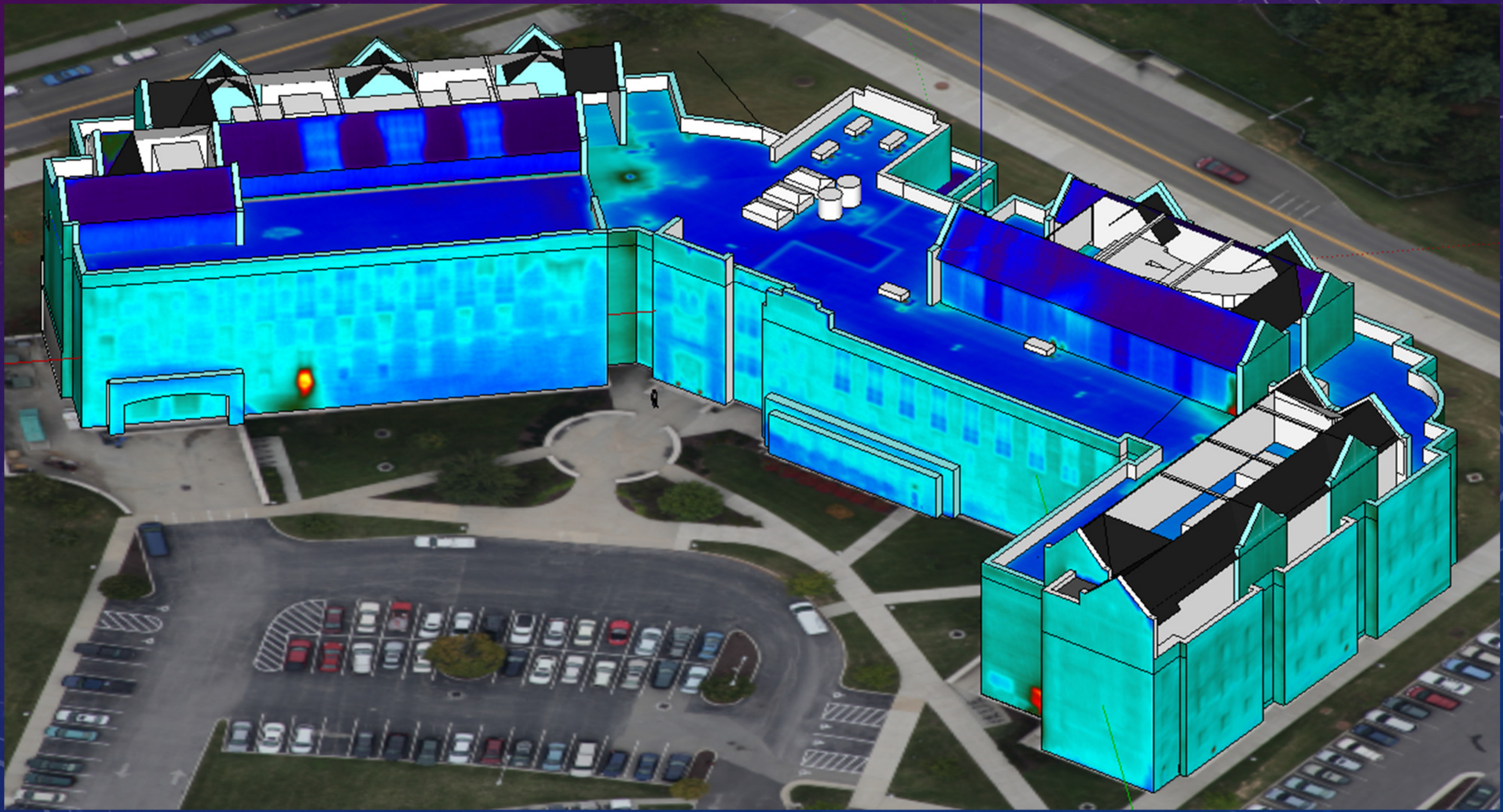
Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

NADIR & Oblique IR Imaging Required for 3D Imaging



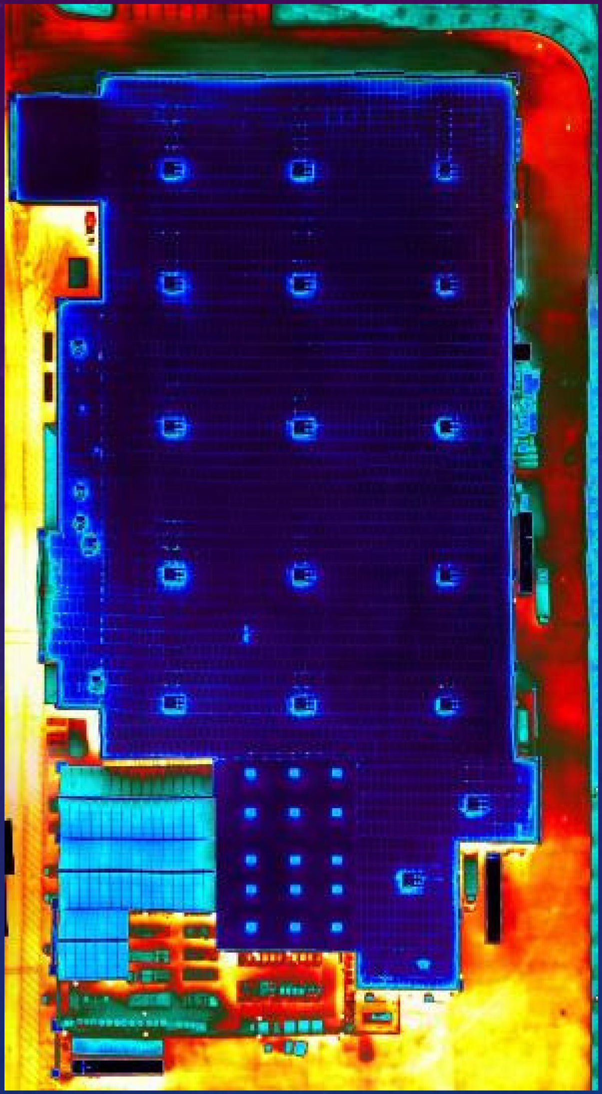
Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

NADIR & Oblique IR Imaging Required for 3D Imaging

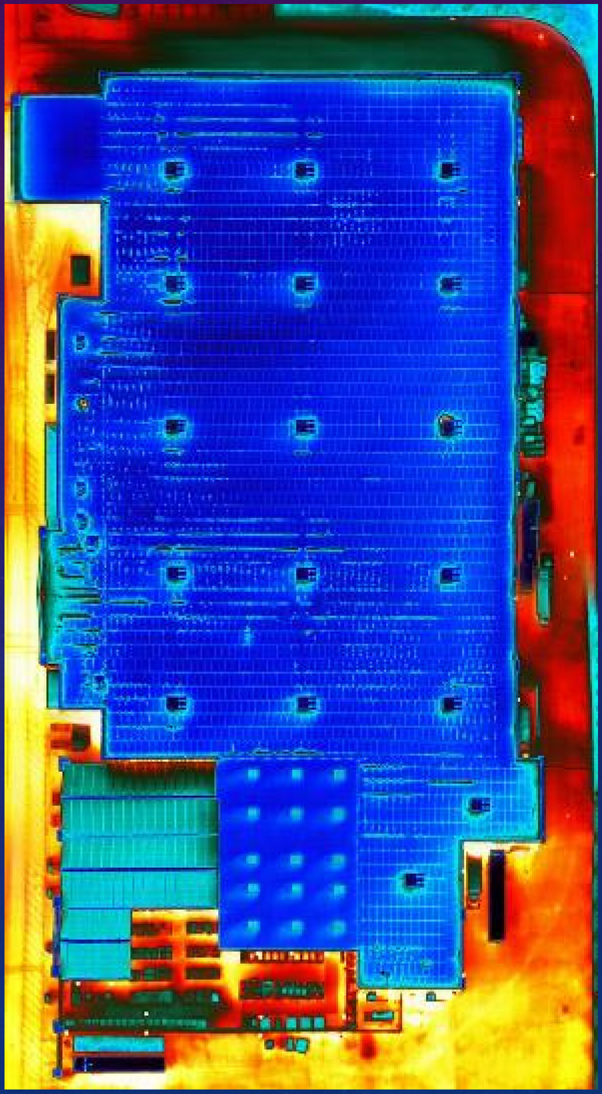


Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

Air Leakage Testing

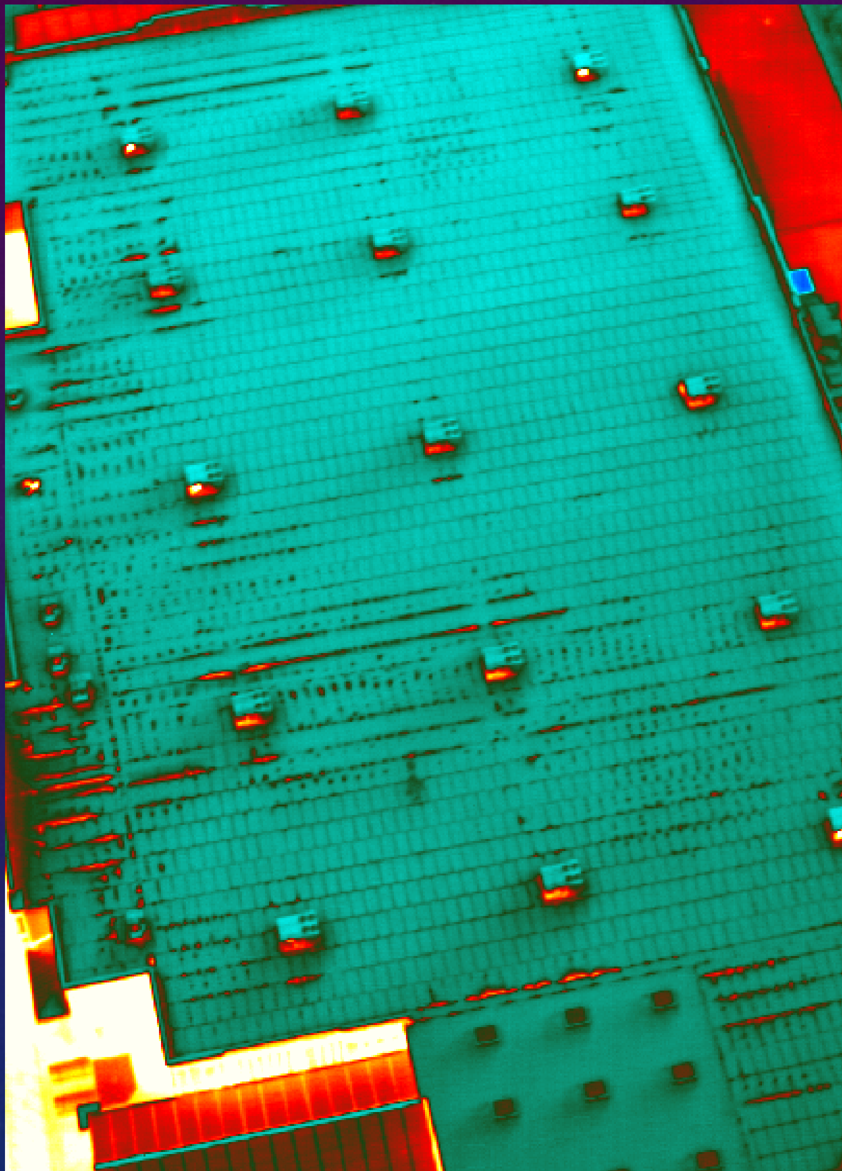


Before Pressurization



After Pressurization

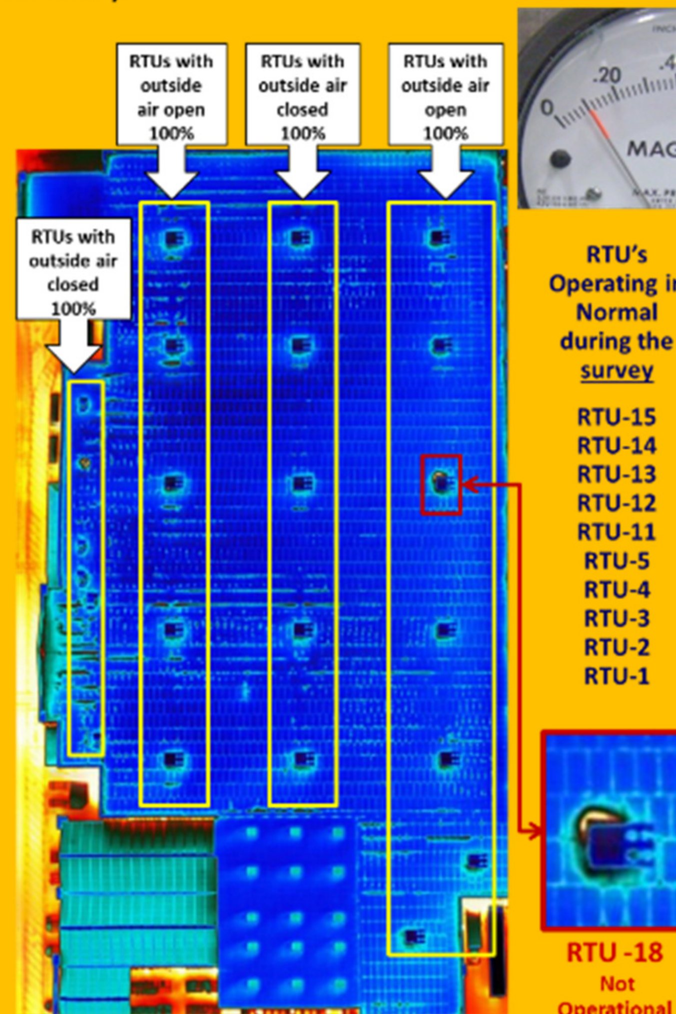
Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems



During the pressurization testing, ~50,000 CFM was supplied to the building with the procedure described in Reports 2. This raised the building pressure from normal (slightly negative) to .1 inches or ~25 Pascal).

RTU's Operating in Full Economizer during the <u>survey</u>

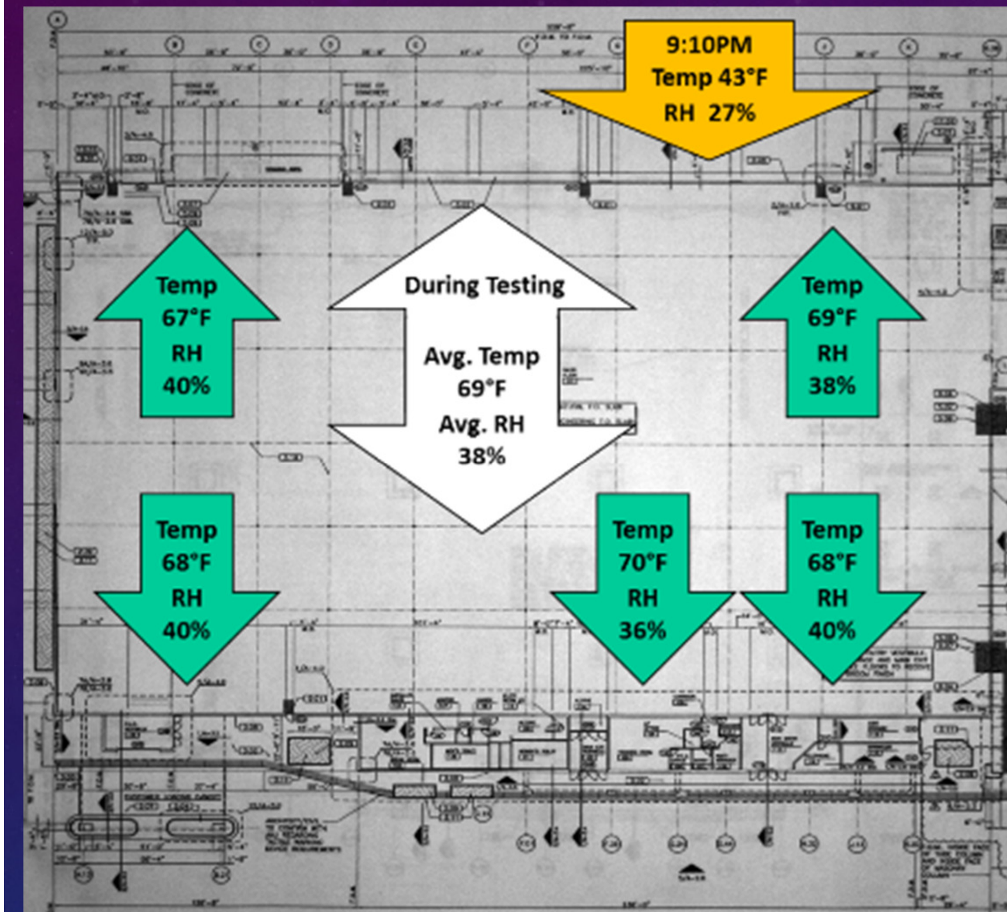
RTU-6
RTU-7
RTU-8
RTU-9
RTU-10
RTU-16
RTU-17
RTU-19
RTU-20
RTU-21
RTU-22

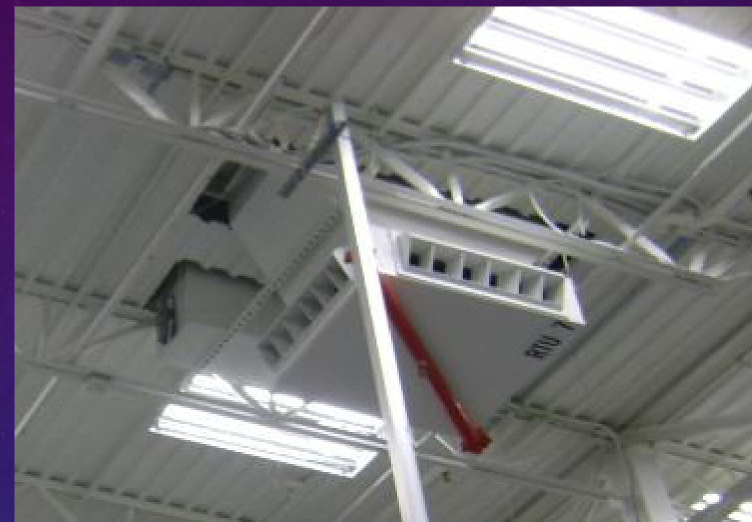


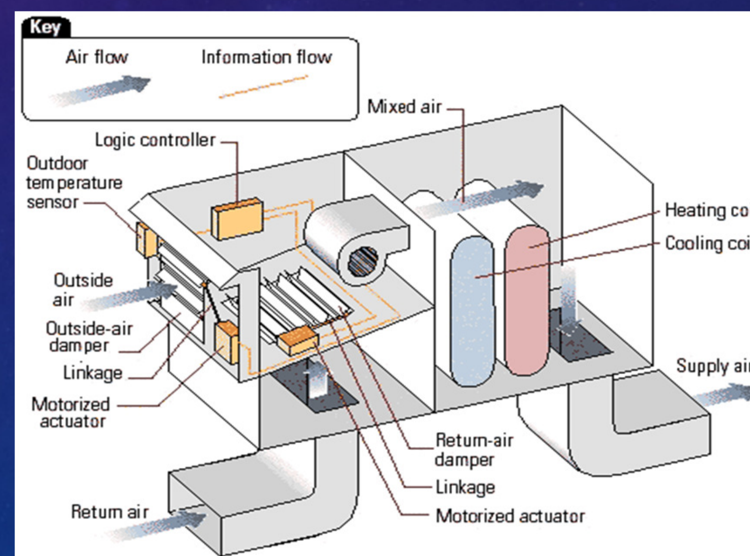
RTU's Operating in Normal during the <u>survey</u>

RTU-15
RTU-14
RTU-13
RTU-12
RTU-11
RTU-5
RTU-4
RTU-3
RTU-2
RTU-1

Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

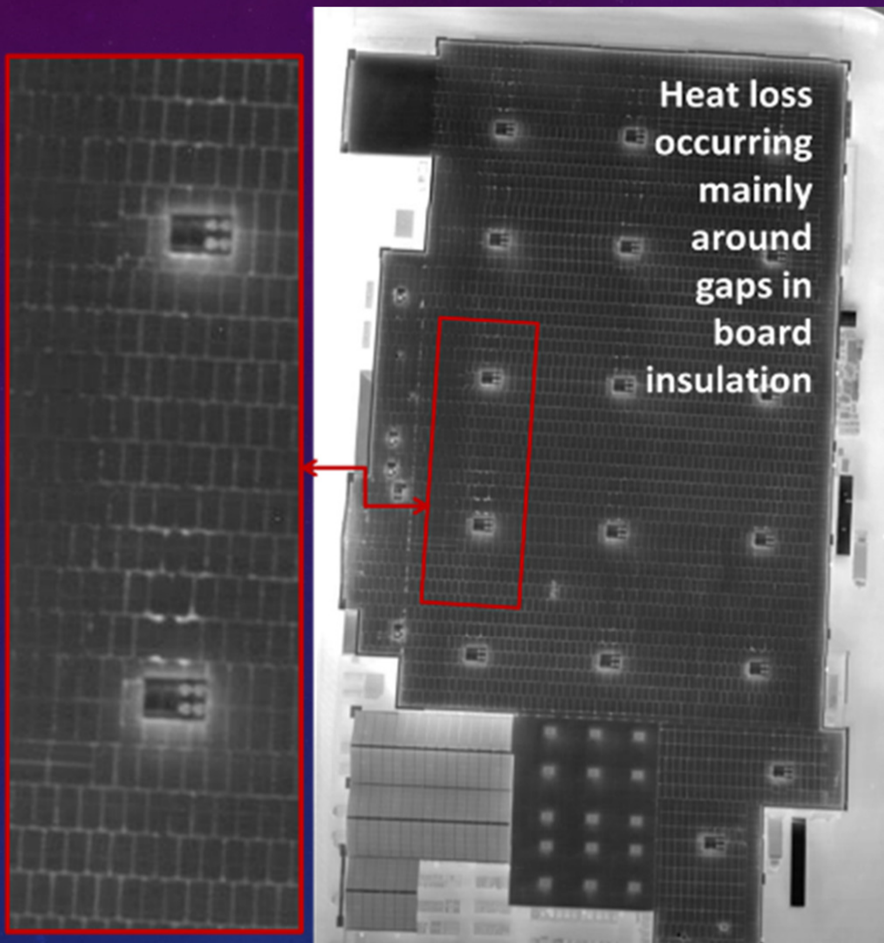




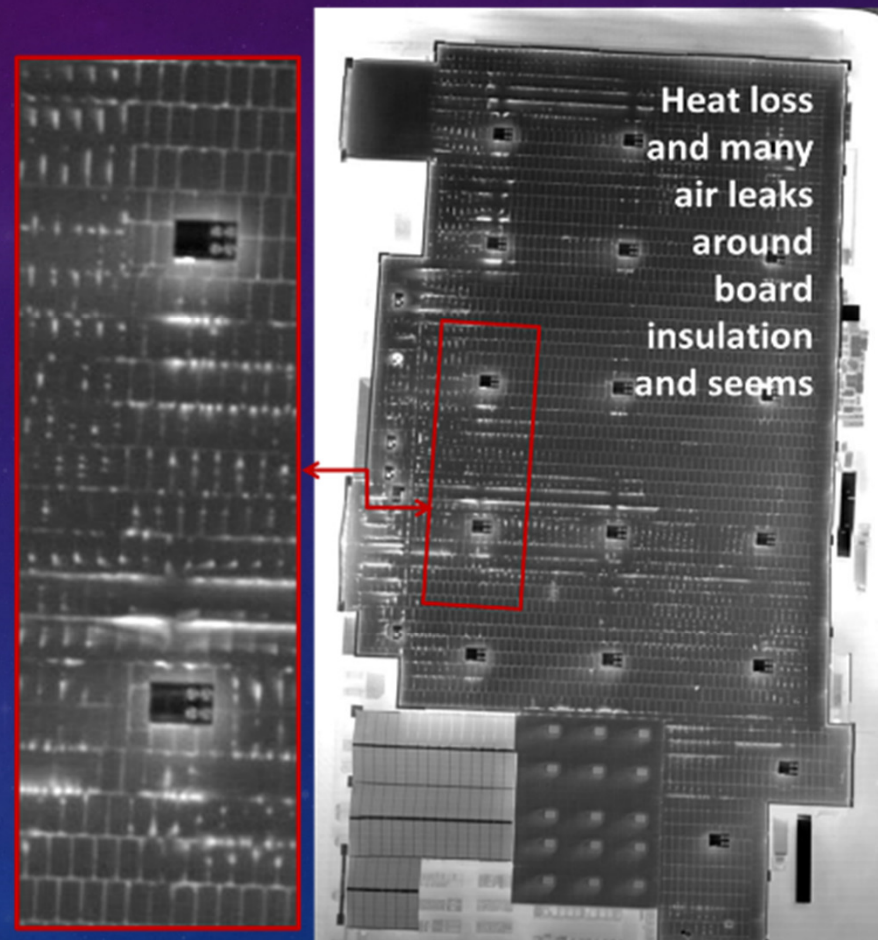


Using Aerial Thermal IR Imaging to Monitor

Underground Piping in District Heating and Cooling Systems



Before Pressurization



After Pressurization

Other Uses for Thermal Mapping

Previously Discussed

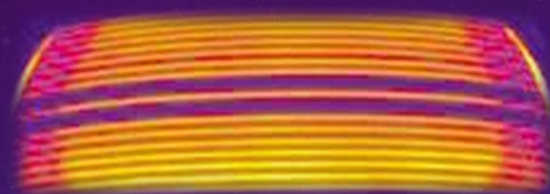
- Steam / HTHW / CWS
- Liquid Leaks
- Roof Moisture Surveys
- Solar Field Commissioning
- Heat Loss & Air leakage from Buildings

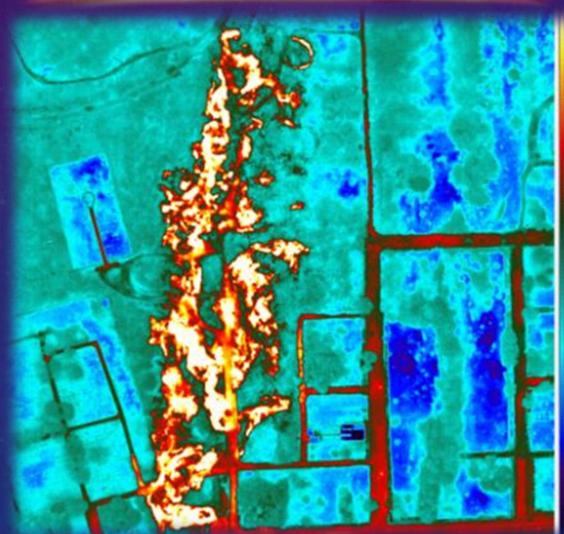
Not Discussed

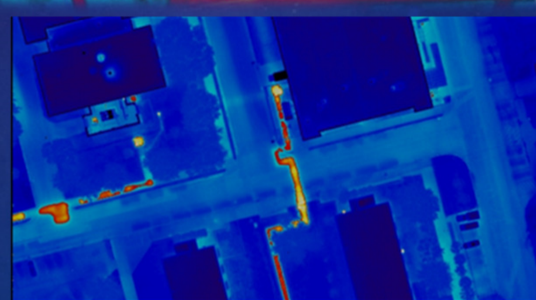
- Waterway Pollution
- High Voltage Transmission Lines
- Forest Fires
- Subsurface Fires
- Structural Fires
- Geothermal
- Pipes and Pipelines
- Animal Census
- Search and Rescue (SAR)

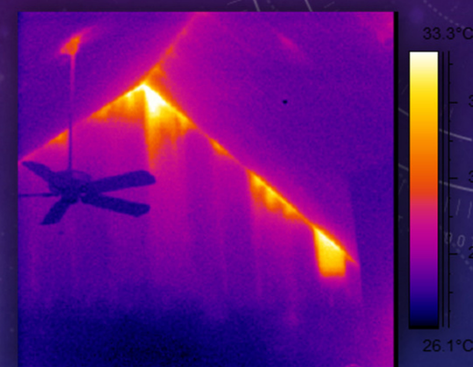
Using Aerial Thermal IR Imaging to Monitor
Underground Piping in District Heating and Cooling Systems

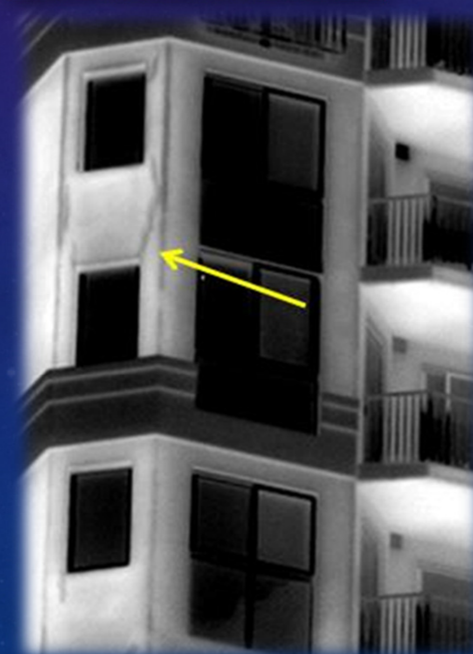
Infrared Applications Everywhere!











About the Presenter

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Gregory R. Stockton, M. CIT

President of Stockton Infrared Thermographic Services, Inc., United Infrared, Inc., and Thermal Imaging Partners, Inc.

Greg has been a practicing infrared thermographer since 1989 and is a Level III Certified Infrared Thermographer with thirty years of experience in infrared thermography, specializing in construction testing, maintenance and energy-related technologies.

Mr. Stockton has published more than 30 technical papers on the subject of IR thermography and has written numerous articles about applications for infrared thermography in trade publications. He is a member of the Program Committee of Thermosense at the Society of Photo-Optical Instrumentation Engineers' (SPIE) Defense and Security Symposium, is a past Chairman of Thermosense, and current Chairman of the Buildings & Infrastructures Session.

Mr. Stockton is also the Chairman of Thermal Imaging Conference, which is the annual user's conference of United Infrared.