DRONES4VET

Co-funded by the European Union

MODULE 08

TRAINING PROGRAMME

THERMOGRAPHY

Comunidad de Madrid | Dirección General de Formación CONSEJERÍA DE ECONOMÍA, HACIENDA Y EMPLEO

DEX Desarrollo de Estrategias Exteriores

CAMPUS DES MÉTIERS ET DES QUALIFICATIONS D'EXCELLENCE

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

BZB Bildungszentren des Baugewerbes e.V.

fh Kufstein Tirol UNIVERSITY OF APPLIED SCIENCES

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1. Objectives of the module

This module allows you to understand the thermographic analysis with drones. The objectives for thermography with drones include identifying anomalies, assessing conditions, improving energy efficiency, and monitoring the environment. These applications offer a non-intrusive, cost-effective, and efficient means of capturing thermal data from aerial perspectives.

Desired skills

- Description of the parts of the building exposed to thermal effect
  - Envelope: Facades and roofs
  - Pipelines of the technical building equipment
  - Solar system / Photovoltaic
- Identification of weak points that influence the thermal / energy behaviour of the building,
  - Envelope
  - Air tightness check
  - Wall humidity
  - Solar system / Photovoltaic
- Analysis of thermographic images
- Equipment / Hardware
  - UAS
  - Cameras
- Camera configuration
  - Software
- Preparation of the documentation / reports

2. Thermography

Thermography is a non-contact imaging technique that uses infrared radiation to create visual representations of temperature variations on the surface of an object or a living organism. It is based on the principle that all objects emit infrared radiation as a function of their temperature.

In thermography, a special camera called a thermal imager or infrared camera is used to capture the infrared radiation emitted by objects. The camera detects and measures the intensity of the infrared radiation, and then converts it into a visual image where different colors or shades represent different temperatures.

Thermography provides a non-invasive and non-destructive way of visualizing temperature differences, which can be useful in a wide range of applications. However, it is important to note that thermography is a diagnostic tool and should not be solely relied upon for definitive diagnoses. It is often used in conjunction with other diagnostic methods to provide a more comprehensive assessment.

Drones can be used for thermography by equipping them with special thermal imaging cameras. These cameras detect the thermal radiation emitted by objects and can use it to create images of the surface temperature of buildings and other objects. The pilot of the drone then steers it in the desired direction and activates the thermal imaging camera. The drone then flies around the areas of interest and captures thermal images. These are then transmitted to a computer where they can be analyzed by experts.

Thermal image analysis can be used, for example, to identify damage or defects in buildings that are not visible to the naked eye. It can also be used to check the energy efficiency of buildings and identify any weak points.

2.1 Use cases in the construction sector

Drone-based thermography offers several advantages over traditional methods of conducting thermal inspections, such as improved accessibility, efficiency, and safety.

Lack of insulation and air leaks

Thermal imaging is a simple method for detecting building deficiencies, such as lack of insulation, plaster peeling, and condensation.

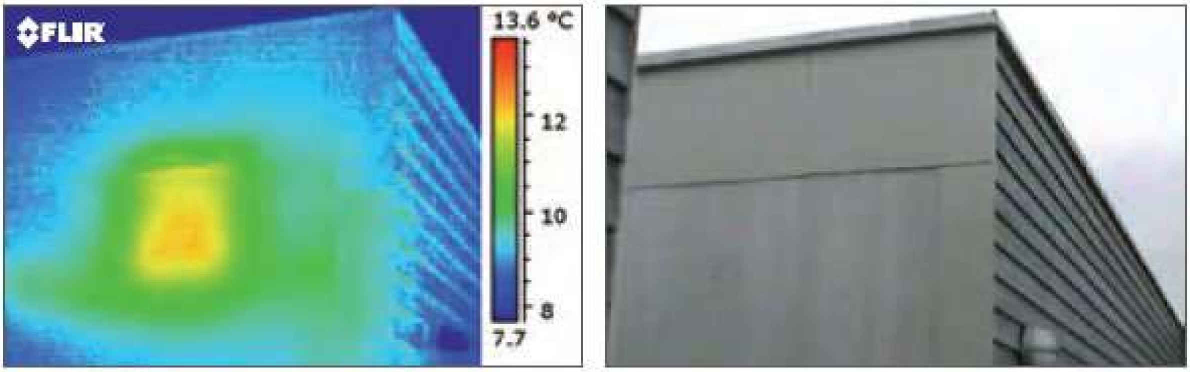


Figure 2-1: Missing insulation in the facade (FLIR Systems)

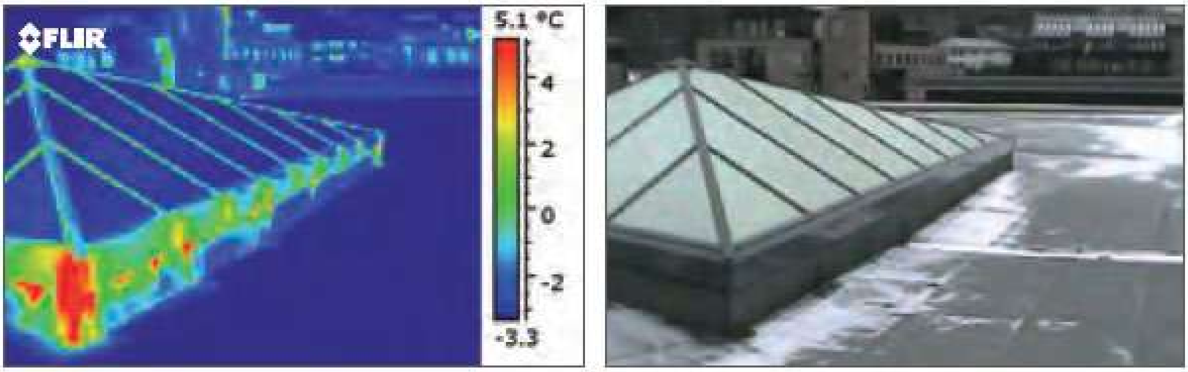


Figure 2-2: Glass roof with warm air escape (FLIR Systems)

When using a thermal imaging camera to look for faulty insulation or energy losses, there should ideally be at least 10 °C between the outside and inside temperatures. When using a thermal imaging camera with a high image resolution and high thermal sensitivity, the temperature difference can also be smaller.

In cold climates, building inspections are often performed in the winter. In warmer climates, where it is important to check insulation to ensure that the cool air produced by ventilation or air conditioning stays in the building, the summer months are ideal for this type of inspection.

Thermal bridges

Another application is, for example, the localization of thermal bridges, which indicate places in a building where energy is wasted. A thermal bridge is a zone where the building envelope has a lower thermal resistance. This is caused by construction-related defects or old buildings. Heat follows the easiest path from the heated area to the outside, the path of least resistance.

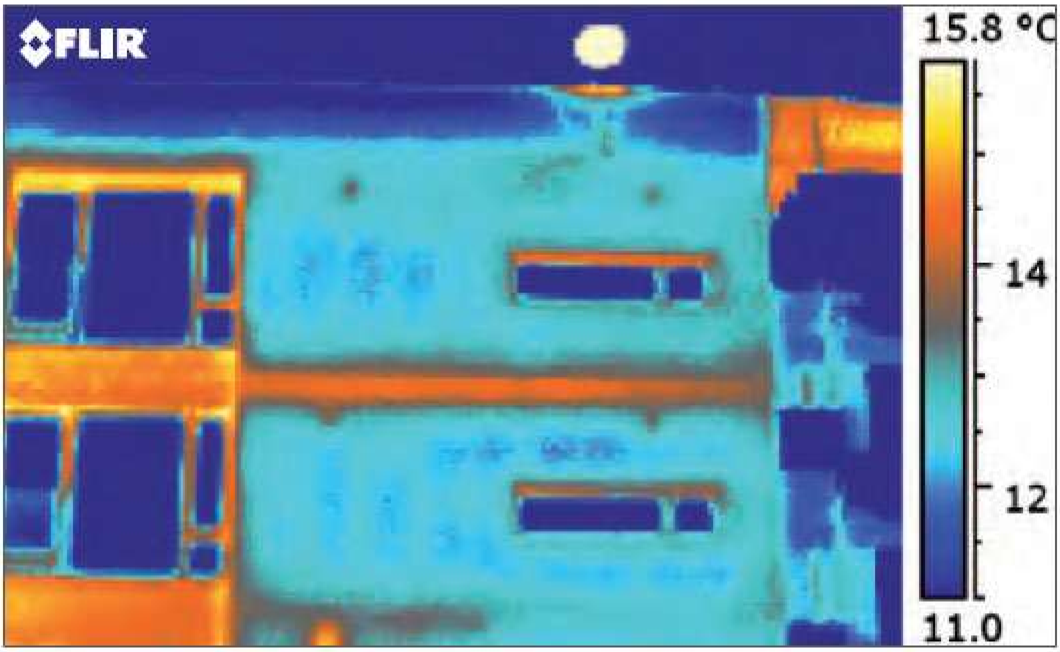


Figure 2-3: Thermal bridge at the ceiling (FLIR Systems)

Localization of underfloor heating systems

Thermal imaging is an easy-to-use technique for locating pipes and tubes and checking for leaks, even when the water pipes are in the floor or under plaster. The heat from the pipes radiates through the surface, making it easy to see the temperature pattern with a thermal imaging camera.

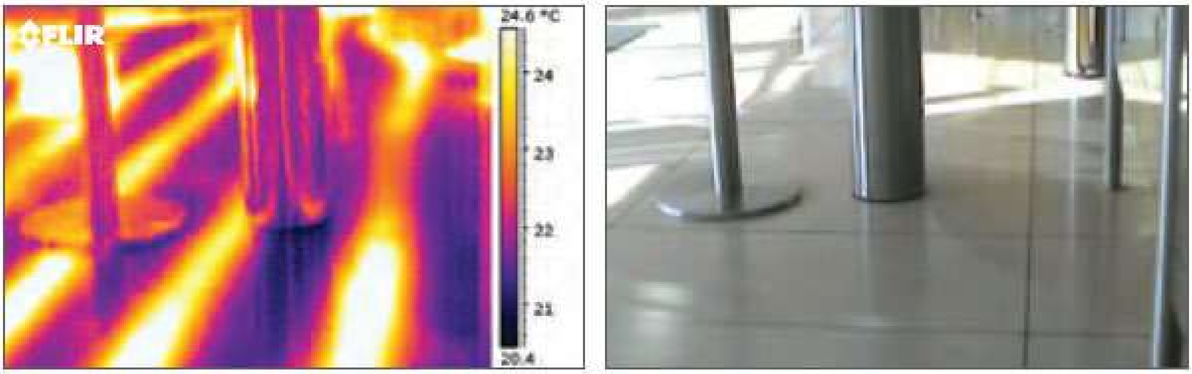


Figure 2-4: Localization of the heating system (FLIR Systems)

Locating water in flat roofs

Thermal imaging is also used to find leaks in flat roofs. Water retains heat longer than the rest of the roofing material and can be easily detected with a thermal imaging camera in the late evening or at night, after the rest of the roof has cooled.

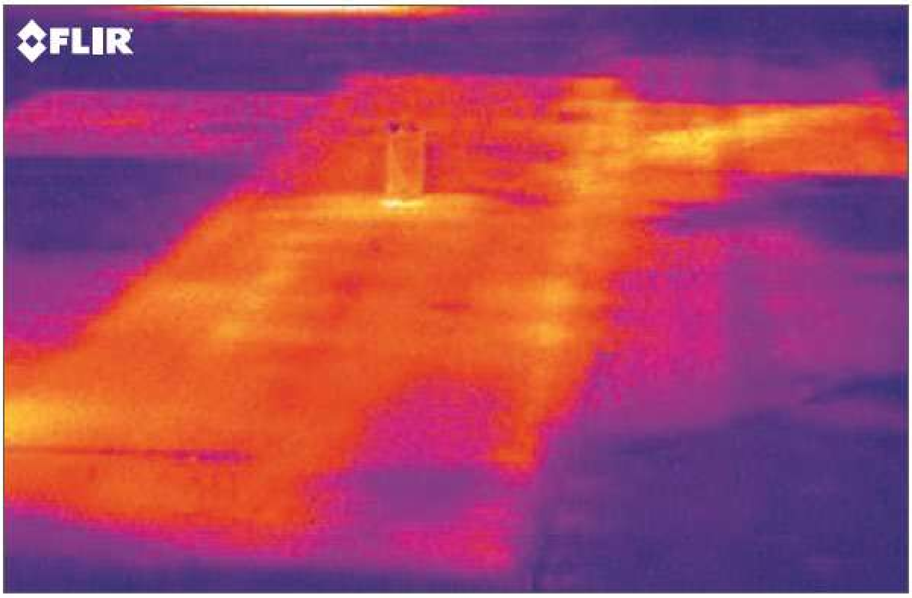


Figure 2-5: Location water in flat roof (FLIR Systems)

Power lines inspection

Electricity passing through a conductor with an insufficient cross-sectional area causes overheating. Thermography can be used in power lines to check for faulty contacts or insufficient cable cross-sectional areas. Examples of defects that can be spotted:

- faulty contactors,
- incorrect tightening of an electrical terminal block,
- Overvoltage or over-current in cables with insufficient cross-section,
- reduced conductor cross-section due to corrosion or friction,
- ...

The drone provides a safe, close-up view of the phenomenon.

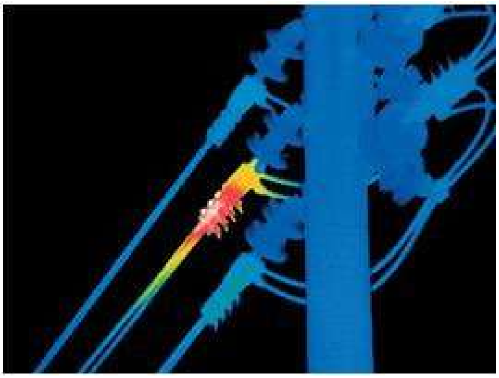


Figure 2-6 Detected increased heat on a faulty powerline

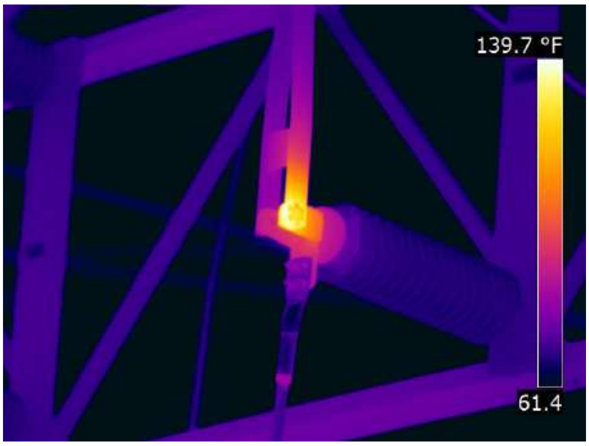


Figure 2-7 Detected increased heat in a faulty contact area

Humidity of civil engineering structures

Moisture in bridges, dams or retaining walls (or buildings) is a factor in concrete pathologies, steel corrosion or even wood rot. All structures are likely to be affected by persistent moisture, even in a dry weather. Analysis should always be carried out after a "normal" drying period, and compared with other similar, unaffected components.

Please see below figures presenting some examples of use of thermography in civil structures:

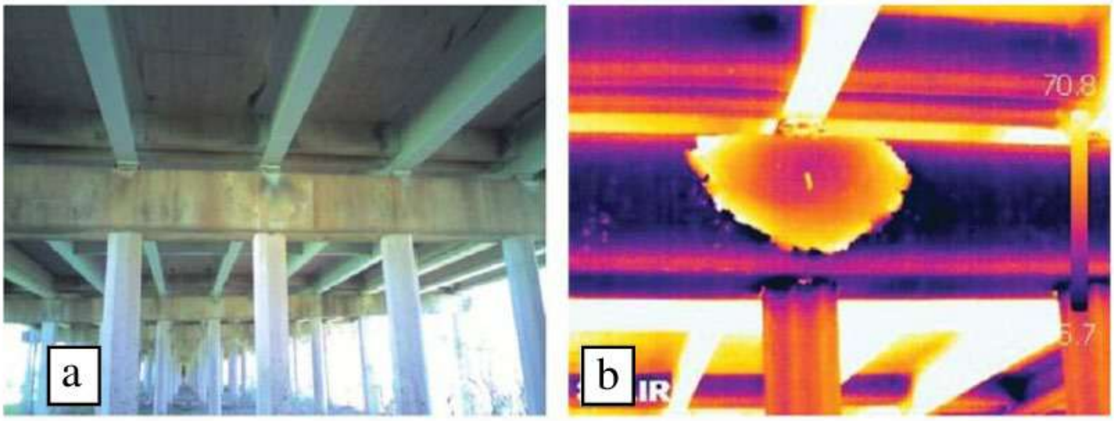


Figure 2-8 Detected bridge beam increased humidity (semanticscolar.org)

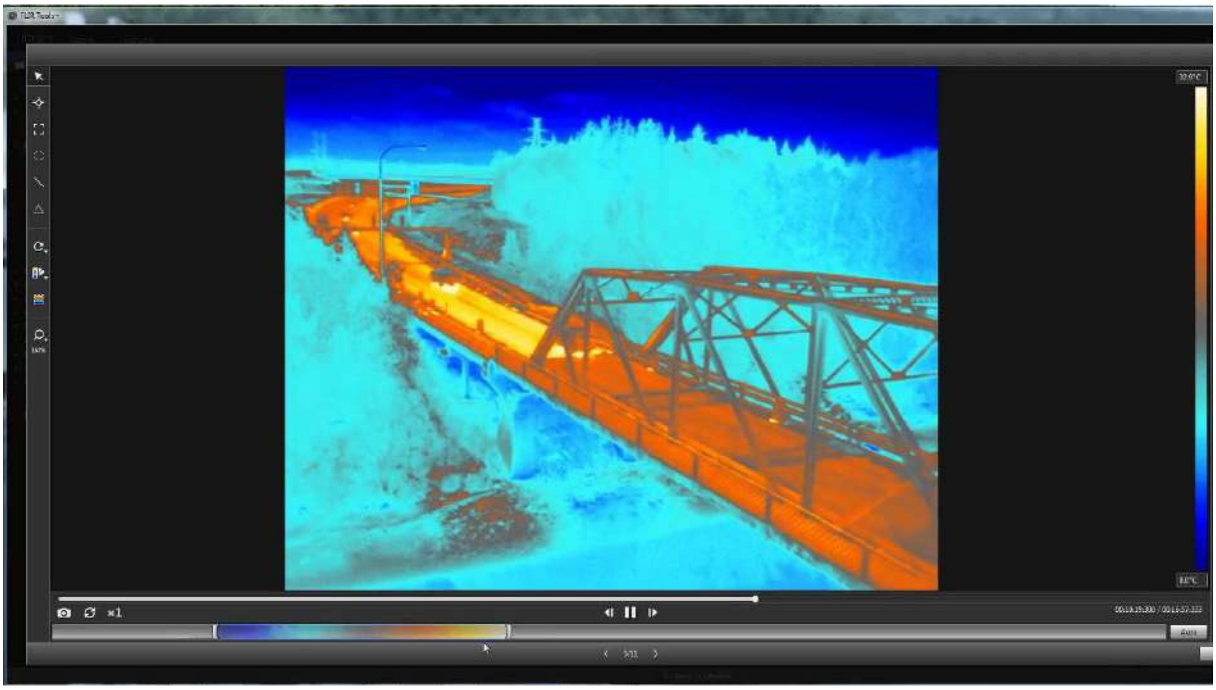


Figure 2-9 Metal bridge thermal analysis (Brunswick Engineering)

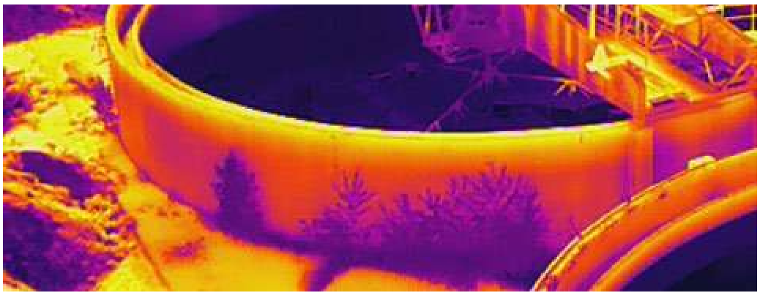


Figure 2-10 Detection of water leaks from wastewater treatment plant tanks (3Dvirtual360.com.au)

Photovoltaic panels analysis

In this scenario cells that are not performing correctly or are broken can be detected. This is due to increased temperature of operation than the others. Similar can be observed with faulty contacts that have increased temperature.

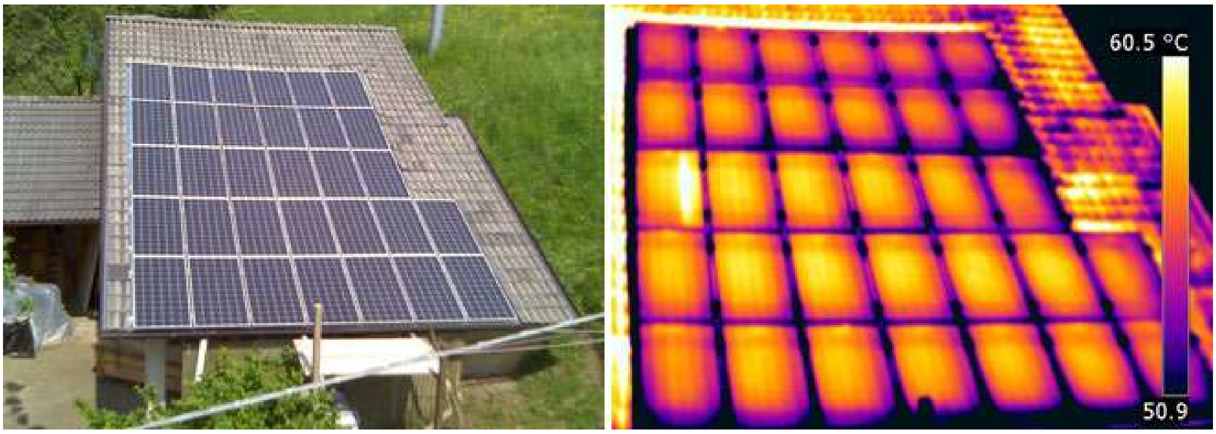


Figure 2-11 Faulty PV cells example (analistgroup.com)

There are number of issues/faults that can occur simultaneously such as:

- hot contacts,
- microinverters overvoltage,
- panels or panel strips out of electrical circuits

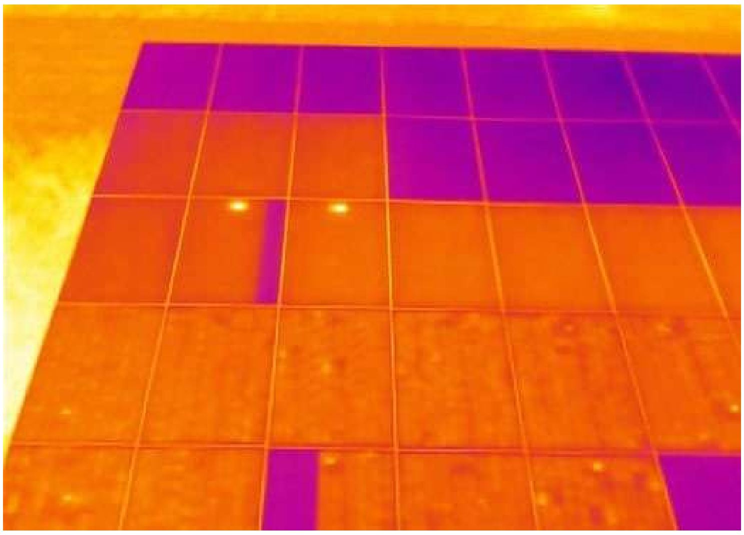


Figure 2-12 Numerous simultaneous defects (diagnosticphotovoltaique.fr)

Networks or ground analysis

Drones, in conjunction with a thermal cameras, can be used to inspect district heating systems or pipes with detectable temperatures. The benefits would include prevention of excavation accidents that could potentially damage underground existing infrastructure.

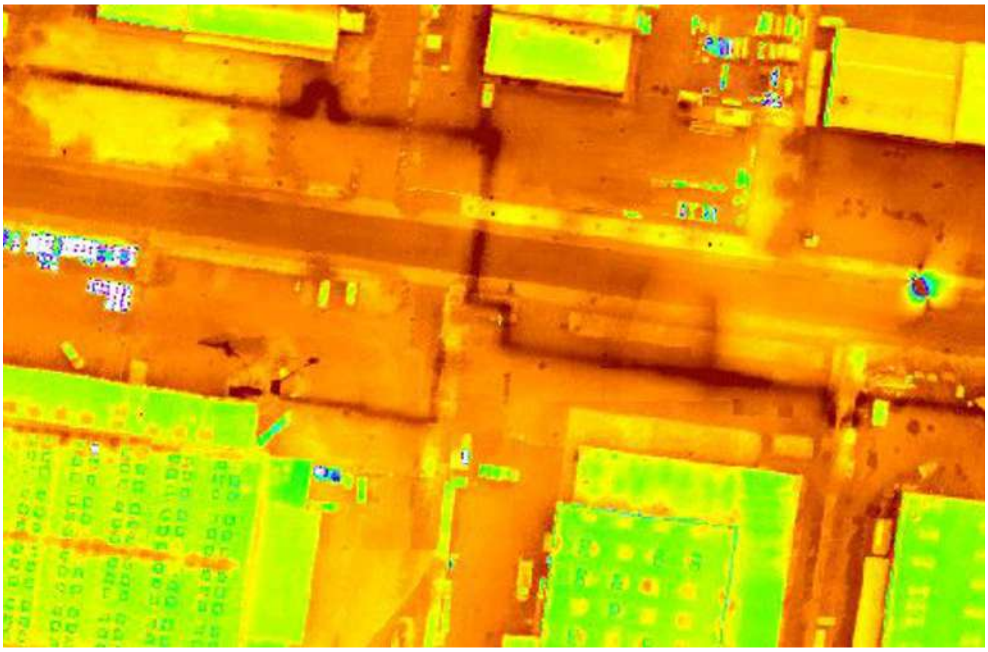


Figure 2-13 Cold Gas pipe (thermalcapture.com)

Thermography can also be used to detect leaks and underground cavities or simply surveying ground conditions…

In order to identify construction remains or other sources of danger thermal images can be taken using drones.

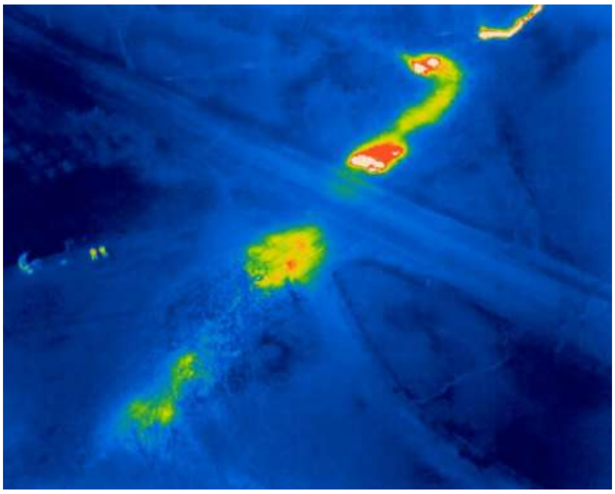


Figure 2-14 presents cold spots that represent cavities. This is due to a temperature difference between cavities and uniform ground surface temperature.

Figure 2-14 Leaks in a district heating system (drone-thermal-camera.com)

2.2 Advantages thermography using drones:

- Accessibility: Drones equipped with thermal cameras can access areas that are difficult or dangerous for humans to reach, such as rooftops, tall structures, or confined spaces.
- Efficiency: Drones can cover large areas in a relatively small amount of time, allowing for efficient thermal inspections. They can capture high-resolution thermal images or video footage while flying over a designated area, providing valuable data for analysis.
- Safety: Using drones for thermography eliminates the need for personnel to physically access potentially hazardous or hard-to-reach locations. This reduces the risk of accidents or injuries associated with inspections performed at heights, in extreme temperatures, or in dangerous environments.
- Flexibility and Mobility: Drones are highly maneuverable and can navigate through complex environments, providing flexibility in capturing thermal data from different angles and perspectives. They can easily adjust their flight path or altitude to focus on specific areas of interest.
- Data Collection and Analysis: Drone-mounted, thermal cameras imagery, can be used to identify temperature anomalies and heat patterns. The collected data can be analyzed to detect energy inefficiencies, insulation problems, or equipment malfunctions in buildings, power lines, solar panels, and other infrastructure.
- Integration with Mapping Software: Drone thermography can be integrated with mapping software and geographic information systems (GIS) to create detailed thermal maps or 3D models. This allows for precise georeferencing and spatial analysis of thermal data, facilitating decision-making and planning.

Overall, drones offer a versatile and efficient platform for conducting aerial thermography, enabling enhanced data collection and analysis in various industries, including construction, energy, agriculture, and infrastructure maintenance.

Passive or active thermography can enable visibility of areas or objects that wouldn`t be visible for normal cameras.. For example, delamination can be made visible in masonry in air pockets or composite materials. This is possible without damaging the surface. Thermography with drones is used in leak detection, building and plant thermography, photovoltaic inspection, energy efficiency systems and smart city sensing.

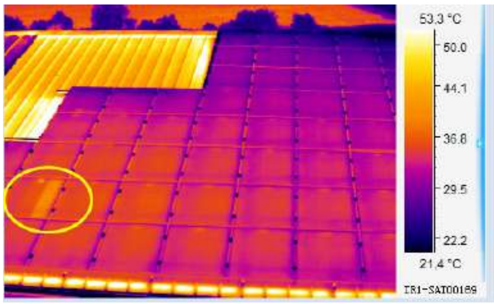
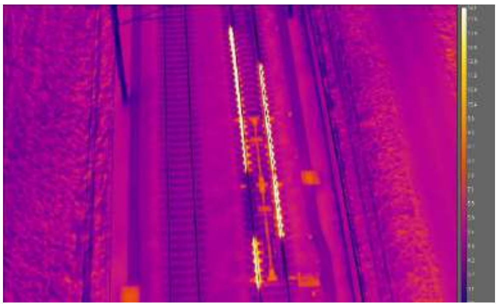
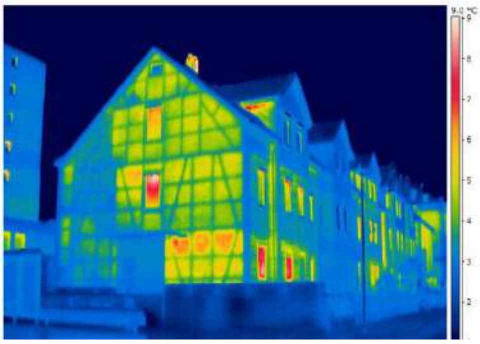
	
Photovoltaik (pv-reinigung.eu)	*Infrastructure / Railway (skyability.com)*
	
Construction outdoor wall (www.htlpinkafeld.at)	*Existing Timber-framed house (thermografie-blowerdoor-hamburg.de)*

Figure 2-15 Examples with drones and thermography

The meaning of the colors is defined. Typically, red illustrates warm areas of the building, while blue represents cooler areas. Temperatures in the middle area are shown in yellow and green, whereby there is again the gradation from the somewhat cooler green and the yellow, which stands for warmer.

2.3 Required Hardware

When it comes to drone thermography, there are specific hardware requirements to consider to ensure accurate and reliable thermal imaging. Here are the key hardware components typically involved in drone thermography:

- Drones: Selecting a suitable drone for thermography is crucial. Factors to consider include flight stability, payload capacity, flight time, and the ability to integrate with thermal cameras. Popular options include DroneVolt Hercules, DJI Mavic, Autelrobotics Evo II, DJI Matrice series, as they offer stable flight characteristics and can accommodate various payloads.
- Thermal Camera: Choosing the right thermal camera is essential for accurate temperature measurements and detailed thermal imaging. Look for cameras with high thermal resolution, temperature range, and sensitivity.

	
Figure 2-16FLIR Vue Pro (firmcameras.com)	*Figure 2-17DJI Zenmuse (dji.com)*

- Gimbal and Mounting: A gimbal is a stabilization system that ensures the thermal camera remains steady during flight, minimizing vibrations and maintaining image quality. The drone should have a compatible gimbal or mounting system to attach and stabilize the thermal camera.
- Camera Control and Integration: The drone's flight controller should allow seamless integration with the thermal camera, enabling control of camera functions such as image capture, video recording, and temperature calibration. Make sure the drone's software or firmware supports the specific thermal camera model you intend to use.
- Transmitter and Receiver: Drones for thermography require a reliable transmitter and receiver system for real-time video streaming and remote control. It allows the operator to view the live thermal imagery and adjust flight parameters as needed.
- Battery and Power Management: Adequate battery capacity is crucial to ensure sufficient flight time for conducting thermography missions. Consider having spare batteries on hand to maximize operational efficiency. Additionally, a power management system can help monitor battery levels and provide alerts for timely battery replacements or recharging.
- Data Storage and Transmission: Drones generate a significant amount of thermal imaging data. Ensure that the drone has sufficient onboard storage capacity or

the ability to transmit the data wirelessly to a ground station for storage and analysis.

- Ground Station and Display: A ground station is typically used to control the drone's flight, monitor the thermal imagery in real-time, and manage mission planning. It consists of a controller, monitor, or mobile device for viewing the live thermal feed and interacting with the drone's control interface.

It's important to note that the specific hardware requirements may vary depending on the intended application, the complexity of the thermal inspections, and the desired level of data accuracy. Consulting with experts or experienced drone thermographers can provide valuable insights into selecting the most suitable hardware components for your specific needs.

Hardware - Options for thermal cameras

When it comes to drone cameras for thermography, there are several options available that can be used to capture thermal images and perform thermographic inspections. Check the compatibility and the respective payload capacities in each case. Here are some commonly used drone camera options for thermography:

- FLIR Vue Pro: The FLIR Vue Pro is a popular thermal camera option for drones. It offers different resolution options (e.g., 336x256 or 640x512) and various lens options to cater to different needs. The Vue Pro is known for its high thermal sensitivity and the ability to capture accurate temperature data.

  DJI Zenmuse XT2: The DJI Zenmuse XT2 is a dual-sensor camera that combines a visual camera with a FLIR Boson thermal camera. It provides high-resolution thermal imagery and can capture both thermal and visual images simultaneously. The Zenmuse XT2 offers advanced thermal imaging features and integration with DJI's drone platforms. This would be suitable for the Matrice 300 / 350 RTK drone model.

- FLIR Duo Pro R: The FLIR Duo Pro R is a dual-sensor camera that combines a thermal camera with a high-resolution visible camera. It provides radiometric thermal imaging, allowing for accurate temperature measurements and analysis. The Duo Pro R is known for its compact size and easy integration with drones.
- Workswell WIRIS Pro: The Workswell WIRIS Pro is a professional-grade thermal imaging camera designed specifically for drones. It offers a high-resolution thermal sensor and various lens options to provide detailed thermal imaging. The WIRIS Pro also has features like GPS and IMU integration for precise geolocation of thermal data.
- TeAx ThermalCapture: TeAx ThermalCapture is a thermal imaging solution that can be integrated with various drone platforms. It includes both hardware and software components, providing the ability to capture radiometric thermal images and perform post-processing and analysis of thermal data.
- Yuneec E20Tvx for H520E H850 Hexacopter 640 x 512

It's important to note that the compatibility of these cameras may vary depending on the specific drone platform and camera model. Before purchasing a thermal camera for drone thermography, ensure that it is compatible with your drone and that you have the necessary mounting and integration options available. Additionally, consider factors such as thermal resolution, sensitivity, data recording capabilities, and the ability to calibrate and analyze thermal data to choose the camera that best fits your specific needs and budget.

Hardware - Options for a thermal imaging camera drone

The following are some drones with thermography functionality. The compilation includes a selection of common drones. The compilation makes no claim to completeness.

DJI Mavic 3T (Thermal)

This compact and portable drone combines a high-resolution visual camera with a FLIR Lepton thermal camera. It offers a dual-sensor setup, allowing you to capture both visible light and thermal images simultaneously. The Mavic 2 Enterprise Dual is suitable for various applications, including inspections, public safety, and search and rescue operations.

Specifications: • 45 minutes maximum possible flight time • Weight: 920g • Resolution thermal imaging camera 640 x 512 pixels • Obstacle avoidance • Suitable for thermal building inspection, as well as inspection of PV systems • Price: appr 5.500 €	 *Figure 2-18 DJI Mavic 3T (store.dji.com)*

DJI Matrice 30 T

The DJI Matrice M30 is a highly powerful drone for demanding inspection tasks on all kinds of structures. It is capable of operating even in adverse weather conditions of up to approximately -20°C and challenging lighting conditions, delivering impressive shots with its 12 MP wide-angle camera and a 48 MP camera with up to 16x optical zoom. A laser rangefinder with a range of up to 1200 m allows for easy distance determination.

Specifications: • 41 minutes max. possible flight time • Weight: 3.770g • Resolution thermal imaging camera 640 x 512 pixels • Obstacle avoidance • Laser rangefinder with a range of 3m - 1200m • Suitable for thermal building inspection, as well as inspection of PV systems • Price: appr 12.500 €	 *Figure 2-19 DJI Matrice 30 T (w.grube.at)*

DJI Matrice 350 RTK

Designed for commercial and industrial applications, the Matrice 350 RTK is a versatile drone that can be equipped with thermal cameras such as the Zenmuse XT2. It offers advanced flight capabilities, longer flight times, and a robust payload capacity. The thermal camera options provide high thermal sensitivity and advanced analytics features for detailed inspections and mapping.

Specifications: • 55 minutes maximum possible flight time • Weight: 3.770 g (without payloads and battery) • Obstacle avoidance • Suitable for thermal building inspection, as well as inspection of PV systems • Price: appr 13.500 € (without the camera)	 *Figure 2-20 DJI Matrice 350 (droon.ee)*

Yuneec H520E-SpecCombo Hexacopter RtF

The Yuneec H520 E is a professional-grade drone that can be integrated with the E20T thermal camera. It features a radiometric thermal camera with adjustable temperature range settings and precise temperature measurements. The H520 is known for its stability, reliable flight performance, and advanced flight planning capabilities.

<table>
<tr>
<td>Specifications:
• 25 minutes maximum possible flight time
• Weight: 1.860 g
• Resolution thermal imaging camera 1344 x 759 pixels
• Obstacle avoidance
• Suitable for thermal building inspection, as well as inspection of PV systems
• Price: appr 5.500 €</td>
<td>
Figure 2-21 Yuneec H520E (shop.yuneec.com)</td>
</tr>
</table>

FLIR SkyRanger R70

This rugged and weather-resistant drone is specifically designed for industrial applications. It can be integrated with the FLIR Vue Pro R thermal camera, offering high-resolution thermal imaging. The SkyRanger R70 provides long flight times, advanced flight control features, and is suitable for various industries such as infrastructure inspections, energy, and public safety.

<table>
<tr>
<td>Specifications:
• 40/59 minutes maximum possible flight time
• Weight: 5.000 g
• Resolution thermal imaging camera StormCaster-T: 640 x 512 pixels
• Price: no info</td>
<td>
Figure 2-22 FLIR SkyRanger R70 (www.flir.eu)</td>
</tr>
</table>

Parrot Anafi Thermal

The Parrot Anafi Thermal is a drone specifically designed for thermal imaging applications. It is a compact and lightweight quadcopter that combines a high-resolution visual camera with a built-in FLIR Lepton thermal camera.

Specifications: • 25 minutes maximum possible flight time • Weight: 315 g • Resolution thermal imaging camera 160 x 120 • No Obstacle avoidance • Suitable for thermal building inspection, as well as inspection of PV systems • Price: appr 2.500 €	 *Figure 2-23 Parrot Anafi Thermal (www.parrot.com)*

Parrot Anafi USA

The Parrot Anafi Thermal is a drone specifically designed for thermal imaging applications. It is a compact and lightweight quadcopter that combines two high-resolution visual camera (zoom) with a built-in FLIR Boson thermal camera.

Specifications: • 32 minutes possible flight time • Weight: 496 g • Resolution thermal imaging camera 320 x 256 • No Obstacle avoidance • 32x Zoom • IP53 • Price: appr 8.000 €	 *Figure 2-24 Parrot Anafi USA (drohnen.de)*

Autel EVO II Dual 640T

The Autel Evo II Dual is a foldable drone that comes equipped with both a visual camera and a FLIR Boson thermal camera. It offers a 48-megapixel visual camera and a 640x512 resolution thermal camera, providing detailed imagery. The Evo II Dual is known for its versatility and user-friendly features, making it suitable for various applications, including inspections and public safety.

Specifications:

- 38 minutes maximum possible flight time
- Weight: 1.110 g
- Resolution thermal imaging camera 640 x 512
- Obstacle avoidance
- Suitable for thermal building inspection, as well as inspection of PV systems
- Price: appr 5.500 €

Figure 2-25 Autel EVO II Dual 640T (shop.autelrobotics.com)

Flyability Elios 3

The Flyability Elios 3 is a specialized indoor inspection drone designed for confined and complex spaces. It is primarily used for industrial inspections in areas such as power plants, oil and gas facilities, construction sites, and infrastructure. The Elios 3 is known for its ruggedness and ability to withstand collisions, making it suitable for inspections in challenging environments.

Specifications:

- 10 minutes
- Weight: 1.800 g
- Lighting system
- Obstacle avoidance
- Lidar sensor
- Indoor GPS Flyware
- Suitable for thermal indoor building inspection
- Price: appr 50.000 €

Figure 2-26 Flyability Elios 3 (halorobotics.com)

2.4 Required Software

There are several software options available for processing and analyzing thermal imagery captured by drones for thermography purposes. These software solutions help extract valuable insights from thermal data, generate reports, and perform various analysis tasks. Here are some popular software options for drone thermography:

- FLIR Tools: FLIR Tools is a software suite provided by FLIR Systems, a leading manufacturer of thermal imaging cameras. It allows users to import, analyze, and generate reports from thermal images captured by FLIR cameras, including those mounted on drones. FLIR Tools offers features such as temperature measurement, image enhancement, and customizable analysis tools.
- Pix4Dmapper: Pix4Dmapper is a photogrammetry software that can process both visual and thermal images captured by drones. It enables the creation of accurate 3D models, orthomosaics, and thermal maps from the captured imagery. Pix4Dmapper offers advanced analysis capabilities, including volumetric measurements, temperature analysis, and change detection over time.
- DroneDeploy: DroneDeploy is a cloud-based software platform that supports thermal imagery analysis. It allows users to upload, process, and analyze thermal images captured by drones. DroneDeploy provides tools for creating thermal maps, performing temperature analysis, and generating customizable reports. It also offers integration with popular drone platforms and has collaboration features for team-based projects.
- FLIR Tools+ or ResearchIR: FLIR Tools+ and FLIR ResearchIR are advanced thermal imaging software options provided by FLIR Systems. These software packages are designed for more complex thermographic analysis tasks. They offer advanced features like emissivity correction, time-lapse analysis, post-processing of radiometric data, and advanced reporting capabilities.
- Raptor Maps: Raptor Maps is a software platform specifically focused on the analysis of thermal imagery for solar panel inspections. It provides tools for detecting defects, classifying issues, and generating detailed reports. Raptor Maps offers automated analysis algorithms and integrates with various drone platforms and thermal cameras commonly used for solar inspections.
- DJI Thermal Analysis Tool 3.0: can be used to analyze and process thermal images. By identifying the temperature information of critical areas of the target, the software can be used to analyze objects across many industrial applications.

These are just a few examples of software options available for drone thermography. The choice of software depends on your specific needs, the type of analysis you require, and the compatibility with your drone and thermal camera. It's advisable to explore the features and capabilities of different software options, consider your specific application requirements, and select the software that best suits your needs.

3. Thermal Surveying using uavs – Theory and Practice

3.1 Theoretical content

Here is some theoretical content related to thermography:

General overview:

- Relevance of drones in the construction sector and frequency of use, -areas.
- Requirements for the general implementation like the wind and weather influences, the season of the year with its temperatures and the time of the day. Therefore, it is important that it is bright during the day with good weather conditions, otherwise this will negatively affect the quality and possibility of implementation. Thus, rain and storm are unsuitable for the implementation. The season also plays a role, as the area should be free of snow or autumn leaves and not overheated by too strong sunlight and too hot temperatures in summer. Furthermore, a dry surface does not lead to distortions in the result.
- Acquisition costs and rough differences between models (which functions are essential for what).

Thermography:

- Infrared Radiation and Temperature:
  - Infrared (IR) radiation: Infrared radiation is a form of electromagnetic radiation with wavelengths longer than those of visible light. Infrared radiation is emitted by every object with a temperature above absolute zero (0 Kelvin = -273,15°C). It is invisible to the human eye.
  - Emissivity: Emissivity is the measure of an object's ability to emit infrared radiation. It varies with material properties and surface condition. As the emissivity changes with temperature and surface characteristics, the values listed here are only indicative. To measure the absolute temperature accurately, the emissivity of the material should be precisely determined.

Material	Emissivity
Aluminum	0.05
Brick	0.91
Concrete	0.93
Sandstone	0.67
Brass, oxidized	0.61
Porcelain	0.92
Steel, oxidized	0.79

Table 3-1: Emissivity of some materials

  - Blackbody radiation: A blackbody is an idealized object that emits and absorbs all incident radiation. It follows Planck's law, which describes the spectral distribution of radiation emitted by a blackbody at a given temperature.
- Thermal Imaging Cameras:
  - Operation: Thermal imaging cameras detect and measure the infrared radiation emitted by objects. They consist of an infrared detector, optics, and image processing electronics.
  - Thermal sensitivity: Thermal sensitivity refers to the smallest temperature difference that a camera can detect. Thermal sensitivity is a term synonymous with Noise Equivalent Temperature Difference (NETD), denoting the smallest detectable temperature difference when utilizing a thermal device. Typically measured in milliKelvin (mK), this value functions as an electronic noise rating for the system.

    Ideally, a thermal camera with the lowest possible mK is desirable. A lower NETD implies that the sensor can more effectively capture minute temperature variations. Conversely, a higher NETD compromises image clarity, adversely affecting analytics performance and visibility, especially in challenging weather conditions.
- Thermal Imaging Principles:
  - Heat transfer modes: Heat can be transferred by conduction, convection, and radiation. Thermal imaging primarily focuses on radiative heat transfer.
  - Thermal anomalies: Thermal anomalies refer to temperature variations or irregularities that can indicate issues such as heat leaks, electrical faults, or mechanical malfunctions.
- Thermographic Inspections:
  - Applications: Thermography is widely used in various fields, including building inspections for detecting energy inefficiencies, electrical

inspections for identifying overheating components, and mechanical inspections for monitoring equipment performance.
    - Environmental factors: Environmental conditions, such as ambient temperature, humidity, and air movement, can influence thermographic inspections and should be considered during data interpretation.
    - Best practices: Proper camera calibration, emissivity adjustment, and accurate distance measurements are essential for reliable thermographic inspections.
- Data Analysis and Reporting:
    - Image analysis: Software tools are used to analyze thermal images, including temperature measurement, temperature profiling, and anomaly detection.
    - Reporting: Thermography reports typically include visual and thermal images, temperature data, annotations, and recommendations for further actions.

It's important to note that thermography is a specialized field with extensive theoretical knowledge and practical experience required for accurate interpretation of thermal images.

3.2 Practical content (practice flights outdoor / indoor if possible)

Practical experience in drone thermography involves the application of the theoretical knowledge of thermography to real-world scenarios using drones equipped with thermal cameras. Here are some aspects of practical experience in drone thermography:

Testing scenario

Illustrations based on self-experiments or demonstrations demonstrated by a professional first and then tested by interested people are also possible indoors in a hall by holding the device against a thermal bridge and observing the change. The process is dictated by a predefined sequence, which was marked on the floor plan. Lines indicate the steps in order to make the best possible use of temperature differences. For this purpose, temperature-influencing devices like a fridge and a freezer, a heating fan, radiant heater, air conditioning device and an electric household tool are positioned at various points in the hall and radiate their temperature. These points are selected one after the other in order to illustrate the effects that they have. Outdoors it is also possible and could be shown via the already mentioned devices, as well as via house walls, the ventilation system and construction parts of the building.

Pre-flight

Flight Planning - Drones:

A thermographic measurement should always be conducted in winter during the heating season. There should be a temperature difference of at least ten to fifteen degrees Celsius between the interior and exterior environments. The thermal image should be captured no later than the morning hours. During the daytime and evening, the parts of the building under investigation may be warmed by the sun, potentially distorting the measurement results. The building must be uniformly heated before and during the measurement. Windows should remain closed one hour before and during the thermographic session.

- Before flying the drone, the pilot has to identify the area / construction which have to be thermographically inspected.
- Check weather conditions to ensure suitability for drone flight. Avoid flying in strong winds, rain, or extreme temperatures. The same for smoke, dust and debris.
- Inspect the area on-site to identify obstacles, potential hazards, and suitable takeoff/landing sites.
- Plan the flight path and altitude based on the inspection requirements, drone specifications, and environmental conditions.
- The flight path should cover the entire area of interest, and the altitude should be optimized for capturing clear and detailed thermal images.

Camera Settings:

- Camera settings, such as temperature range, emissivity, and palette, need to be optimized for capturing accurate and reliable thermal images.
- The pilot should adjust the camera settings based on the type of inspection and material being inspected.

Other factors to consider IR capture related:

- Objects to be surveyed
  - Emissivity
  - Transparency
  - Reflectivity
  - Paint on an object
  - Glass
  - Distance from target
  - Viewing angle
  - Surface roughness or smoothness
- Amount of thermal energy
- Drone – payloads to consider

In flight

Image Acquisition:

- The drone needs to be flown at a steady / programmed speed and altitude to capture clear and detailed thermal images.
- The pilot should ensure that the thermal camera captures images with enough overlap to enable accurate stitching of the images during post-processing.

Data Analysis:

- After capturing the thermal images, the data needs to be analyzed to identify any thermal anomalies or temperature variations.
- Software tools such as FLIR Tools or DJI thermal analysis tool can be used to analyze thermal images and generate reports.

Reporting:

- The thermal analysis report should include visual and thermal images, temperature data, annotations, and recommendations for further actions.
- The report should be prepared in a clear and concise manner, making it easy for stakeholders to understand and act upon the results.

4. Conducting a thermographic survey

4.1 Conditions

When a heat flow forced by temperature differences (between outside and inside of a building) flows as constant as possible in time makes a perfect thermal inspection conditions. This heat flow then generates locally different surface temperatures due to the different thermal resistances of the components flowing through, which are recorded by the thermographic camera. In order to ensure this, a number of important criteria must be observed when a thermography is carried out by an energy consultant. Failure to comply with these criteria could make interpretation more difficult or lead to incorrect conclusions. The most important point is the weather. Since temperature differences play a major role in the measurement, winter is the ideal season for thermal imaging.

Thermography from the outside can theoretically be done regardless of the time of day, as long as it is not too bright (< 1500 lux). Therefore, thermographic images are mainly taken in the morning, since all surfaces illuminated by the sun are not yet too sunny. Sunlight can also interfere with indoor images, despite the high thermal inertia of the building fabric, by shining the sun into the windows.

On the other hand, it is recommended to carry out thermography when the sky is completely cloudy, because then the temperature at the cloud base almost corresponds to the ambient temperature and thus there is an almost perfect equilibrium and radiation as well as shadowing effects are almost completely absent.

Thermal sensitivity

Thermal sensitivity describes how small a temperature difference the camera can still detect. The better the thermal sensitivity, the smaller the minimum temperature difference that the thermal imaging camera can detect and display. Normally, thermal sensitivity is specified in °C or mK. The most modern thermal imaging cameras for building applications have a thermal sensitivity of 0.03 °C (30 mK).

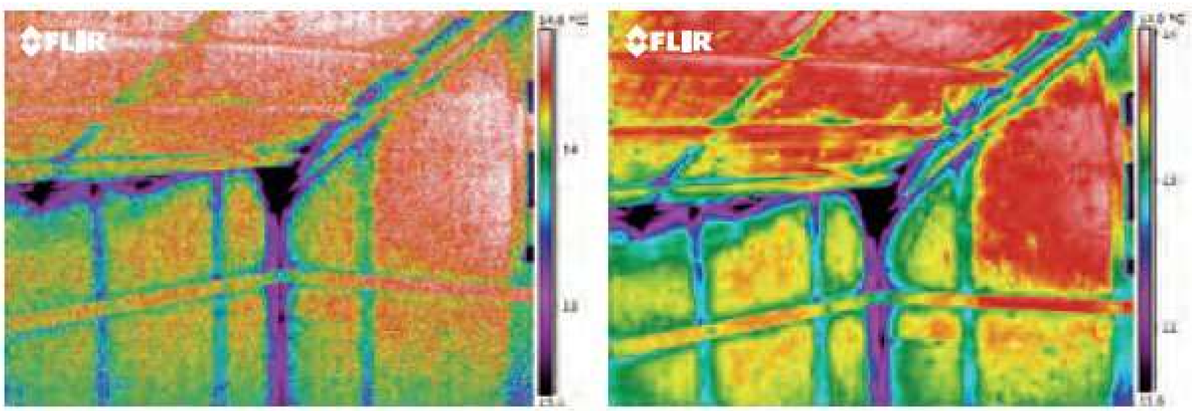


Figure 4-1: Thermal sensitivity 65mk left vs 45mk right (FLIR Systems)

Detecting such small temperature differences is critical in most thermal imaging applications. High camera sensitivity is especially important in construction applications where temperature differences are typically smaller. Higher sensitivity is required to capture more detailed images for better diagnoses, based on which decisions are made about necessary actions. The greater the sensitivity, the better the camera's ability to capture minute details even at small temperature differences.

Emission Value

Thermography is closely related to the term emission value. Since for most materials the transmission (transmittance for radiation) is rather low, reflection and emission still remain as important measuring factors in order to obtain in total the above mentioned 100 percent or the value 1.

Figure 4-2: Emission Value (FLIR Systems)

In the thermal image on the left, the correct emissivity for human skin (0.97) has been set, and the temperature read indicates the correct value (36.7 °C). In the thermal image on the right, the wrong emissivity has been entered (0.15), and this results in an incorrect temperature value (98.3 °C). See table 1 before with the emissivity values of different materials.

Reflection

Some materials, which include most metals, reflect thermal radiation as strongly as a mirror reflects visible light. Reflections are often the cause of misinterpretation of the thermal image; the reflection of thermal radiation from the operator's own body or from a lamp can lead to incorrect temperature data. The operator should therefore carefully choose the angle at which the thermal imaging camera is pointed at the object to avoid reflections of this kind.

Do not use metal surfaces for real measured values! Do not observe bare copper busbars!

Measure cable outlets of copper bars, cable insulation or heat shrink tubing at the cable lug!

Building application: Be careful with gutters: they are mostly made of zinc or copper and may reflect the sky. Glass windows viewed from the outside will reflect trees, opposite buildings, or the sky and clouds. Old, bare aluminum windows and doors also reflect. Double-glazed windows are separated by sheet metal profiles, which are a thermal bridge due to their construction. Interior corners or edges in rooms represent a geometric thermal bridge and are usually colder than the wall or ceiling. It is important to keep the temperature below the dew point. Zinc sheet facades reflect.

Suppose you are standing in a room and want to measure the temperature of a glass pane of a window. The glass pane has an emissivity value of 0.5, which means that the radiation arriving at the camera is composed of 50 percent glass radiation (depending on the glass temperature) and 50 percent radiation reflected from the surface. If a matt dark interior wall is reflected in the glass pane, one can approximately set the interior temperature of e.g. 20°C and the emission value of 0.5 or 50 percent on the camera or in the evaluation software. However, if a radiator with 65°C is reflected in the pane, or if the infrared camera operator sees himself there, then the corresponding value must be set as the background temperature. In the following picture it is easy to see why this is important and which factors have to be considered.

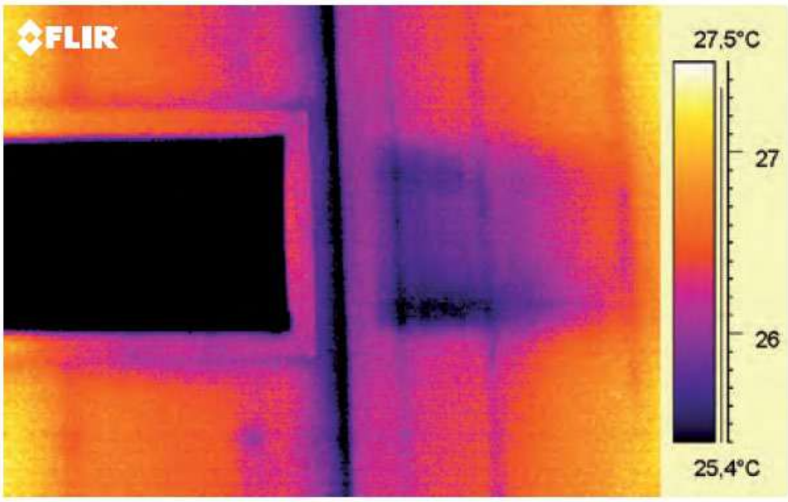


Figure 4-3: Reflection on the right wall from the left window (FLIR Systems)

In midsummer with outside temperatures of 35°C and a bright blue sky, measuring the glass surface temperature of a window from the street can reflect the sky (e.g. -20°C) or e.g. the black slate facade of the neighboring house (60°C) and in the result, without correct background temperature consideration, considerable measurement errors occur.

Inspection of solar modules with thermal imaging cameras

In order to have sufficient thermal contrast when inspecting solar cells on site, a solar irradiance of 500 W/m2 and more is required. An optimal result can be achieved at a radiation intensity of 700 W/m2. Location and local weather conditions exert a major influence. Low outdoor temperatures can also increase the thermal contrast.

Generally, PV modules are mounted on highly reflective aluminum frames, which appear as cold zones on the thermal image because they reflect the thermal radiation from the sky. In practice, this means that the thermal imaging camera will display the frame temperature as clearly below 0 °C. However, since its display algorithm automatically adjusts to the highest and lowest measured temperatures, many low thermal anomalies will not be immediately visible. For a high thermal contrast of the thermal image, the level and span would therefore have to be constantly corrected by hand.

To avoid reflections of the thermal imaging camera and the operator in the glass, the camera should not be arranged at right angles to the module to be examined. However, the emissivity is greatest at right angles and decreases with increasing angle. A viewing angle of 5 to 60° is a good compromise (0° is perpendicular).

Ambient and measurement conditions: To carry out a thermographic examination, the sky should be cloudless, since clouds reduce the solar radiation and additionally produce disturbing reflections. Nevertheless, meaningful images can be obtained even in cloudy conditions, provided that the thermal imaging camera used is sensitive enough. Likewise, windless conditions are desirable, since any airflow on the surface of the solar panel will cause cooling by convection, and this in turn will reduce the temperature gradient. The lower the air temperature, the higher the potential thermal contrast. Conducting thermographic surveys in the early morning is therefore a possibility.

4.2 Camera

An infrared camera displays temperatures. This can be done black / white, then the brightnesses correspond to the temperatures. Usually, however, different false color representations are chosen. The assignment of colors to temperatures are often intuitively expected by the viewer from blue to red, i.e. from cold to warm. In the camera image, a color wedge provides the assignment of temperatures to colors.

An infrared camera is a calibrated system and is also called a radiometer. Various factors play a role in the absolute measurement accuracy of the camera. Among other things, the temperatures of the optics or the detector are measured in the camera in order to correctly parameterize the internal calibration characteristics.

It is therefore always important that the camera itself is thermally stable. Thus, for a building thermography, one should not get out of the car with the camera at a temperature of 20°C and expect correct measured values at outside temperatures of -20°C. The camera should not be used to measure the temperature of the building. These are only obtained when the camera itself is thermally stable, i.e. when it has been running at -20°C for about ½ hour.

4.3 Analysis and reporting

There are a few features that make documentation and also reporting more traceable.

The picture-in-picture function (PIP)

That allows the user to combine images from the digital camera and thermal imaging camera. The combined image shows a frame over the digital image with a portion of the thermal image that can be moved and resized. This allows the user to locate problems more easily.

Figure 4-4: Picture in Picture function PIP (FLIR Systems)

Thermal Fusion

This feature allows the user to seamlessly combine the two images by setting temperature parameters, showing the thermal data inside the limits and the digital photo outside. This allows problems to be isolated and repairs to be made more efficiently.

Figure 4-5: Real - Infrared - Thermal fusion (FLIR Systems)

Report

A thermography report typically includes detailed information about the thermal imaging inspection conducted on a particular subject, such as a building, electrical system, or mechanical equipment. The content of a thermography report may vary depending on the specific application, but here is a general outline of what it might include:

1. Introduction:
    a. Purpose of the thermographic inspection.
    b. Date and location of the inspection.
    c. Identification of the inspected subject (e.g., building, electrical panel).
2. Scope of Work:
    a. Explanation of the areas or components covered in the inspection.
    b. Any limitations or constraints during the inspection.
3. Equipment and Methodology:
    a. Details about the thermal imaging equipment used.
    b. Description of the inspection methodology.
    c. Any specialized techniques employed during the inspection.
4. Environmental Conditions:
    a. Temperature and weather conditions during the inspection.
    b. Notation of any factors that may have affected the results (e.g., wind, sunlight).
5. Preparation and Considerations:
    a. Steps taken to prepare the subject for thermographic inspection.
    b. Considerations for achieving accurate and reliable results.
6. Thermal Images:
    a. Presentation of thermal images captured during the inspection.
    b. Annotation of significant findings and anomalies.

7. Analysis and Interpretation:
    a. Interpretation of thermal patterns and anomalies observed.
    b. Identification of potential issues or areas of concern.
    c. Comparison of temperature differentials and their significance.
8. Recommendations:
    a. Recommended actions based on the findings.
    b. Priority levels for addressing identified issues.
    c. Suggestions for further investigation, if necessary.
9. Conclusions:
    a. Summary of key observations and conclusions.
    b. Overall assessment of the subject's condition.
10. Appendix:
    a. Additional supporting documentation, charts, or graphs.
    b. Raw thermal images for reference.
11. Contact Information:
    a. Contact details of the thermographer or inspection team.
    b. Information on how to seek further clarification or additional services.

It's important for a thermography report to be clear, concise, and easily understood by both technical and non-technical readers. Additionally, the report should comply with any relevant industry standards and guidelines.

In **Appendix A**, an excerpt from an exemplary report for the inspection of a photovoltaic (PV) system is provided.

List of figures

List of tables

5. Appendix a


SOLARTESTER
INSPECTION REPORT
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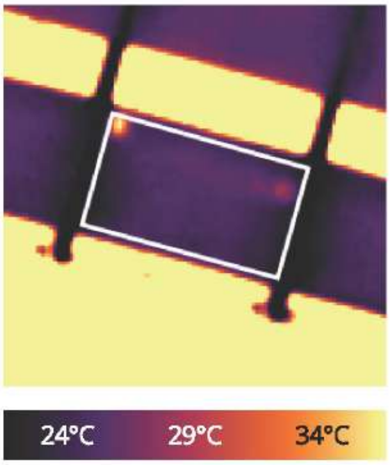
Content

SOLAR TESTER

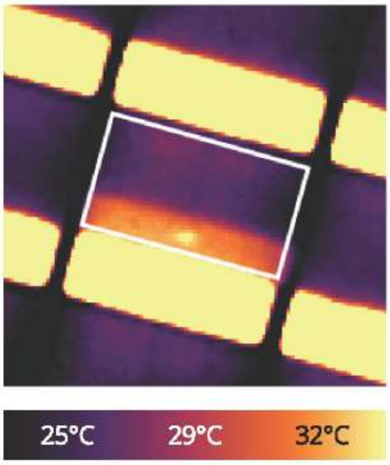
THERMAL ANOMALIES - ID 7



ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	25.5 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	23.6 °C
MAX TEMPERATURE	34.3 °C	LONGITUDE	4.5281328 °
DELTA TEMPERATURE	8.9 °C	LATITUDE	51.7144612 °

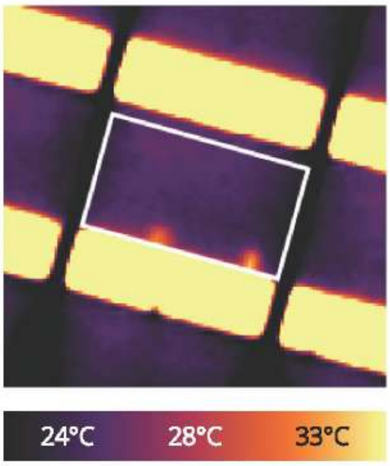
SOLAR TESTER

THERMAL ANOMALIES - ID 8



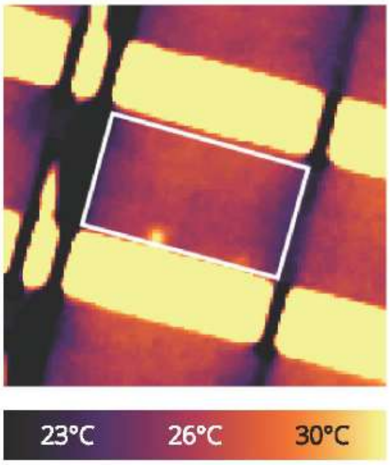
ANOMALY TYPE	Single bypassed	MEAN TEMPERATURE	27.9 °C
ANOMALY CAUSE	Physical internal	MIN TEMPERATURE	24.8 °C
MAX TEMPERATURE	32.4 °C	LONGITUDE	4.5286966 °
DELTA TEMPERATURE	4.6 °C	LATITUDE	51.7144612 °

THERMAL ANOMALIES - ID 9



ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	25.6 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	23.9 °C
MAX TEMPERATURE	32.7 °C	LONGITUDE	4.5290964 °
DELTA TEMPERATURE	7.1 °C	LATITUDE	51.7144612 °

THERMAL ANOMALIES - ID 10



ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	25.7 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	23 °C
MAX TEMPERATURE	29.6 °C	LONGITUDE	4.5288414 °
DELTA TEMPERATURE	3.9 °C	LATITUDE	51.714461 °

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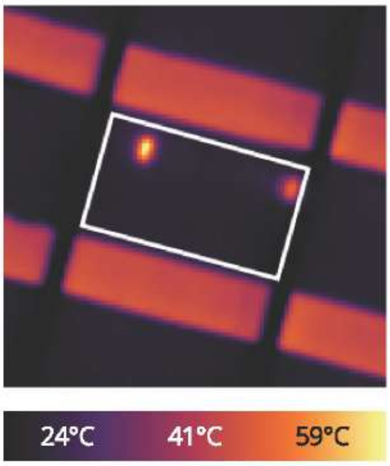
THERMAL ANOMALIES - ID 11



ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	26.2 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	24 °C
MAX TEMPERATURE	58.5 °C	LONGITUDE	4.5289707 °
DELTA TEMPERATURE	32.3 °C	LATITUDE	51.7144612 °

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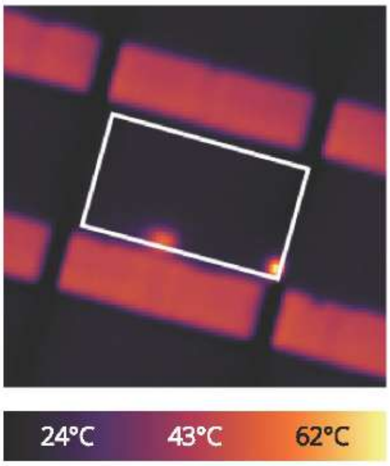
THERMAL ANOMALIES - ID 12



ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	26.7 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	24.3 °C
MAX TEMPERATURE	61.9 °C	LONGITUDE	4.5287534 °
DELTA TEMPERATURE	35.3 °C	LATITUDE	51.714461 °

SOLAR TESTER

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ST-9999 SOLARTESTER SAMPLE REPORT

This section gives a brief overview of site-specific information, including inverter and panel properties.

SITE PROPERTIES

ADDRESS	Graafsebaan 139 Rosmalen
PEAK POWER	1 MWp
NUMBER OF PANELS	2800
PANEL INCLINATION	30

PANEL ORIENTATION	S
PANEL MAXIMUM POWER	370 Wp
AREA	0.85 ha
PANEL MODEL	Solar Tester
INVERTER MODEL	Demo

HIGH LEVEL SITE PLAN

INSPECTION HISTORY

23 Jul 2022	Solar Inspection Pro	COMPLETED

INSPECTION DETAILS

DATA PRODUCT

Our "Pro" Solar Site Inspection functionality provides a complete overview of all the issues of your site and their potential causes.

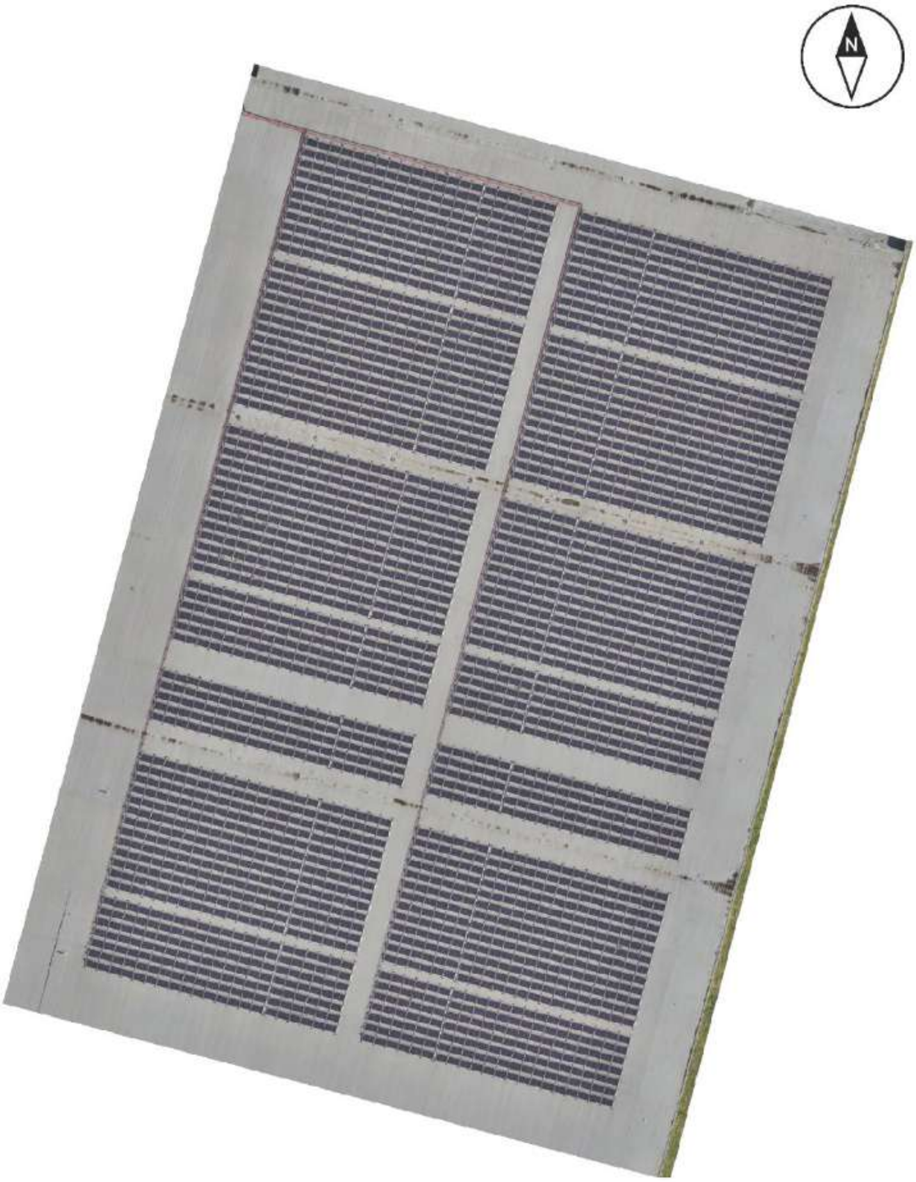
TIMING

TIMEZONE	GMT+2
THERMAL FLIGHT(S)	START 23 Jul 2022 10:08
RGB FLIGHT(S)	START 23 Jul 2022 10:08

MAIN EQUIPMENT

THERMAL DRONE	DJI Matrice 200
THERMAL CAMERA	FLIR Zenmuse XT2 Thermal - 9Hz 640 R 13mm
RGB DRONE	DJI Matrice 200
RGB CAMERA	FLIR Zenmuse XT2 RGB

RGB ORTHOMOSAÏC



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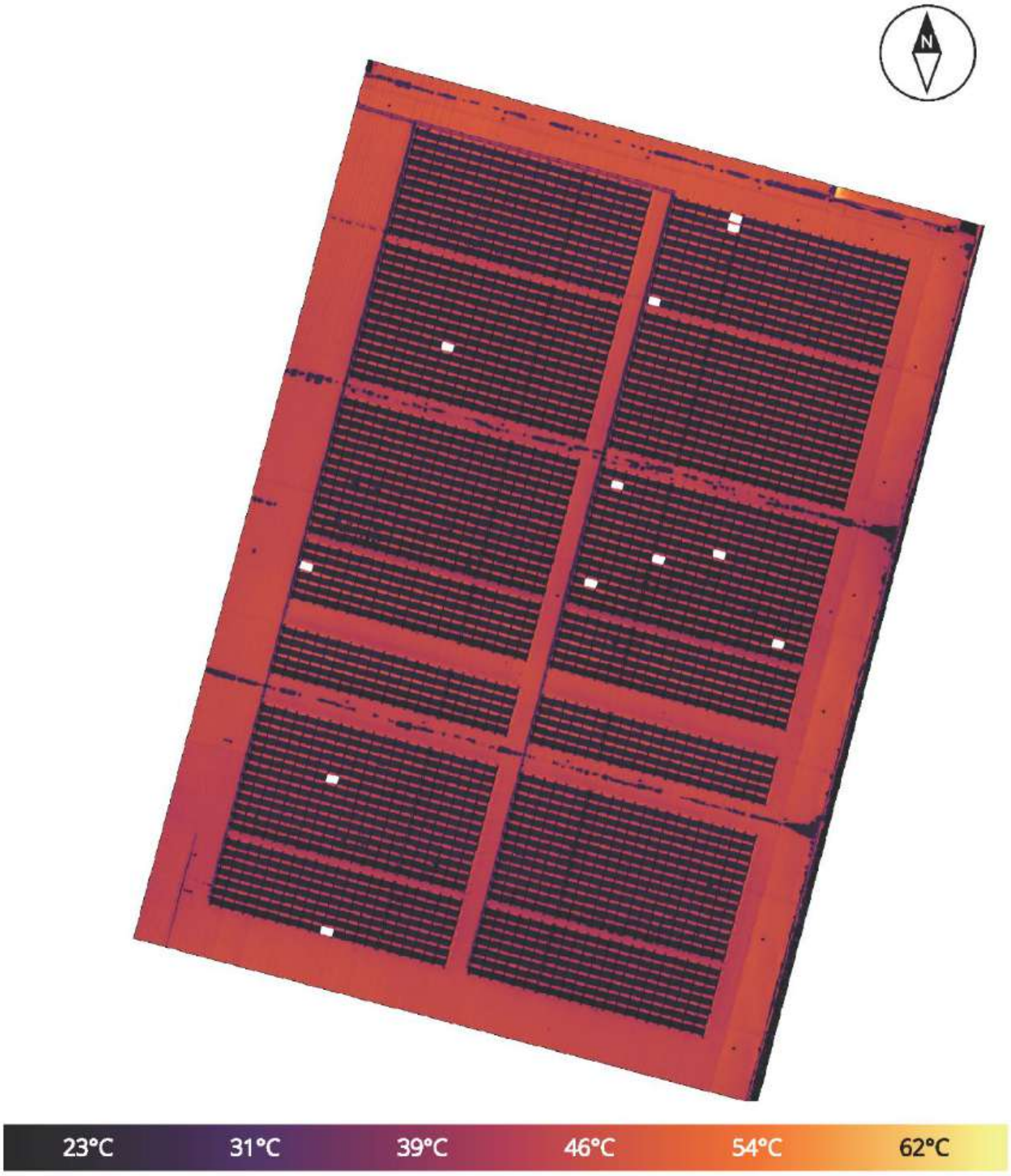
THERMAL ORTHOMOSAÏC



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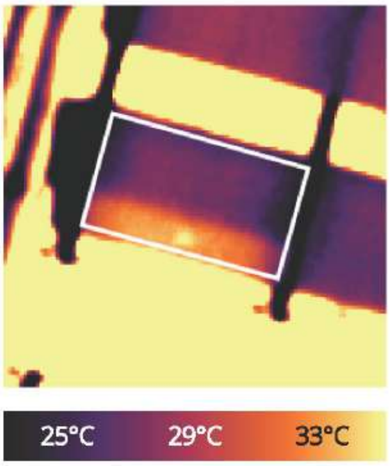
TESTER

LAYER FEATURES

THERMAL ANOMALIES - ID 1



ANOMALY TYPE	Single bypassed	MEAN TEMPERATURE	28.2 °C
ANOMALY CAUSE	Physical internal	MIN TEMPERATURE	24.7 °C
MAX TEMPERATURE	33.1 °C	LONGITUDE	4.5288326 °
DELTA TEMPERATURE	5 °C	LATITUDE	51.7144612 °

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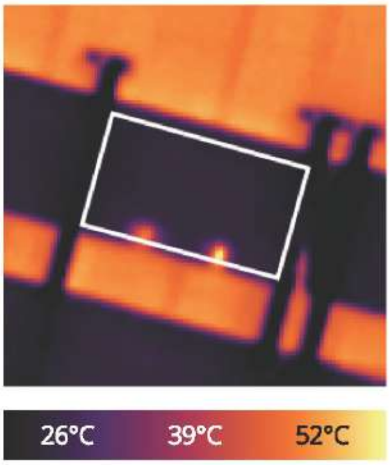
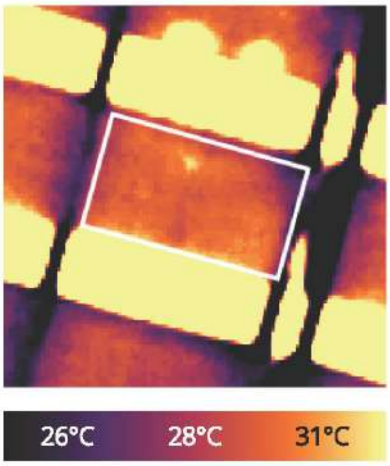
THERMAL ANOMALIES - ID 2



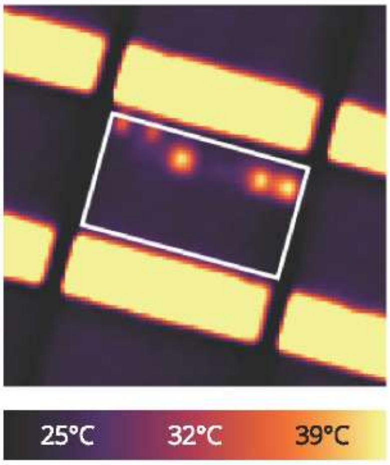
ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	28.4 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	26.2 °C
MAX TEMPERATURE	52.5 °C	LONGITUDE	4.5290063 °
DELTA TEMPERATURE	24 °C	LATITUDE	51.7144612 °

THERMAL ANOMALIES - ID 3



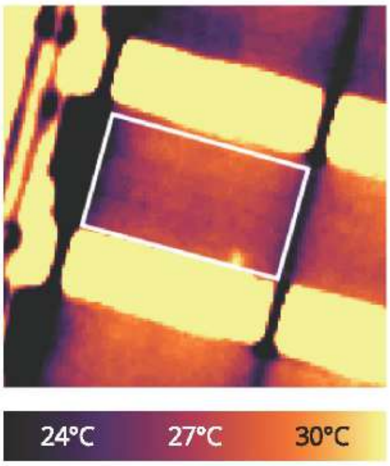
ANOMALY TYPE	Hotspot	MEAN TEMPERATURE	28.9 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	26.1 °C
MAX TEMPERATURE	30.5 °C	LONGITUDE	4.5290015 °
DELTA TEMPERATURE	1.6 °C	LATITUDE	51.714461 °

THERMAL ANOMALIES - ID 4



ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	26.6 °C
ANOMALY CAUSE	Physical internal	MIN TEMPERATURE	24.8 °C
MAX TEMPERATURE	39.2 °C	LONGITUDE	4.5283909 °
DELTA TEMPERATURE	12.5 °C	LATITUDE	51.7144612 °

THERMAL ANOMALIES - ID 5



ANOMALY TYPE	Hotspot	MEAN TEMPERATURE	27.1 °C
ANOMALY CAUSE	Dropping	MIN TEMPERATURE	24.4 °C
MAX TEMPERATURE	30 °C	LONGITUDE	4.5280887 °
DELTA TEMPERATURE	2.9 °C	LATITUDE	51.7144612 °

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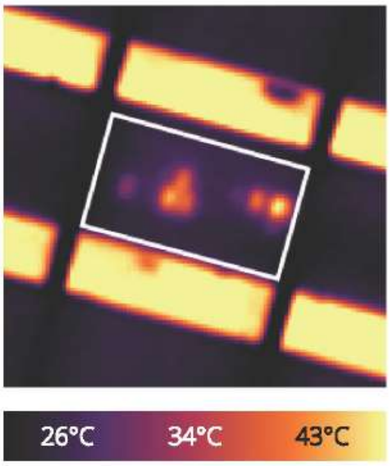
THERMAL ANOMALIES - ID 6



ANOMALY TYPE	Multiple hotspot	MEAN TEMPERATURE	27.8 °C
ANOMALY CAUSE	Physical internal	MIN TEMPERATURE	25.6 °C
MAX TEMPERATURE	43.3 °C	LONGITUDE	4.5281439 °
DELTA TEMPERATURE	15.6 °C	LATITUDE	51.7144612 °

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